



Best environmental management practice for the agriculture sector - crop and animal production

Final draft

Ioannis-Sofoklis Antonopoulos¹, Paolo Canfora¹, Marco Dri¹,
Pierre Gaudillat¹

David Styles², Julie Williamson², Alice Jewer², Neal
Haddaway², Martin Price³

¹ European Commission, Joint Research Centre

² Bangor University

³ Martin Price Consulting



Disclaimer: The views expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

Abstract

This report outlines Best Environmental Management Practices (BEMPs) in the Agriculture sector - Crop and Animal Production. Scientific information on the contribution of agricultural production towards key environmental burdens in the EU, including geographic distribution, is summarised in the first chapter, alongside economic statistics for the sector. In the second chapter, a life cycle perspective is taken to illustrate hotspots of environmental pressure within the supply chains of major agricultural products. These two first chapters provide the rationale for the selection of a sequence of BEMPs systematically described throughout the remainder of the report (chapter 3 to 12). BEMPs include pertinent measures and control points to drive maximum environmental improvement at the European level, considering geographic and product related hotspots across key environmental pressures including: greenhouse gas emissions, acidification, eutrophication, resource depletion, soil degradation, water stress, biodiversity loss and ecotoxicity. Information was synthesised from existing best practice documentation, online agricultural calculation tools, inputs from a Technical Working Group, expert consultation, farm visits, and life cycle assessment modelling. Key components of BEMP descriptions are short lists of priority measures, priority management and environmental performance indicators, and, where possible, benchmarks of best practice. Some pertinent techno-economic issues for implementation are also described, alongside case studies of best practice implementation, and with links to relevant detailed technical documentation.

FINAL DRAFT

Table of Contents

ACKNOWLEDGEMENTS	VI
INTRODUCTION	VII
A.1 GENERAL ASPECTS.....	VII
A.2 SCOPE.....	X
A.3 STRUCTURE.....	XIV
1 GENERAL INFORMATION ABOUT THE AGRICULTURE SECTOR - CROP AND ANIMAL PRODUCTION	1
1.1 Turnover and Employment	2
1.1.1 Main Economic Data	2
1.1.2 Structural Profile of the Sector	3
1.1.3 Geography of EU-27 Agriculture	4
1.1.4 Reference literature	8
1.2 Environmental Issues of the Agriculture Sector	10
1.2.1 Driving forces behind agricultural production and impacts	10
1.2.2 Defining environmental aspects, pressures and impacts.....	13
1.2.3 Environmental burdens.....	18
1.2.4 Environmental Burden Overview	37
1.2.5 Reference literature	39
2 MAPPING BEST PRACTICE FOR PRODUCT GROUPS AND FARM TYPES	43
2.1 Dairy production	51
2.2 Beef production	54
2.3 Sheep production	56
2.4 Pig production	58
2.5 Poultry production	60
2.5.1 Broiler production	60
2.5.2 Egg production	62
2.6 Grain production.....	64
2.7 Potato production.....	67
2.8 Oil seed rape production	68
2.9 Horticultural production	69
2.9.1 Imported versus local	69
2.9.2 Tomatoes	71
2.9.3 Strawberries.....	73
2.9.4 Apples.....	75
2.9.5 Wine	77
2.10 Reference literature.....	79
3 SUSTAINABLE FARM AND LAND MANAGEMENT.....	81
3.1 Strategic farm management plan	86
3.1.1 Examples of strategic farm management priorities in different regions	96
3.2 Embed benchmarking in environmental management	98
3.2.1 Quantitative environmental management case studies	105
3.3 Landscape water quality management	108
3.3.1 Catchment sensitive farming case studies	122
3.4 Landscape scale biodiversity management.....	124
3.4.1 Habitat management case studies	132
3.5 Energy and water efficiency	137
3.6 Waste management.....	149
3.7 Engage consumers with responsible production and consumption.....	156
4 SOIL QUALITY MANAGEMENT.....	164
4.1 Assess soil physical condition	170
4.2 Maintain/improve soil organic matter on cropland.....	180

4.2.1	Organic matter input case studies	191
4.3	Maintain soil structure (avoid erosion and compaction).....	196
4.3.1	Soil aeration case study	208
4.4	Soil drainage management.....	210
4.4.1	Soil drainage case studies	223
5	NUTRIENT MANAGEMENT.....	225
5.1	Field nutrient budgeting.....	231
5.2	Crop rotation for efficient nutrient cycles.....	258
5.3	Precision nutrient application	263
5.3.1	Precision nutrient application case studies	276
5.4	Select lower impact synthetic fertilisers	277
6	SOIL PREPARATION AND CROP PLANNING	286
6.1	Matching tillage operations to soil conditions	289
6.2	Minimise soil preparation operations	296
6.3	Mitigate tillage impacts	308
6.4	Crop rotations as one measure for soil protection	312
6.5	Establish cover/catch crops.....	321
7	GRASS AND GRAZING MANAGEMENT.....	328
7.1	Grass management.....	333
7.2	Managing high nature value grassland	346
7.2.1	Case studies	353
7.3	Pasture renovation and legume inclusion in permanent pasture and leys.....	357
7.4	Efficient Silage Production.....	365
8	ANIMAL HUSBANDRY	373
8.1	Locally adapted breeds	378
8.1.1	Locally productive breeds	378
8.1.2	Resource efficient breeds	380
8.2	Nutrient Budgeting on livestock farms.....	386
8.2.1	Case Study: Nutrient cycling in BPM ‘pilot’ commercial dairy farms, Netherlands. ..	400
8.3	Dietary reduction of N excretion (ruminants and monogastric)	401
8.4	Dietary reduction of enteric fermentation methane (ruminants).....	413
8.5	Green procurement of feed (ruminants and monogastric)	422
8.6	Maintain animal health	427
8.6.1	Case Study: Sheep Dipping and Treatments for Scab in UK flocks.....	435
8.7	Herd/flock profile management	437
9	MANURE MANAGEMENT.....	440
9.1	Efficient housing.....	443
9.2	Anaerobic digestion of organic waste.....	451
9.2.1	Dairy farm AD case study: Lodge Farm.....	460
9.3	Slurry and digestate separation	466
9.4	Appropriate slurry processing and storage systems	474
9.5	Appropriate solid manure storage	487
9.6	Injection slurry application and manure incorporation	492
9.7	Injection slurry application to grassland	502
9.7.1	Trailing shoe application case studies	511
10	IRRIGATION.....	513
10.1	Agronomic methods for optimising irrigation - Soil management and crop water requirements ..	515
10.2	Optimisation of irrigation delivery	529
10.3	Management of irrigation systems.....	535
10.4	Efficient and controlled techniques	539
11	CROP PROTECTION PRODUCTS.....	547
11.1	Optimising and reducing the use of crop protection products	548
11.2	Crop protection products selection	563
12	PROTECTED HORTICULTURE	572

12.1	Energy efficiency measures in protected horticulture	574
12.2	Water management in protected horticulture.....	588
12.3	Waste management in horticulture	596
13	CONCLUSIONS	603
13.1	Specific conclusions	603
13.2	Best environmental management practices: Environmental performance indicators and benchmarks of excellence	603
14	APPENDIX	612
14.1	List of Abbreviations - Glossary.....	612

FINAL DRAFT

Acknowledgements

This report was produced by the European Commission's Joint Research Centre in the framework of supporting the development of an EMAS Sectoral Reference Document¹ for the agricultural sector – crop and animal production. The work of authors was supported by a Technical Working Group comprising European experts in agriculture and environmental sustainability.

The authors wish to thank all the colleagues from the Directorate-General for the Environment (DG ENV), the Directorate-General for Health and Food Safety (DG SANTE) and the Directorate-General for Agriculture and Rural Development (DG AGRI) who provided insight and expertise that greatly assisted the research.

Furthermore, the authors would like to thank especially the members of the Technical Working Group for providing assistance with important data, information and case studies, as well as comments that greatly improved the report (the members are listed alphabetically): Barbara Amon, John Boardman, Claude Bourguignon, Frank Brentrup, Euan Brierly, Klára Čámská, Henriette Christensen, Caroline Drummond, Marion Hammerl, Katarina Hedlund, Laure Le Queré, Carlo Leifert, Daniele Massa, Bram Moeskops, Nicholas Mole, Jon Moorby, Audrey Moulhierac, Philippe Nicot, Urs Niggli, Nathaniel Page, Christian Pallier, Ermis Panagiotopoulos, Alberto Pardossi, Nigel Penington, Arnaud Petit, Xabier Poux, Jaroslav Prazan, Kate Pressland, Miguel Quemada, Karl Richards, Richard Riestler, Tania Runge, Juern Sanders, Robby Schreiber, Karin Stein-Bachinger, Rodney Thompson, Koos Verloop, Georg Vogl, Anne Vonesch, Henk Westhoek, Birgit Wilhelm, Wilfried Winiwater and Esther Zippel.

¹ Further information on the development of the EMAS Sectoral Reference Documents is available at: <http://susproc.jrc.ec.europa.eu/activities/emas/documents/DevelopmentSRD.pdf>

INTRODUCTION

A.1 GENERAL ASPECTS

Background

This report represents the scientific and technical basis of the Sectoral Reference Document (SRD) on Best Environmental Management Practice in the Agriculture sector - Crop and Animal Production, which has been developed according to Article 46 of the Eco-Management and Audit Scheme (EMAS) regulation⁽²⁾. The document was developed together by the European Commission's JRC and Bangor University (under a contract with the JRC) on the basis of desk research, interviews with experts, site visits and inputs from a Technical Working Group (TWG) comprising experts from the sector.

Context and overview

EMAS is a management tool for companies and other organisations to evaluate, report and improve their environmental performance. The latest revision of the EMAS Regulation (EC No. 1221/2009) introduced a particular focus on promoting best environmental management practices. To support this aim, the European Commission is producing SRDs to provide information and guidance on BEMPs in eleven priority sectors, including the Agriculture sector – Crop and Animal Production.

The document is intended to support environmental improvement efforts of all actors in the Agriculture sector – Crop and Animal Production. It can be used by all organisations, farmers and stakeholders of the sector who seek for reliable and proven information to improve their environmental performance. The document intention is to provide guidance on BEMP not only for EMAS organisations/companies etc., but rather to be a useful reference document for any relevant company that wishes to improve its environmental performance or any actor involved in promoting best environmental performance.

For this purpose, this document describes BEMPs, i.e. those techniques, measures or actions that allow farms (or companies of the sector) to minimise their environmental impacts in all the aspects under their direct control (direct environmental aspects) or on which they have a considerable influence (indirect environmental aspects). Following this integrated approach, the scope of this document is broad and covers the most important direct and indirect environmental aspects. For each BEMP, the document also presents appropriate environmental performance indicators, which enable farms to monitor their performance and compare it over time and with benchmarks. Indeed, the document also reports a list of benchmarks of excellence representing the exemplary environmental performance achieved by frontrunner organisations in the sector (EC, 2014³).

BEMPs encompass techniques, measures or actions that can be taken in order to minimise environmental impacts. These can include technologies (such as more efficient machinery) and organisational practices (such as staff training).

An important aspect of the BEMPs proposed in this document is that they are proven and practical, i.e.:

- They have been implemented at full scale by several companies (or by at least one company if replicable/applicable by others);
- They are technically feasible and economically viable.

In other words, BEMPs are demonstrated practices that have the potential to be taken up on a wide scale in the agriculture sector, yet at the same time are expected to result in exceptional environmental performance compared to current mainstream practices.

⁽²⁾ Regulation (EC) No 1221/2009 of the European Parliament and of the Council of 25 November 2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), OJ L 342, 22.12.2009

³ EC (2014), Development of the EMAS Sectoral Reference Documents on Best Environmental Management Practice, Learning from frontrunners, Promoting best practice, edited by: Schoenberger H., Canfora P., Dri M., Galvez-Martos J.L., Styles D., Antonopoulos I.S., ISSN 1831-9424 (online),

A standard structure is used to outline the information concerning each BEMP, as shown in Table A.1. Amongst others, this includes their “applicability”, to provide clear indications under which conditions or circumstances a certain technique can be implemented (technical feasibility) as well as economic information concerning investment and operation costs (economic viability). Likewise, the potential negative environmental impacts on other environmental pressures arising as side effects when implementing each BEMP (listed as cross media effects) are included in the common structure (Table A.1).

Table A.1. Information gathered for each BEMP

Category	Type of information included
Description	Brief technical description of the BEMP including some background and details on how it is implemented.
Achieved environmental benefits	Main potential <i>environmental benefits</i> to be gained through implementing the BEMP.
Environmental indicators	Indicators and/or metrics used to monitor the implementation of the BEMP and its environmental benefits.
Cross-media effects	Potential <i>negative</i> impacts on other environmental pressures arising as side effects of implementing the BEMP.
Operational data	Operational data that can help understand the implementation of a BEMP, including any issues experienced. This includes actual and plant-specific performance data where possible.
Applicability	Indication of the type of plants or processes in which the technique may or may not be applied, as well as constraints to implementation in certain cases.
Economics	Information on costs (investment and operating) and any possible savings (e.g. reduced raw material or energy consumption, waste charges, etc.).
Driving force for implementation	Factors that have driven or stimulated the implementation of the technique to date.
Reference organisations	Examples of organisations that have successfully implemented the BEMP.
Reference literature	Literature or other reference material cited in the information for each BEMP.

Sector-specific environmental performance indicators and benchmarks of excellence are also derived from each BEMP. These aim to provide organisations with guidance on appropriate metrics and levels of ambition when implementing the BEMPs described.

- **Environmental Performance Indicators** represent the metrics that are employed by organisations in the sector to monitor either the implementation of the BEMPs described or, when possible, directly their environmental performance. For some of the BEMPs of this particular document, the environmental performance indicators are distinguished into the following categories in order to be more comprehensive and to better support farmers (or companies of the sector):
 - Management indicators, which refer to *actions* by the farmers, and
 - Performance indicators, which refer to *environmental impacts* or *environmental efficiency* and they are measurable.

Moreover, a selection of the most relevant indicators is listed in Table 13.1 as "key environmental performance indicators".

- **Benchmarks of Excellence** represent the highest environmental standards that have been achieved by farms implementing each related BEMP. These aim to allow all actors in the sector to understand the potential for environmental improvement at the process level. Benchmarks of excellence are not targets for all organisations to reach but rather a measure of what is possible to achieve (under stated conditions) that they can use to set priorities for action in the framework of continuous improvement of environmental performance.

Approach used to develop this document

A TWG was set up to get a broader access to the sector, to obtain more qualified information and to verify the techniques described as well as to draw the conclusions with respect to appropriate environmental performance indicators and benchmarks of excellence. There was one meeting at the beginning of the whole development process on 14-15 October 2013 (so-called kick-off meeting) as well as a final meeting at the end on 23-24 June 2014 (final meeting). A lot of information needed to draft this document was already publicly available from various sources, including a number of comprehensive reports. That was supplemented with information collected directly from farmers, stakeholders of the sector, non-governmental organisations, site visits and technology providers.

The techniques enclosed and described in the document were selected according to the frontrunner approach (EC, 2014⁴). Frontrunner farms were identified and evaluated in-depth through desk research, site visits and eventually expert consultation. Therefore the enclosed information was properly assessed in order to set appropriate environmental performance indicators and eventually benchmarks of excellence (wherever possible and for almost each BEMP), which are the major outcome of the whole process.

⁴ EC (2014), Development of the EMAS Sectoral Reference Documents on Best Environmental Management Practice, Learning from frontrunners, Promoting best practice, edited by: Schoenberger H., Canfora P., Dri M., Galvez-Martos J.L., Styles D., Antonopoulos I.S., ISSN 1831-9424 (online),

A.2 SCOPE

Target sub-sectors

This report primarily addresses crop and animal production, which together have henceforth been referred to as the “agricultural sector” unless otherwise stated. The production activities are represented by NACE codes A1.1 to A1.6, including all animal, annual and perennial crop production (Table A.2).

Table A.2. NACE codes for agricultural production (EC, 2010⁵)

NACE Code	Agricultural Production	Farm types included in this report (and some common crop types)
A	Agriculture, forestry and fishing	
A1	Crop and animal production, hunting and related service activities	
A1.1	Growing of non-perennial crops	
A1.1.1	Growing of cereals (except rice), leguminous crops and oil seeds	Arable farms (wheat, barley, maize, peas, oil seed rape, sunflowers)
A1.1.2	Growing of rice	
A1.1.3	Growing of vegetables and melons, roots and tubers	Arable and horticulture farms (potatoes, sugar beet, onions, cabbage, carrots, broccoli, melons, tomatoes)
A1.1.4	Growing of sugar cane	
A1.1.5	Growing of tobacco	
A1.1.6	Growing of fibre crops	
A1.1.9	Growing of other non-perennial crops	
A1.2	Growing of perennial crops	
A1.2.1	Growing of grapes	Horticulture farms
A1.2.2	Growing of tropical and subtropical fruits	
A1.2.3	Growing of citrus fruits	Horticulture farms (oranges, lemons)
A1.2.4	Growing of pome fruits and stone fruits	Horticulture farms (apples, pears, plums, peaches, cherries, avocados)
A1.2.5	Growing of other tree and bush fruits and nuts	Horticulture farms (strawberries, black berries, black currants)
A1.2.6	Growing of oleaginous fruits	Horticulture farms (olives)
A1.2.7	Growing of beverage crops	Horticulture and arable farms (apples, black currants, barley)
A1.2.8	Growing of spices, aromatic, drug and pharmaceutical crops.	Horticulture farms (coriander, parsley, basil)
A1.2.9	Growing of other perennial crops	
A1.3	Plant propagation	
A1.3.0	Plant propagation	
A1.4	Animal production	
A1.4.1	Raising of dairy cattle	Dairy farms
A1.4.2	Raising of other cattle and buffaloes	Beef farms
A1.4.3	Raising of horses and other equines	
A1.4.4	Raising of camels and camelids	
A1.4.5	Raising of sheep and goats	Sheep farms
A1.4.6	Raising of swine/pigs	Pig farms
A1.4.7	Raising of poultry	Poultry farms
A1.4.9	Raising of other animals	

⁵ EC (2010), List of NACE codes, available online: http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

NACE Code	Agricultural Production	Farm types included in this report (and some common crop types)
A1.5	Mixed farming	
A1.5.0	Mixed farming	Mixed farms
A1.6	Support activities to agriculture and post-harvest crop activities	
A1.6.1	Support activities for crop production	
A1.6.2	Support activities for animal production	
A1.6.3	Post-harvest crop activities	
A1.6.4	Seed processing for propagation	
A1.7	Hunting, trapping and related service activities	
A1.7.0	Hunting, trapping and related service activities	

Activities listed in Table A.2 represent a massive scope, especially when the range of production methods employed across European member states are considered; this report cannot address all aspects of all types of crop and animal production in all regions of Europe. Best practice descriptions have therefore targeted environmental hotspots and areas of maximum environmental improvement potential within the sector, as determined by:

- the most produced crops and livestock products
- the major regions and systems of production for these products within Europe
- the lifecycle environmental burden arising from production and consumption

Based on these criteria, the main farm types and some common crop types included in the scope of this report are presented in green cells in Table A.2.

In section 1.1.3, Figure 1.4 and Figure 1.5 provide an overview of the main crops and livestock products across the EU27, and the top three producing member states. However, production quantities alone do not necessarily represent environmental hotspots. With respect to crop production, some horticultural crops such as tomatoes and strawberries may be associated with high environmental burdens depending on how they are produced (e.g. > 4 kg CO₂e per kg for tomatoes from heated greenhouses). Heated greenhouses, cultivation of peat soils and high application rates of crop protection agents are particular hotspots for horticultural production (transport may also be a downstream hotspot, depending on mode). With respect to the livestock sector, cattle and sheep production occupy large areas of land, and may be located in sensitive areas. Therefore, despite representing a smaller harvest yield per year compared with pig and poultry production, they are also an important focus of this report (pig and poultry production are addressed in an IPPC BREF (EC, 2013)⁶).

Target actors

The scope of this report primarily covers best environmental management practices applicable by farm managers, but is also targeted at farm advisors and farm suppliers, along with any other interested stakeholders (Table A.2).

There are many important environmental aspects of agricultural production arising both up- and down-stream of farms. Farm managers can have a strong influence on upstream environmental aspects through measures such as green procurement. Thus, key upstream aspects such as fertiliser manufacture and animal-feed production are considered to the extent that they can be

⁶ EC (2013), Best Available Techniques (BAT) Reference Document for the Intensive Rearing of poultry and Pigs, Industrial Emissions Directive 2010/75/EU, Integrated pollution Prevention and Control, available online: http://eippcb.jrc.ec.europa.eu/reference/BREF/IRPP_D2_082013online.pdf

influenced by farm managers. Downstream aspects are typically less strongly influenced by farmers, and with the exception of few sections, this report considers environmental impacts arising up to the farm gate only. This is also to avoid overlap with the EMAS SRD on Food and Beverage Manufacturing also being developed by the JRC.

Nonetheless, a life cycle perspective is taken throughout this background report, to ensure that any proposed best practice does not incur significant negative downstream consequences through for example compensatory production. In order to inform this, relevant consequential Life Cycle Assessment (LCA) principles and studies are referred to.

Chapter 2 of this report sets out the lifecycle environmental burdens arising from major sub-sectors, in relation to production of specific product groups such as dairy, beef, lamb, chicken, pork, eggs, tomatoes, strawberries, apples, etc. That chapter also outlines the supply chain hotspots of some products where these can occur after the farm gate; e.g. apples imported from New Zealand.

FINAL DRAFT

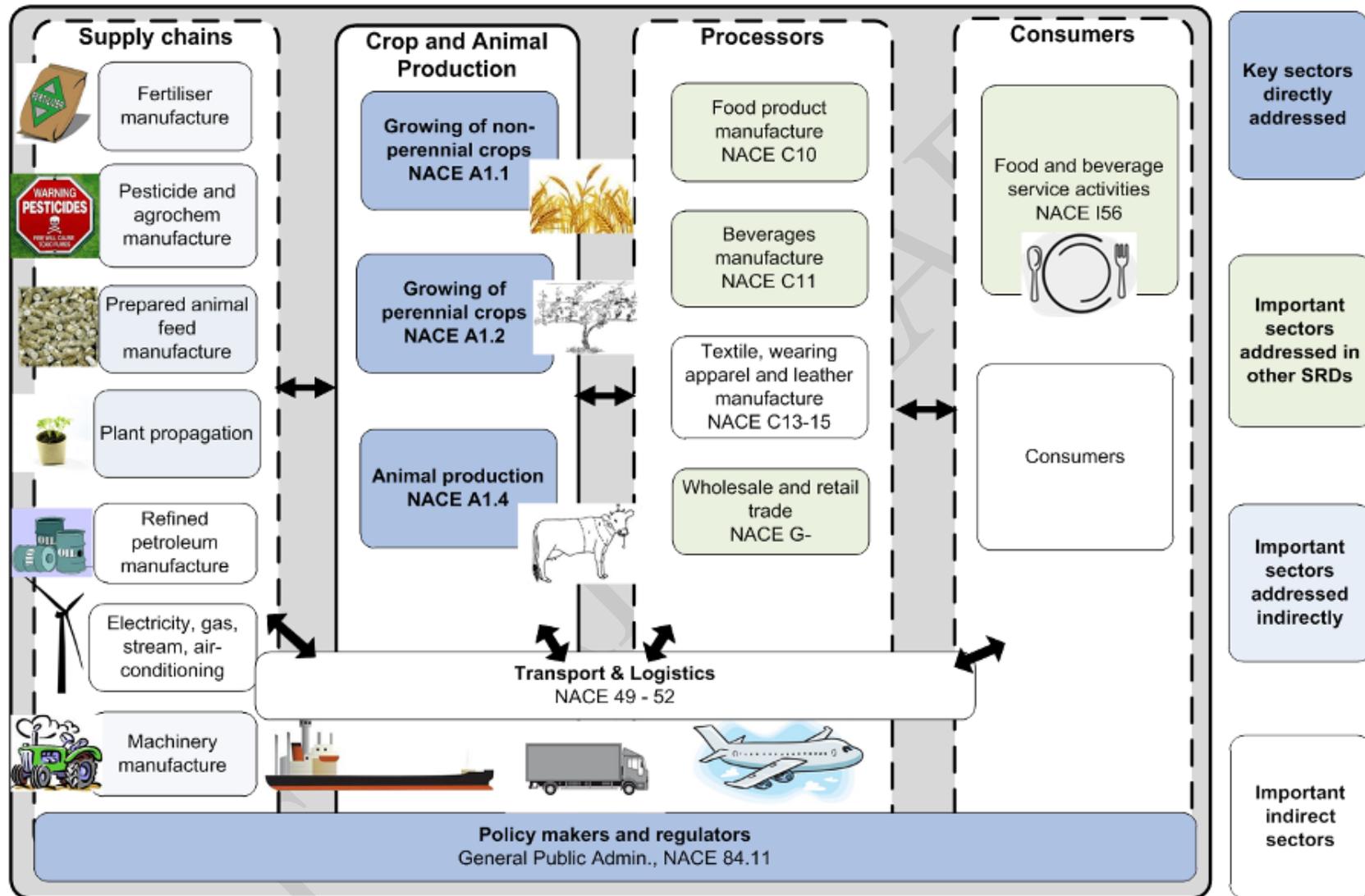


Figure A.1. Scope of this report in terms of the core crop and animal sector and related suppliers and influential actors

A.3 STRUCTURE

Following a brief description of the context and scope of this report (current section), Part 1 ('GENERAL INFORMATION') provides some background information on the agriculture sector - crop and animal production – in the EU. Part 2 is the main body of the report, containing BEMPs. These are divided according to: (i) actors; (ii) environmental aspects; (iii) processes. Contents are summarised in Table A.3.

Table A.3. Structure of the background report

Part	Chapter	Target actors	Contents
1	1	All actors with influence over food and drink supply chain	General information about the sector, including: <ul style="list-style-type: none"> – Turnover and employment – Environmental aspects
	2	All actors with influence over food and drink supply chain	<ul style="list-style-type: none"> – Life cycle assessment of major product groups – Additional environmental burdens (soil quality, biodiversity, ecosystem services) – Mapping farm and supply chain BEMP
2	3	Farmers, farm advisors	Cross-cutting BEMPs, in particular related to: <ul style="list-style-type: none"> – Environment management systems – Record keeping – Benchmarking – Housekeeping – Landscape planning – Waste management – Energy and water efficiency – Biodiversity – Engaging consumers with responsible production and consumption
	4	Farmers, farm advisors	Soil quality management, including: <ul style="list-style-type: none"> – Nutrient management planning – Organic amendments – Maintenance of soil structure – Soil drainage
	5	Farmers, farm advisors	Soil nutrient management planning, including: <ul style="list-style-type: none"> – Field nutrient management planning – Crop rotation – Precision application – Low impact fertilisers
	6	Tillage and horticulture	Soil preparation and cropping BEMPs, including:

Part	Chapter	Target actors	Contents
		farmers and farm advisors	<ul style="list-style-type: none"> – Matching tillage to soils – Minimising soil disturbance – Low impact tillage – Crop rotations – Cover and catch crops
	7	Pasture farmers and farm advisors	<p>Grass and grazing BEMPs including:</p> <ul style="list-style-type: none"> – Maximising grass production and grazing uptake – Managing grazing in high nature value areas – Pasture renewal and clover incorporation – Efficient silage production
	8	Livestock farmers and farm advisors	<p>Animal husbandry BEMPs including:</p> <ul style="list-style-type: none"> – Breed selection – Farm nutrient budgeting – Dietary optimisation of protein intake – Dietary reduction of enteric methane emissions – Green procurement of feed – Animal health plans – Herd/flock profile management
	9	Livestock farmers and farm advisors	<p>Manure management BEMPs including:</p> <ul style="list-style-type: none"> – Low emission housing systems – Anaerobic digestion – Slurry separation – Appropriate liquid manure storage – Appropriate solid manure storage facilities – Injection application of slurries – Trailing shoe and banded application of slurries
	10	Farmers, farmer advisors on irrigation management	<p>Irrigation management including;</p> <ul style="list-style-type: none"> – Agronomic methods – Optimisation of irrigation delivery – Management of irrigation systems (distribution and storage) – Efficient and controlled strategies
	11	Farmers, farmer advisors on crop protection products	<p>The crop protection products chapter includes:</p> <ul style="list-style-type: none"> – Optimising and reducing the use of crop protection products

Part	Chapter	Target actors	Contents
			– Crop protection products selection
	12	Farmers, farmer advisors on protected horticulture	The protected horticulture chapter includes: – Energy efficiency in protected horticulture – Water management in protected horticulture – Waste management in protected horticulture

FINAL DRAFT

1 GENERAL INFORMATION ABOUT THE AGRICULTURE SECTOR - CROP AND ANIMAL PRODUCTION

Member state codes

For reference throughout this report, Table 1.1 provides a list of country codes for EU member states and candidate countries.

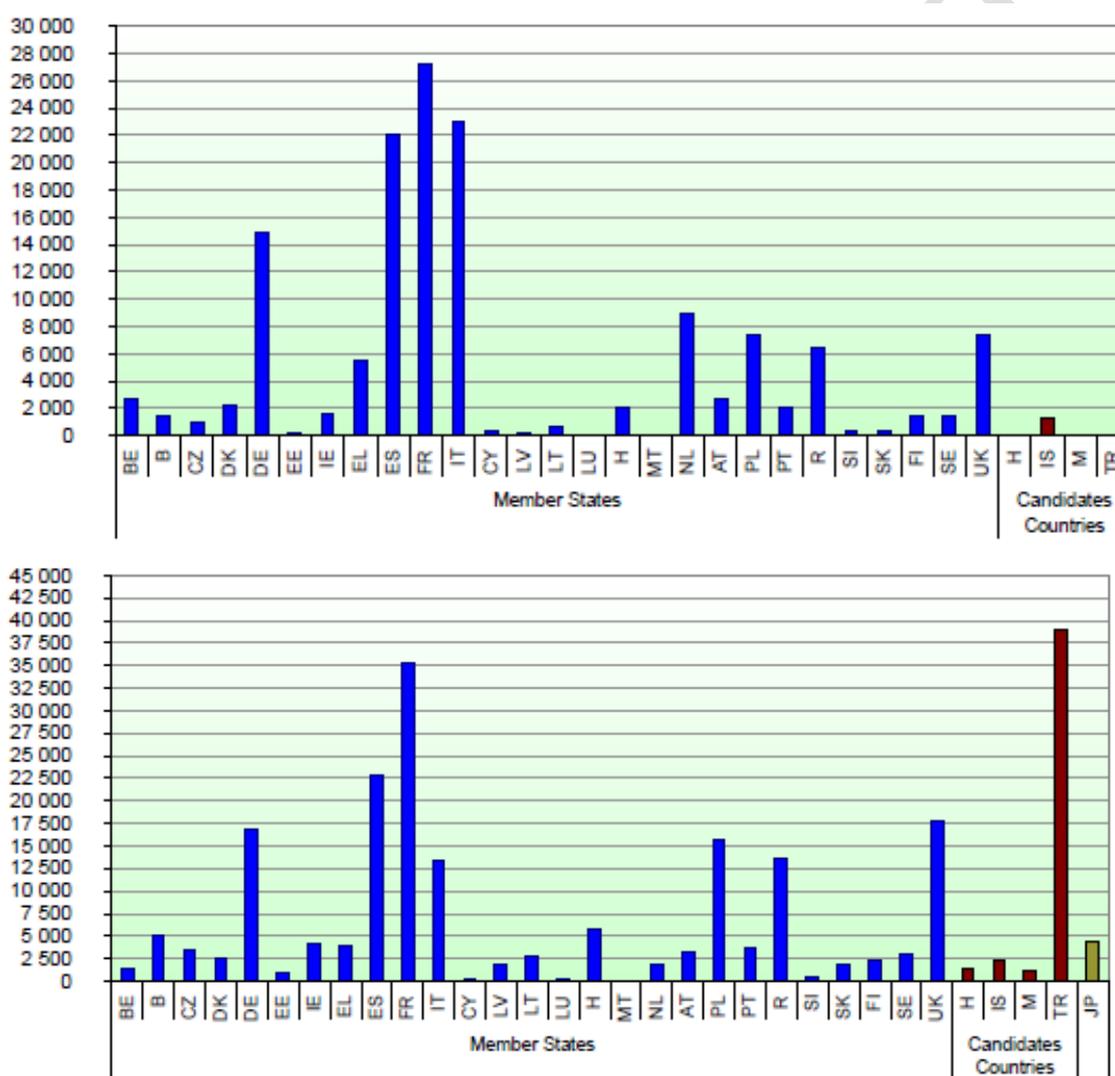
Table 1.1. List of EU Member states and Candidate countries and associated country code.

EU Member State	Country Code
Belgium	BE
Bulgaria	BG
Croatia	H
Czech Republic	CZ
Denmark	DK
Germany	DE
Estonia	EE
Ireland	IE
Greece	EL
Spain	ES
France	FR
Italy	IT
Cyprus	CY
Latvia	LV
Lithuania	LT
Luxembourg	LU
Hungary	HU
Malta	MT
Netherlands	NL
Austria	AT
Poland	PL
Portugal	PT
Romania	RO
Slovenia	SI
Slovakia	SK
Finland	FI
Sweden	SE
United Kingdom	UK
Candidate Countries	Country Code
Montenegro	M
Iceland	IS
Turkey	TR

1.1 Turnover and Employment

1.1.1 Main Economic Data

Agriculture is the most important land user in Europe, with around 50% of the surface used for agricultural production (184 million ha) (DG AGRI, 2012a). The sector is crucial in terms of its economic contribution towards the European economy, contributing 144 billion EUR to the EU-27 economy in 2010 (Eurostat, 2012a, DG AGRI, 2012a). Agricultural trade represents around 6% of the total trade in the EU-27, and underpins most of the valuable imports and exports of food and drink products (DG AGRI, 2012b). Contributions to the economy, as measured by gross value added (GVA), and the utilised agricultural area of each of the 27 member states plus four candidate countries, can be seen in Figure 1.1.



Source: Adapted from DG AGRI (2012a).

Figure 1.1. Gross value added at basic prices (million EUR) (above) and utilised agricultural area (1000 ha) (below) across the EU-27 and candidate countries in 2010.

Agriculture further contributes to the economy through providing important levels of employment. The FADN field of observation during 2009 recorded 4.9 million agricultural holdings across the EU-27, employing some 10.5 million people (DG AGRI, 2012a). Whilst the combined agricultural and food sector is reported to account for 17 million jobs (7.6% of total employment). The sector often

provides the main source of income and employment in rural areas where average GDP per capita is typically significantly below that of urban areas (Eurostat, 2012a). When considering the agricultural labour force, including the family labour force as well as permanently employed non-family workers, some 27 million were reported to work within the sector during 2007 (Eurostat, 2011).

Not only a crucial sector in itself agriculture also underpins a multitude of additional sectors, including the economically important food and drink processing and retail sectors, which are almost entirely reliant on agricultural outputs. Consumers purchase the majority of the food they eat and the beverages they drink from a range of retail outlets (supermarkets, specialist food retailers, markets and stalls), but food and drinks can also be purchased from food service providers (restaurants, take-away outlets, cafés or bars).

1.1.2 Structural Profile of the Sector

In the EU-27, during 2009, horticulture farming provided the largest average net value added per holding, at 62,340 EUR, followed by pigs and/or poultry production at 51,120 EUR, whereas mixed farming was the lowest at 14,330 EUR. Labour input from each of the farming types follows a similar pattern, utilising 3.36 annual work units (AWU) per holding within the horticulture sector, followed by 1.93 AWU per holding for pigs and poultry. UAA is largely dominated by grazing livestock (54.4 ha per holding) and field crops (42.9 ha per holding) (Table 1.2). The commodities representing the highest share of products in agricultural production during 2010 were milk (13.8%), pigs (8.9%), fresh vegetables (8.7%), followed by cattle (8.2%) and fruit (6.5%) (DG AGRI, 2012a).

Table 1.2. Structural profile of the agricultural sector by farming type.

Type of Farming	No. of holdings (FADN field of observation)	UAA (ha)	AWU	FNV added (Average result per holding, 1000 EUR)
Field crops	1,498,467	42.93	1.50	19.99
Horticulture	164,547	5.20	3.36	62.34
Wine	231,378	13.94	1.79	38.16
Permanent crops	853,086	9.28	1.35	17.05
Milk	500,383	39.87	1.86	30.28
Grazing livestock (excl. milk)	611,024	54.41	1.65	23.72
Pigs and / or poultry	137,741	20.64	1.93	51.12
Mixed (crops + livestock)	951,804	30.08	1.68	14.33

Source: DG AGRI (2012a)

Small holdings, classified as below 5 ha of UAA, generally dominate the agricultural industry across Europe, accounting for 70% of the total in 2007. Holding size between 0 and 10 ha accounted for over half the total in 18 of the 27 member states, whereas those over 50 ha are minimally distributed across the member states, reaching over 30% of the total in only Denmark (34.2%), France (37.4%) and Luxembourg (48.1) (Figure 1.2) (DG AGRI, 2012a).

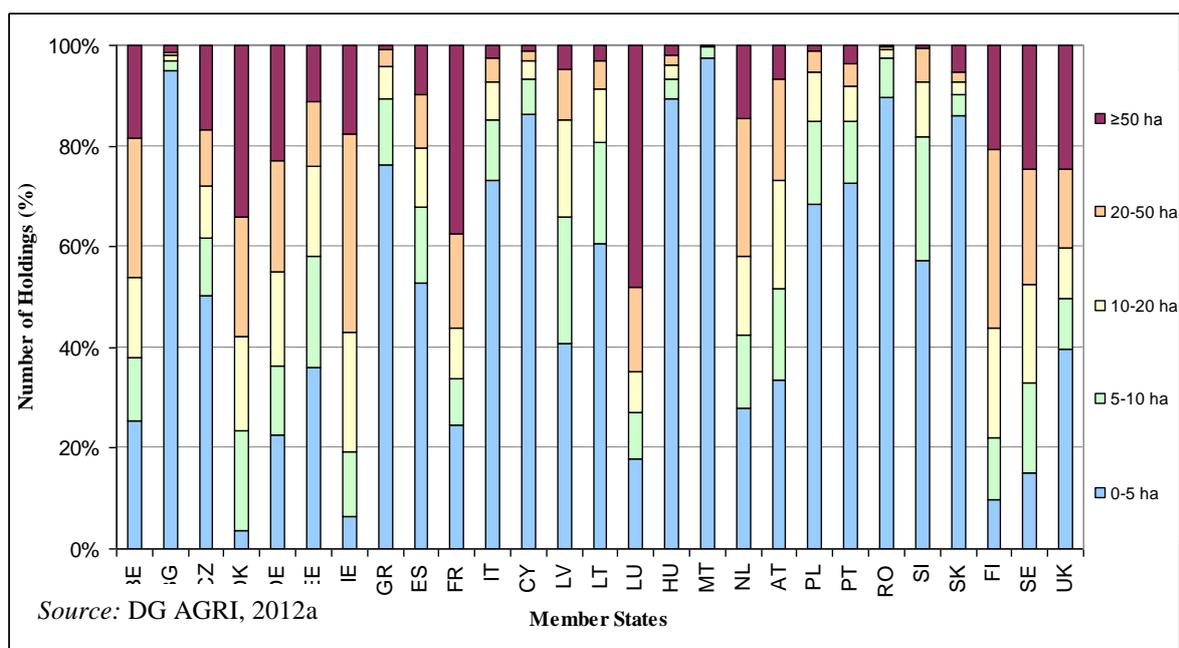


Figure 1.2. Size distribution of agricultural holdings in the EU-27, by number of holdings

1.1.3 Geography of EU-27 Agriculture

Rates of agricultural production and therefore the contribution of the sector to national economies vary greatly across the countries within Europe. Details for each of the member states and candidate countries, as presented in Table 1.3, show that the countries in which agriculture contributed the most to the economy in 2010 were France (27 billion EUR), Italy (23 billion EUR) and Spain (22 billion EUR); together accounting for half of the 144 billion EUR total across Europe.

Table 1.3. Agricultural production in the EU Member States and candidate countries, 2010. Italics represent candidate countries

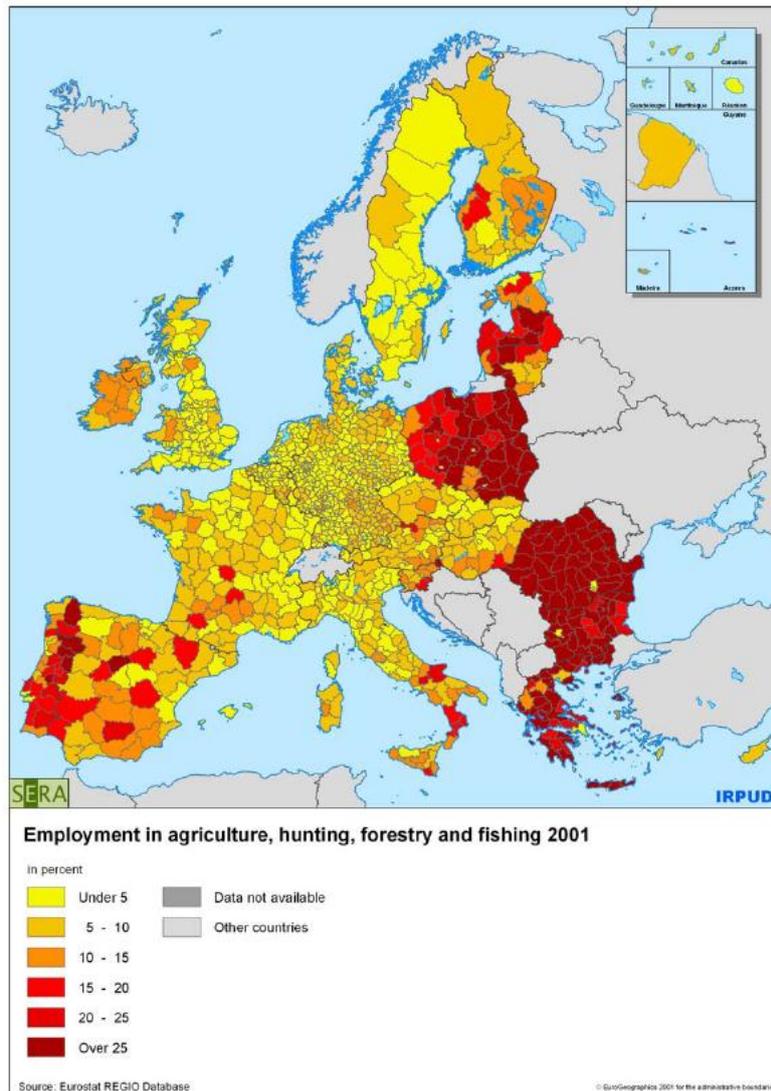
	No. of persons employed* (1,000 persons)	Turnover (output) (€ million)	GVA at basic prices (1,000)	No. of holdings
EU-27	10,459	355,573	143,810	13,700
Austria	177	6,452	2,682	165
Belgium	81	7,757	2,622	48
Bulgaria	515	3,832	1,457	493
Cyprus	15	695	318	40
Czech Republic	135	3,990	994	39
Denmark	73	9,214	2,155	45
Estonia	19	636	236	23
France	779	66,651	27,172	527
Finland	107	4,159	1,456	68
Germany	730	45,044	14,970	371
Greece	429	10,245	5,567	860
Hungary	220	6,561	2,093	626
Ireland	79	5,634	1,529	128
Italy	838	44 439	23 007	1 679
Latvia	62	934	263	108
Lithuania	95	2,005	648	230
Luxembourg	7	298	95	2
Malta	3	125	57	11

	No. of persons employed* (1,000 persons)	Turnover (output) (€ million)	GVA at basic prices (1,000)	No. of holdings
Netherlands	251	24,772	8,979	77
Poland	1,604	19,437	7,385	2,391
Portugal	434	6,998	2,092	275
Romania	1,726	15,342	6,456	3,931
Slovakia	45	1,902	377	69
Slovenia	68	1,092	402	75
Spain	712	39,033	22,016	1,044
Sweden	100	5,046	1,447	73
United Kingdom	593	23,372	7,335	300
<i>Croatia</i>	<i>216</i>	<i>2,921</i>	<i>1,264</i>	<i>177</i>
<i>Iceland</i>	<i>6</i>	<i>-</i>	<i>-</i>	<i>-</i>
<i>Y R of Macedonia</i>	<i>127</i>	<i>-</i>	<i>-</i>	<i>-</i>
<i>Turkey</i>	<i>5,356</i>	<i>-</i>	<i>-</i>	<i>3,077</i>

Source: DG AGRI (2012a)

Despite the major contribution of agriculture to the European economy coming from agricultural holdings in western Europe, the largest number of agricultural holdings are located in eastern Europe, in particular Romania (4 million), Turkey (3 million) and Poland (2 million). Turkey utilises the largest area for agriculture at 39 million hectares, and displays the highest employment rates, employing over 5 million people - representing a 21.6% share of the employed civilian working population (DG AGRI, 2012a). Romania follows, with an employment rate of nearly 2 million people in the agricultural sector.

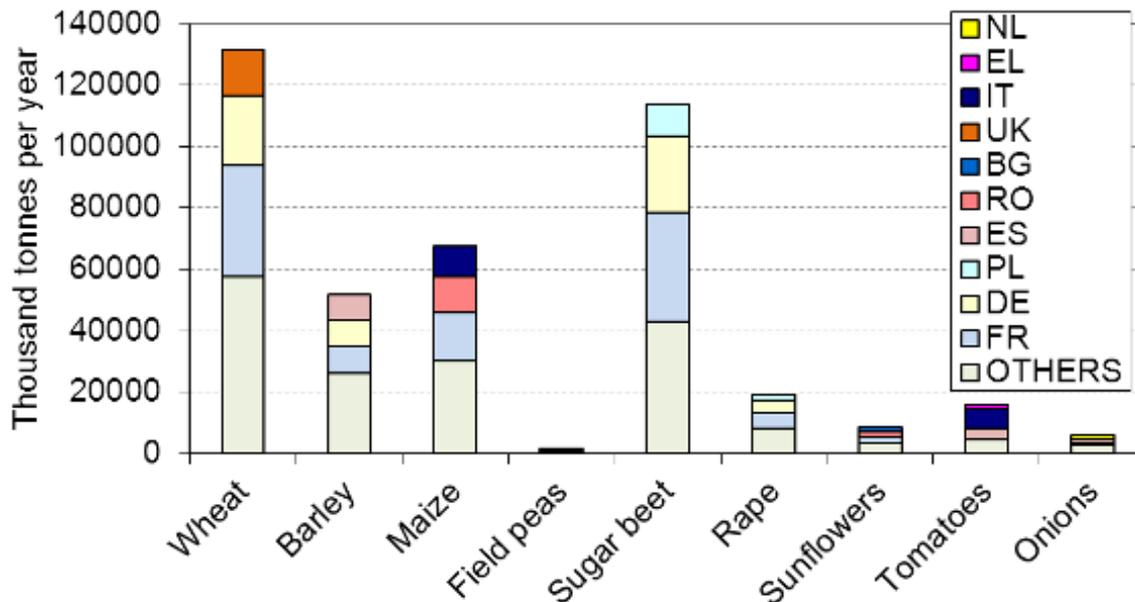
These findings remain consistent when considering the share of employment in agriculture within overall employment, with Figure 1.3 displaying high employment percentage rates in Romania, Poland, Lithuania and Greece, as well as high rates in certain regions of Spain. In the predominantly rural regions of Romania more than a half of the workforce is employed in the primary agriculture sector, in Bulgaria and Greece it is one third, and in Latvia, Poland, Lithuania and Portugal around one quarter. In contrast, many regions of the EU-15 have a low share of employment (below 5 %) in the primary agriculture sector, as in Luxembourg, the United Kingdom, Belgium, Germany, Sweden, the Netherlands, France and Northern Italy. But even in these countries there exist regions with a higher significance of this sector (above 5 or 10 %), particularly in rural regions (DG AGRI, 2012a).



Source: Copus et al., (2006)

Figure 1.3. Share of employment in agriculture, hunting, forestry and fishing (persons with main employment in the primary sector) in total employment, 2001

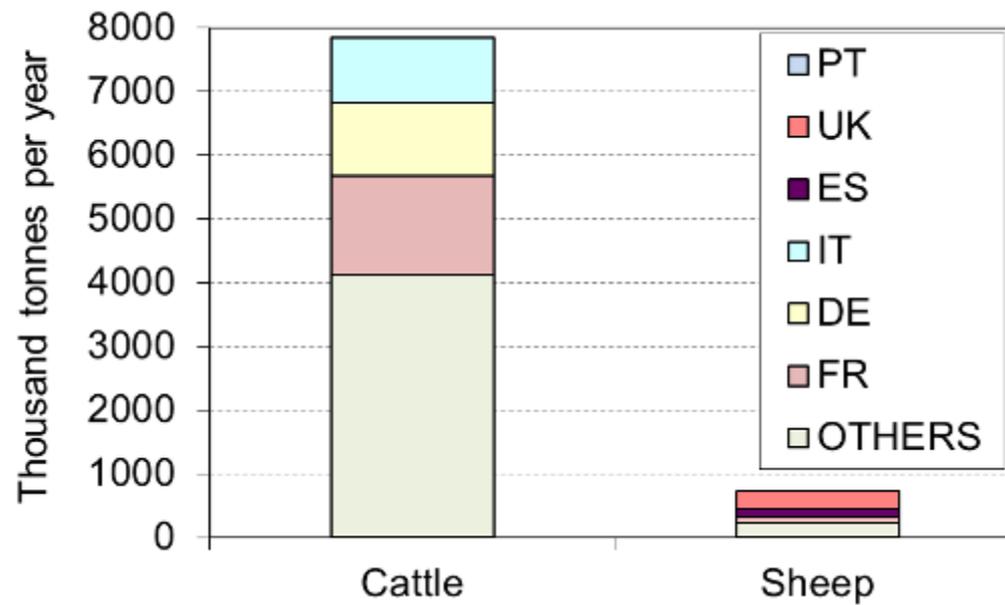
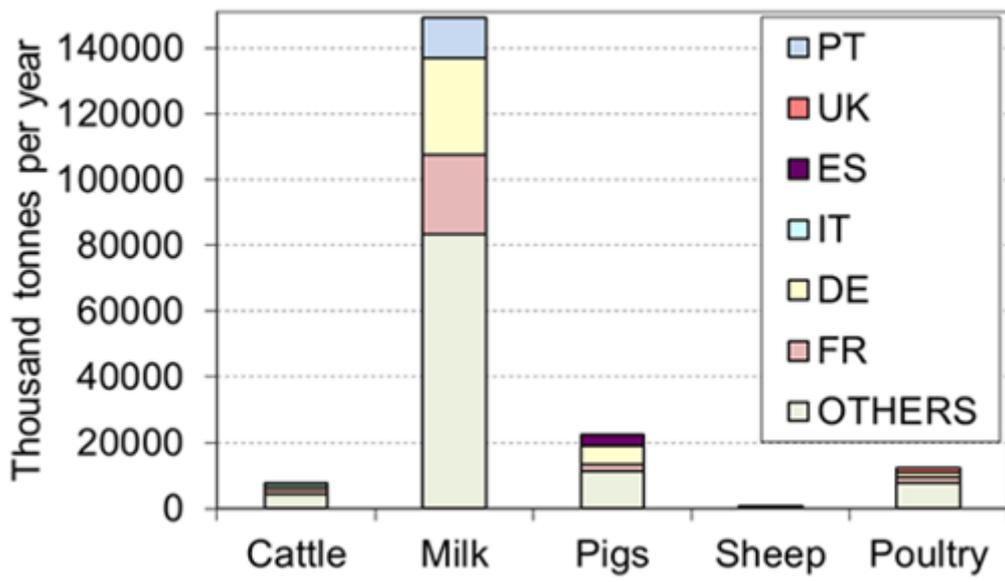
Within EU-27, the crop with the highest production rate (as measured in tonnes of harvested product) is wheat, with 132 million tonnes harvested in 2011, representing almost half of the entire cereal production (45%). Those countries producing the highest share of this crop were, in descending order, France (36Mt), Germany (23Mt) and the UK (1.5Mt). The following crops with the highest tonnage produced in 2011 in the EU-27 were Sugar beet (114Mt) maize (67Mt, 23% of cereals harvested) and barley (52Mt, 18% of cereal harvested) (Figure 1.4). In 2006, the crops utilising the largest area of agricultural arable land within the EU-27 were wheat, covering 29% of arable land on average, followed by barley and maize. Aside from cereals oilseeds use 17% of arable land (dominated by rapeseed), and sugar beet (12%). Figure 1.4 displays the main crops produced in the EU-27, and provides a focus for the present report within the crop sector.



Data source: Eurostat (2012b).

Figure 1.4. Harvested production of major crops in the EU27, and the top three producing member states for each crop

Within the livestock sector, the animal product with the highest rate of production is milk; in 2010 approximately 149 Mt were produced. Those countries with the highest production rate of milk in 2010 were Germany (30 Mt), France (24 Mt) and Portugal (12 Mt). The production of pig meat in the EU-27 is second to milk production within the livestock sector, with the EU-27 producing 22 Mt in 2011. The highest producing countries of pig meat in the EU-27 in 2011 were Germany (6 Mt), Spain (3 Mt) and France (2 Mt), which together supply around half (49%) of the EU production of pig meat. The quantity of poultry meat produced in the EU-27 totalled 12 Mt; France (2 Mt), UK (2 Mt) and Germany (1 Mt) were the largest producers of poultry meat (Eurostat, 2012b). Figure 1.5 displays the main types and locations of livestock production within the EU-27, and therefore provides a focus for this report with respect to livestock production.



NB: Data for 2011, except milk (2010)

Data source: Eurostat (2012b)

Figure 1.5. Animal produce in the EU27 in 2011, displaying the top three producing countries of each product (top), with a focus on cattle and sheep production

1.1.4 Reference literature

- Copus A., Hall C., Barnes A., Graham D., Cook P., Weingarten P., Baum S., Stange H., Linder C., Hill A., Eiden G., McQuaid R., Grieg M. 2006, *Study on Employment in Rural Areas (SERA) Final Deliverable*, European Commission Report.
- EDA (European Dairy Association) 2009, Online available at http://www.euromilk.org/eda/content_html.aspx?cid=426, accessed March 2013.

- EC 2003. Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs. IPTS, Seville, online available at: http://eippcb.jrc.es/reference/BREF/irpp_bref_0703.pdf.
- European Parliament 2010, *The poultry and egg sectors: evaluation of the current market situation and future prospects*, Agriculture and rural development, Directorate general for internal policies
- Eurostat 2011, *Food: From farm to fork statistics*. Eurostat Pocketbooks.
- Eurostat 2012a, *The economy of rural regions*. Statistics in Focus 30/2012.
- Eurostat 2012b, *Agriculture, fishery and forestry statistics*, Pocketbooks, ISSN 1977-2262.
- DG AGRI, 2012a. *Agriculture in the European Union: Statistical and economic information 2011*.
- DG AGRI, 2012b. *Agricultural Trade Statistics, 2001-2010*.

FINAL DRAFT

1.2 Environmental Issues of the Agriculture Sector

1.2.1 Driving forces behind agricultural production and impacts

In recent years an increasing pressure has been placed on the agricultural sector in order to increase food production rates and meet the change in food demand, whilst also providing increasing quantities of fibre and fuel. This pressure has risen from a growing human population, economic development, the nutrition transition, increasing fossil energy prices and biofuels policy targets. A threefold increase in global gross agricultural production rates has been seen between 1961 and 2010 (Figure 1.6), dominated by demand for meat and milk production. In the developing countries, between 1962 and 2003 meat consumption rates rose from 10 to 29 kg/person/year, whilst milk rose from 28 to 48 kg/person/year. The rise in agricultural production demand is expected to increase by a further 70% by 2050.

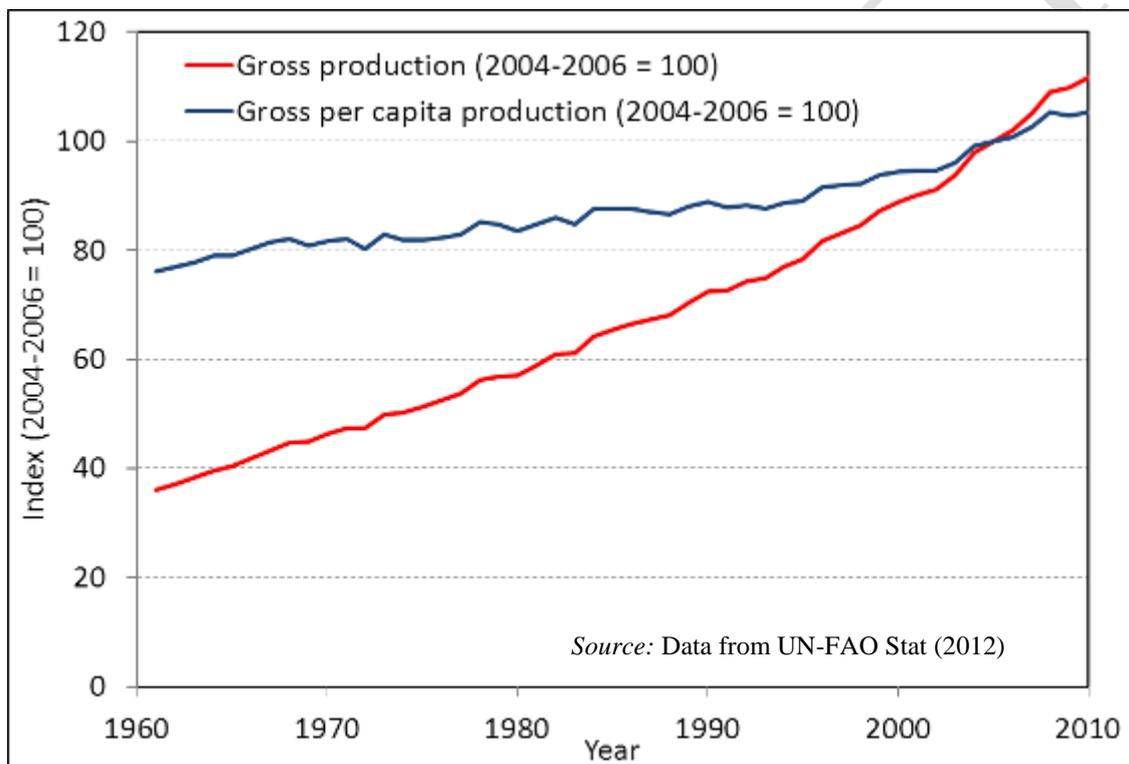
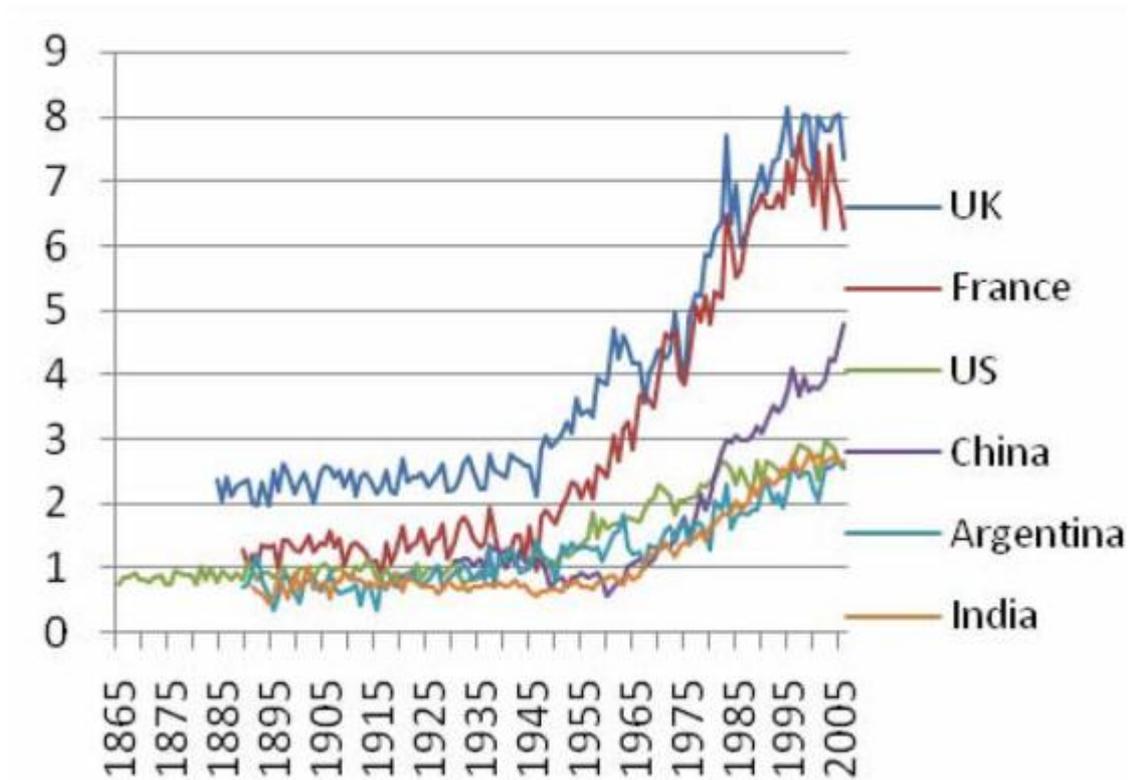


Figure 1.6. Trend in total global agricultural production between 1961 and 2010, according to data from UN FAO Stat (2012)

The range and magnitude of environmental impacts associated with agricultural production coupled with the growing global demand for agricultural products, point to an urgent requirement for improved sustainability within the sector. Notably, the negative impacts of intensive agriculture on the environment need to be balanced against the imperative to maintain Europe's capacity to feed a growing population. The objective of improving sustainability is an acknowledged priority issue within the new Common Agricultural Policy (CAP), which provides incentives for farmers to produce food in a hygienic manner, maintaining high standards of animal welfare, using environmentally-friendly production methods, whilst promoting a sustainable rural economy.

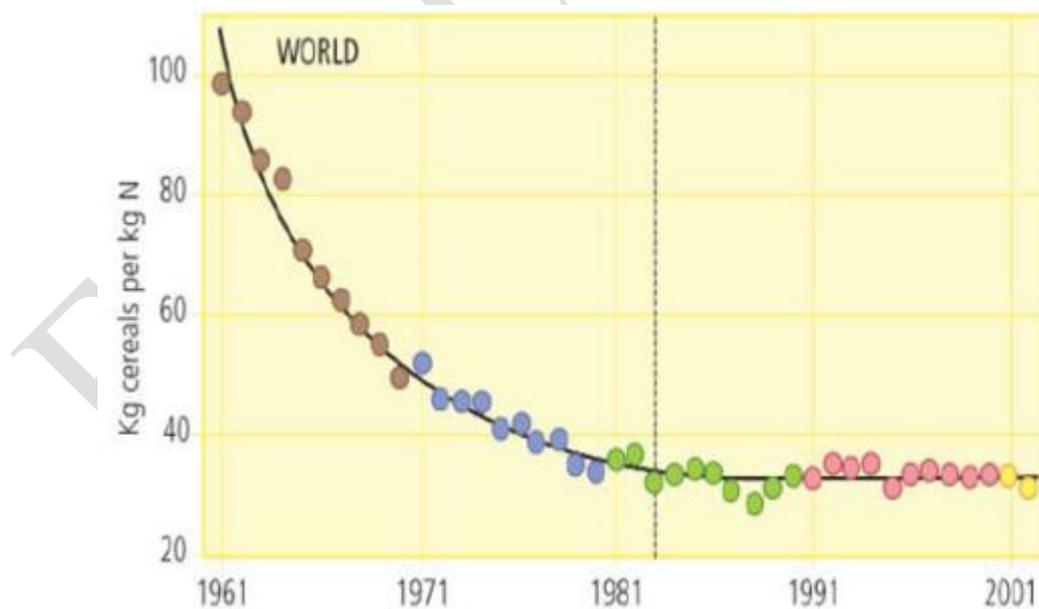
One worrying aspect of the large gains in real yields over the past 60 years that have enabled agricultural output to keep pace with demand (e.g. Figure 1.7) is that they required large increases in synthetic fertiliser application and were associated with a steep decline in nutrient, and especially Nitrogen Use Efficiency (NUE) (Figure 1.8). Meanwhile, there is some evidence that areal yield gains

for staple crops such as wheat and rice are tailing off, from 2-3% per year to 1% per year (Fischer et al., 2009).



Source: Fischer et al. (2009)

Figure 1.7. Trends in areal grain yields ($t\ ha^{-1}\ yr^{-1}$) for six leading wheat producing countries over the past 150 years

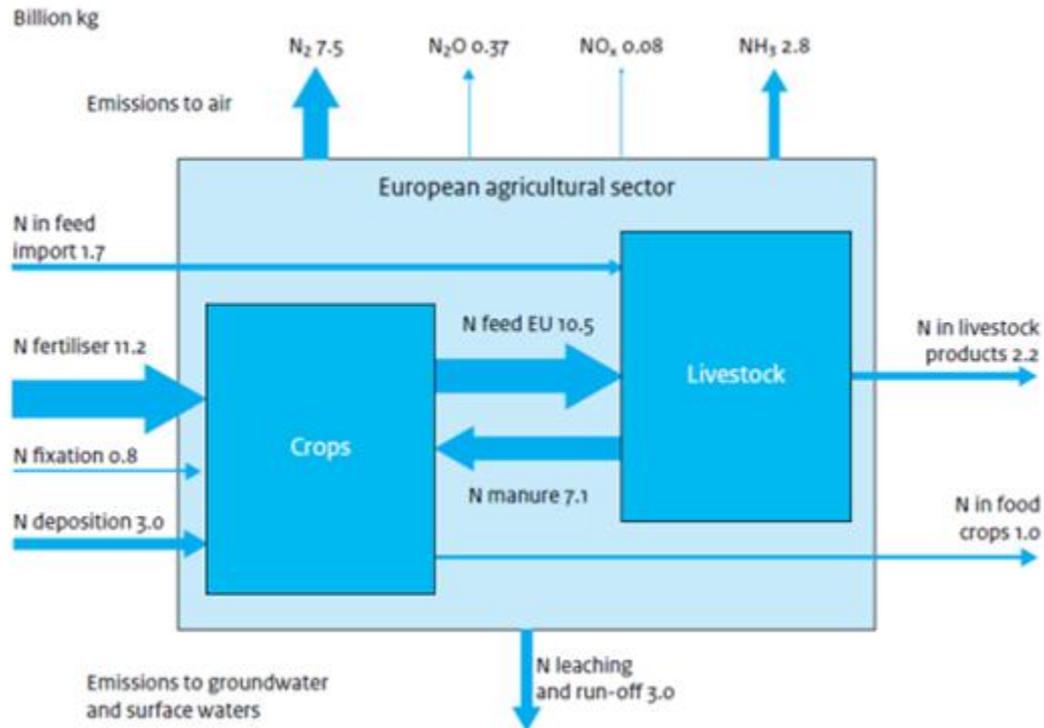


Source: IFA (2007)

Figure 1.8. Trend in global average nitrogen use efficiency for cereal production between 1961 and 2001

The Dutch environmental assessment agency (PBL) has published a useful overview of the environmental impacts and challenges of protein production in the EU (PBL, 2011). In that, they

report the low NUE of European agriculture (Figure 1.9), estimating that just 19% of N inputs to agriculture end up in the final products. The remaining 81% is lost from the system in various fractions, from harmless N_2 to environmentally damaging reactive compounds such as ammonia (NH_3), nitrate (NO_3) that cause acidification, particulate formation and eutrophication, and also and nitrous oxide (N_2O) that causes climate change (with a global warming potential 298 times higher than CO_2 on a weight basis).



Source: PBL (2011)

Figure 1.9. Nitrogen flows within European agriculture

Nitrogen losses are therefore a major concern with respect to environmental impacts arising from crop and animal production, but also represent a major economic inefficiency within the sector. Improving NUE is an eco-efficiency priority and a necessary prerequisite for sectoral sustainability.

Farm systems can be categorised as conventional, organic, intensive, or extensive. Intensive livestock production systems are characterized by a high output of meat, milk, and eggs per unit of agricultural land and per unit of stock (i.e. livestock unit), which usually coincides with a high stocking density per unit of agricultural land. Intensive livestock production systems now account for a dominant share of the global pork (56%), poultry meat (72%) and egg (61%) production and a significant share of milk production (TFRN, 2011 cite FAO 2006; 2009). Whilst most animal products were traditionally produced using locally produced animal feeds, many animal products are now produced using animal feeds imported from areas further afield, especially for pig and poultry products. This geographic disconnection is possible because of efficient transport infrastructure and the relatively low price of fossil energy, so that e.g. shipping concentrated feed thousands of kms is economically viable (TFRN, 2011). However, the uncoupling of animal feed production from animal production has a negative impact on tight nutrient cycling and nutrient management planning (TFRN, 2011).

1.2.2 Defining environmental aspects, pressures and impacts

According to EMAS Regulation (EC 1221/2009), an 'environmental aspect' is an element of an organisation's activities, products or services that has or can incur an impact on the environment, both the natural environment and people. Environmental impacts arise from pressures generated by environmental aspects, such as the emission of greenhouse gases or air pollution. Environmental aspects may be classified accordingly:

- Direct environmental aspects are associated with activities, products and services of the agricultural sector over which it has direct management control and can thus influence directly.
- Indirect environmental aspects are associated with activities, products and services of the agricultural sector, over which the sector does not have full management control, and thus cannot influence directly. These include interactions of the sector with stages both downstream and upstream of agricultural production, such as aspects related to the supply of input products used, transportation, and other factors in the supply chain such as food waste potentially having significant implications for the environmental impact of agricultural output products, seen from a lifecycle perspective.

Figure 1.10 provides a basic overview of the main stages and processes giving rise to major environmental impacts within the agricultural sector. The production of feed imported from outside Europe is an important indirect environmental aspect for European livestock farmers owing to the large environmental impact associated with some of this feed production.

Table 1.1 lists some of the main direct and indirect environmental pressures arising from particular activities within the sector. Meanwhile, Table 1.6 provides a basic map of the environmental hotspots associated with environmental aspects on a product life cycle basis, according to the major crop and animal commodities.

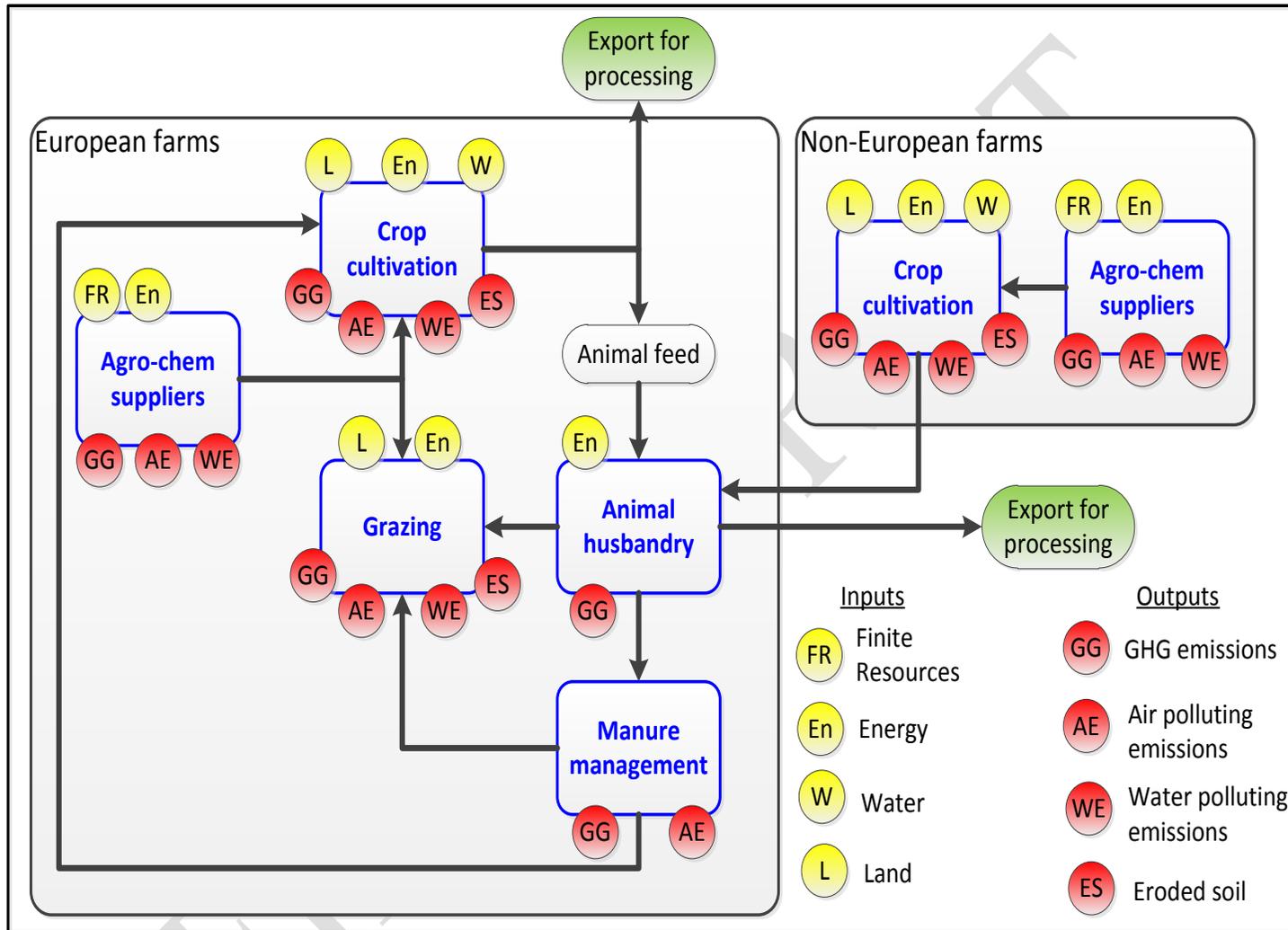


Figure 1.10. Schematic representation of the main environmental hotspots considered within the scope of the agricultural sector.

Table 1.4. Activities in livestock production and associated direct and indirect environmental pressures

Service/ Activity	Main environmental pressures	
	Direct	Indirect
Fertiliser application	NH ₃ emissions N ₂ O emissions Nutrient losses to water Biodiversity loss	Manufacturing and transport energy (and associated impacts)
Feed	CH ₄ from enteric fermentation On-site cultivation (see arable below)	Off-site cultivation (see arable below) Potential land use change Transport energy (CO ₂ emissions)
Housing	NH ₃ emissions CH ₄ emissions Nutrient losses dirty water Energy consumption	Electricity generation
Manure storage	CH ₄ emissions NH ₃ emissions N ₂ O emissions	
Manure spreading	NH ₃ emissions N ₂ O emissions Energy consumption	Avoided fertiliser manufacture (and application emissions)
Fertiliser application	NH ₃ emissions N ₂ O emissions Nutrient losses to water Biodiversity loss Heavy metal accumulation	Manufacturing and transport energy, NH ₃ , N ₂ O emissions Resource depletion
Grazing	NH ₃ emissions N ₂ O emissions Soil erosion and compaction Nutrient losses to water Biodiversity loss (potential gain) Biomass C loss if land use has changed from forest	
On-farm operations (e.g. milking)	Energy (fuel) consumption	Electricity generation
Additional services e.g. medical	Energy consumption Eco-toxicity effects Antibiotic resistance	Energy water and raw material consumption
Irrigation	Water stress Salinisation Energy consumption	Electricity generation (and associated impacts)
Agrochemical application	Ecotoxicity effects Biodiversity loss	Manufacturing and transport energy

Table 1.5. Activities in arable and horticultural production and associated direct and indirect environmental pressures

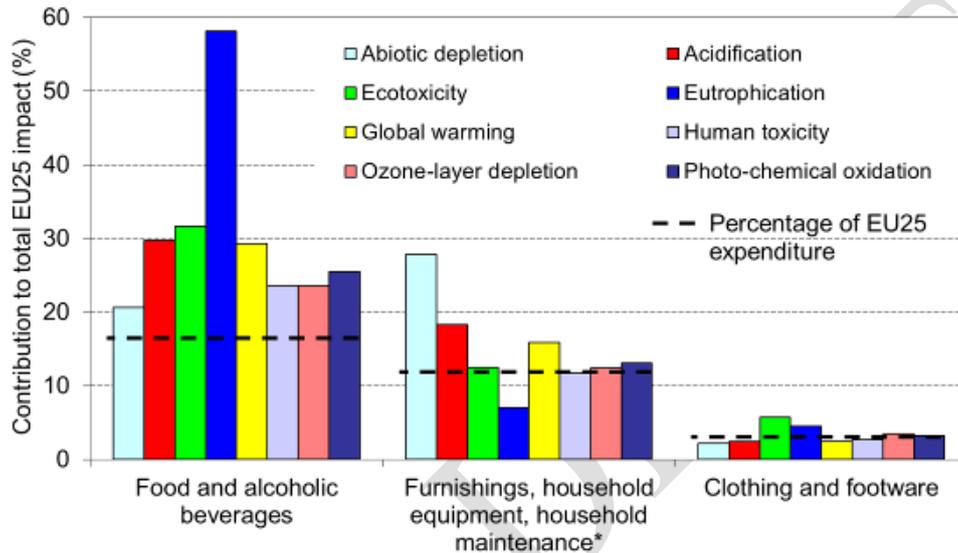
Service/Activity	Main environmental pressures	
	Direct	Indirect
Tillage/ploughing	Soil C and N loss Erosion Potential water sedimentation GHG emission	Fuel supply chains Machinery manufacture
Fertiliser application	NH ₃ emissions N ₂ O emissions Nutrient losses to water Biodiversity loss Heavy metal accumulation	Manufacturing and transport energy, NH ₃ , N ₂ O emissions Resource depletion
Transport	Energy (fuel) consumption GHG emissions NOx and SOx emissions	Manufacturing and transport energy (and associated impacts)
Machinery Use (e.g. harvesting)	Energy consumption, air emissions,	Electricity generation Machinery production
Irrigation	Water stress Salinisation Nutrient losses Energy consumption	Electricity generation (and associated impacts)
Agrochemical application	Ecotoxicity effects Biodiversity loss	Manufacturing and transport energy
Seedling propagation	Disposal of peat Energy consumption	Extraction of peat Electricity generation
Crop protection (plastic/glass)	Disposal of plastic Biodiversity threat	Manufacturing and transport energy Resource depletion

Table 1.6. Environmental aspects associated the production of various commodities, and estimated environmental relevance

	Enteric fermentation	Grazing	Feed production	Manure management	Tillage	Synthetic fertilisers	Agro-chem application	Irrigation
Dairy	+++	++	+++	+++	(++)	++	++	(++)
Beef	+++	+++	++	++	(++)	++	+	(+)
Sheep	++	+++	+	+	(+)	+	++	
Pigs		+	+++	+++	(+++)	(+++)	+++	(++)
Poultry			+++		(+++)	(+++)	+++	(++)
Wheat					+++	+++	+++	++
Barley					+++	+++	+++	++
Maize					+++	+++	++	++
OSR					+++	++	++	++
Sugar beet					+++	++	++	+++
Potatoes					+++	++	+++	+++
Vegetables					+++	++	+++	+++
Fruit					++	++	+++	+++
Estimated direct environmental relevance: + to +++; estimated indirect environmental relevance (+) to (++++)								

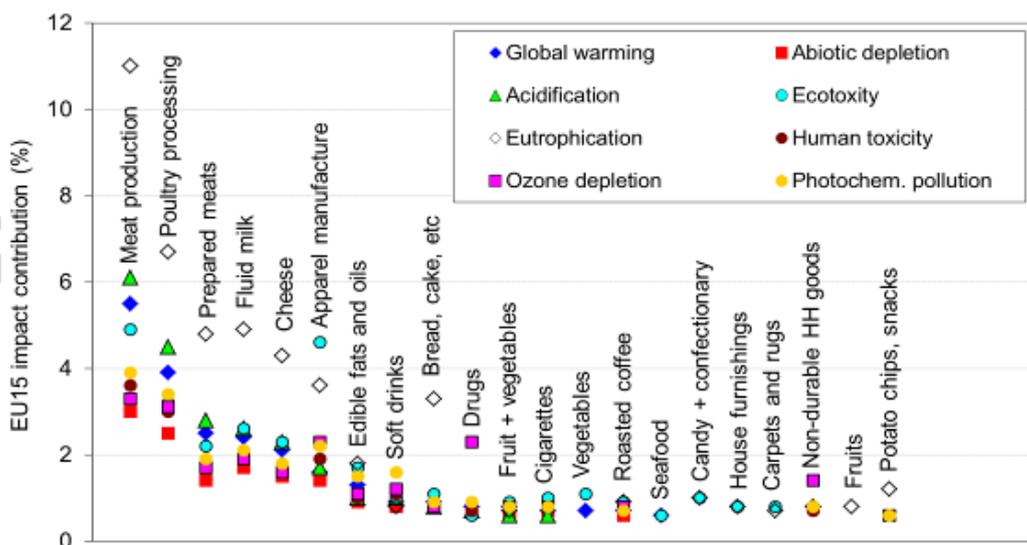
1.2.3 Environmental burdens

It is convenient to take a life cycle assessment (LCA) perspective and categorise various environmental pressures/impacts arising from agricultural production as environmental burdens defined according to various life cycle impact assessment (LCIA) characterisation methodologies. Within the EU25, food and drink production, dominated by agriculture, makes large contributions to aggregate environmental burdens, particularly eutrophication (57%), ecotoxicity (31%), acidification (30%) and climate change (29%) (Figure 1.11). Environmental burdens of production and consumption calculated in EC (2006) were further disaggregated according to NACE code product categories (Figure 1.12). This shows that meat and dairy products are the most environmentally burdensome products produced and consumed within the EU, from a lifecycle perspective.



Source: Based on data from EC (2006)

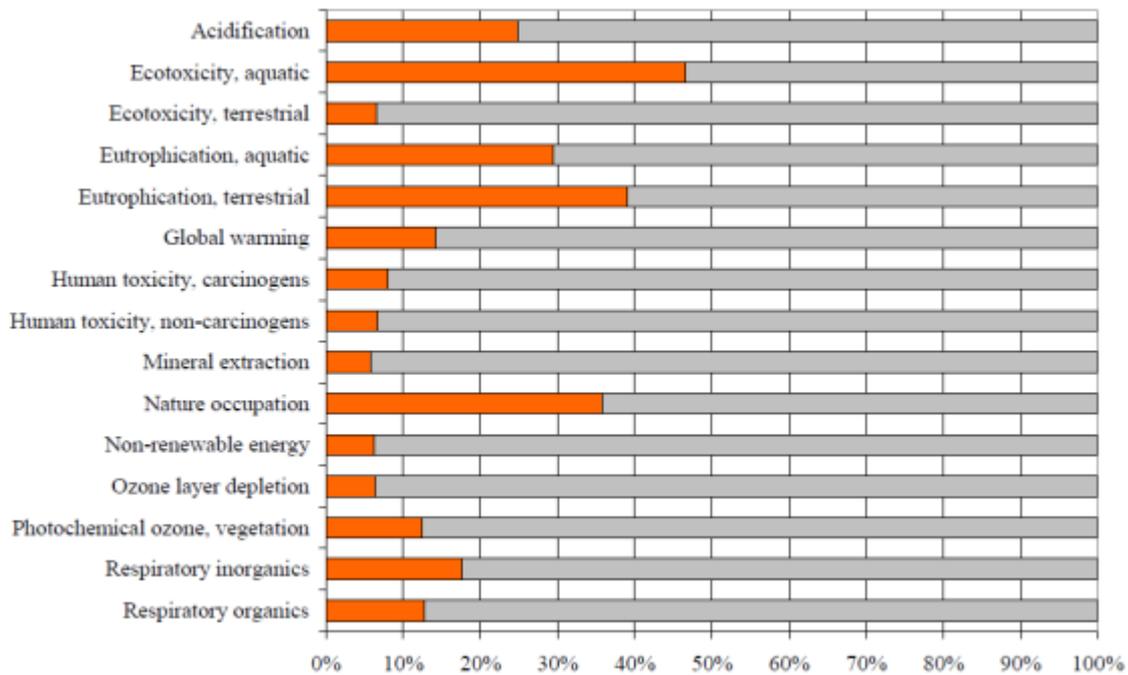
Figure 1.11. The contribution of the production and consumption of three broad product groupings to eight major environmental burdens within the EU25



Source: Schoenberger et al. (2013), based on information from EC (2006)

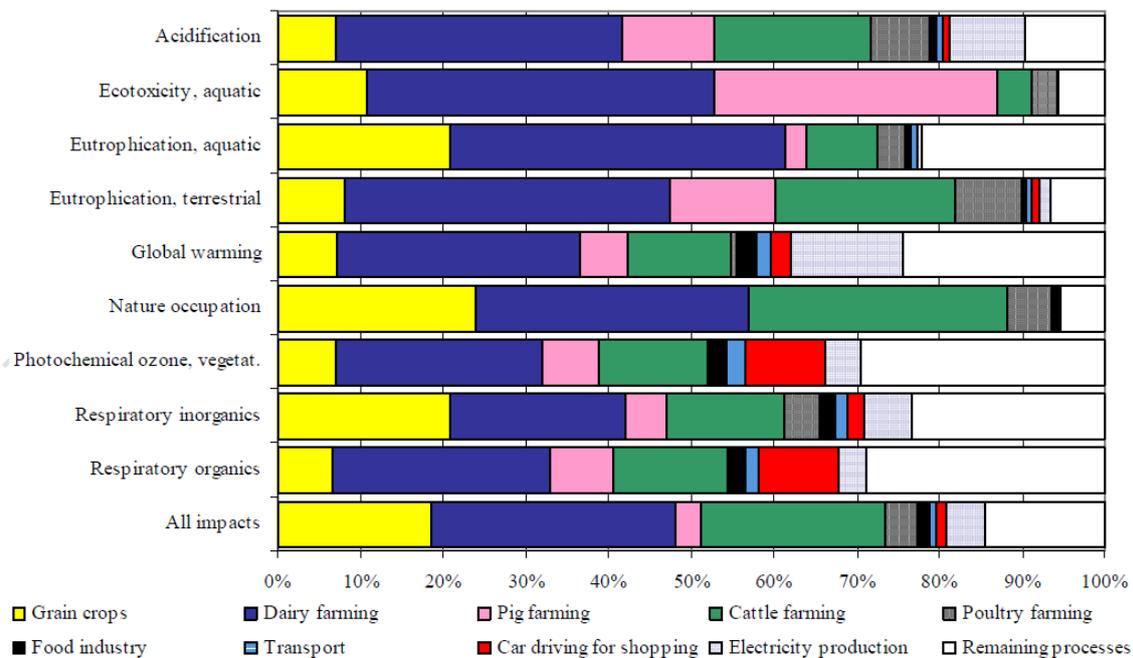
Figure 1.12. The relative contribution of NACE-classified product categories towards eight major environmental burdens in the EU25

In a subsequent study commissioned by the JRC and reported in 2008 (JRC, 2008), the environmental impact of meat and dairy production was quantified as 24% of the total impact of final consumption in the E27. The relative contribution of meat and dairy production to discrete environmental burdens is displayed in Figure 1.13. The contribution of different processes to environmental burdens of meat and dairy production are displayed in Figure 1.14.



Source: EC (2008)

Figure 1.13. Contribution of meat and dairy products to the environmental burdens of final consumption in the EU27



Source: EC (2008)

Figure 1.14. Contribution of different processes to lifecycle environmental burdens of meat and dairy products in the EU27

Climate change

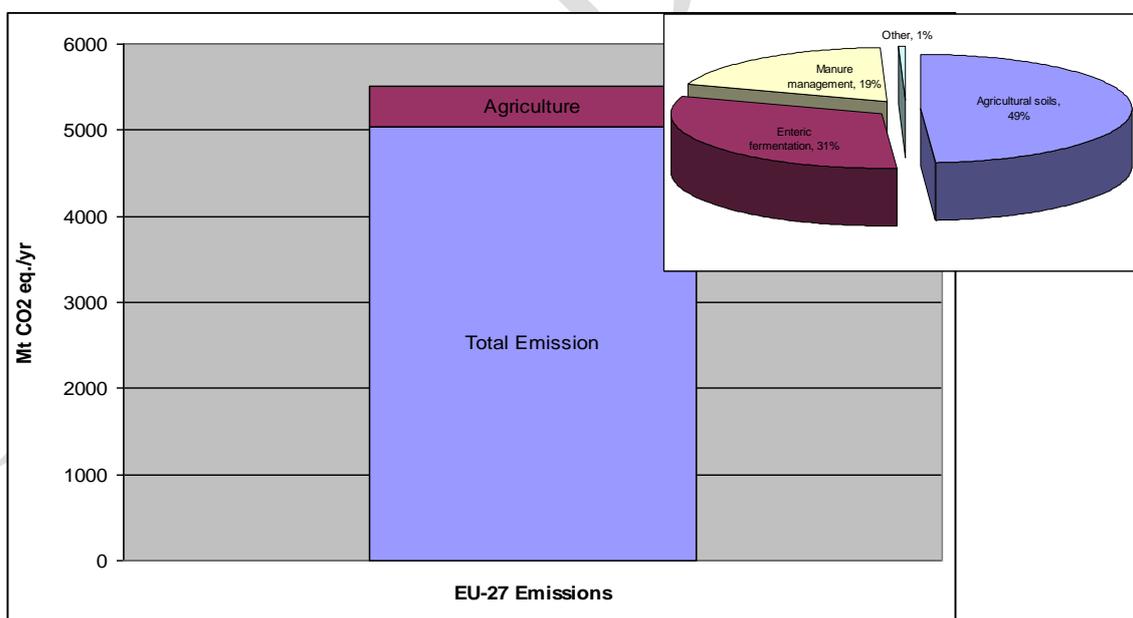
Agriculture is globally one of the main drivers of environmental pollution and a major contributor to greenhouse gas (GHG) emissions causing climate change (FAO, 2006; Johnson et al., 2007). The United Nations Food and Agriculture Organisation (FAO) has calculated that, globally, agriculture generates 30% of total man-made emissions of greenhouse gases, including half of methane (CH₄) emissions and more than half of the emissions of nitrous oxide (N₂O). Table 1.7 displays the major agricultural sources of GHG emissions globally, according to Bellarby et al. (2008).

Table 1.7. Major sources of GHG emissions within the agricultural sector

Source	Emissions (Mt/yr CO ₂ eq.)
Soil N ₂ O emissions (soil fertilisation)	2128
Enteric fermentation	1792
Biomass burning (e.g. forest clearing)	672
Rice production, largely methane emissions from flooded rice paddy soils	616
Manure management	413
Fertiliser manufacture	410

Source: Bellarby et al. (2008)

In the EU-27, the agricultural sector was reported to account for 9.6% of the total greenhouse gas (GHG) emissions in 2008, emitting 471 million tonnes of CO₂ equivalents (Eurostat, 2010). The vast majority of these emissions were reported to arise from one of three sources; soils, enteric fermentation and manure management; with soils responsible for 49% of the emissions at 226 million tonnes CO₂ eq. per year (Figure 1.15).



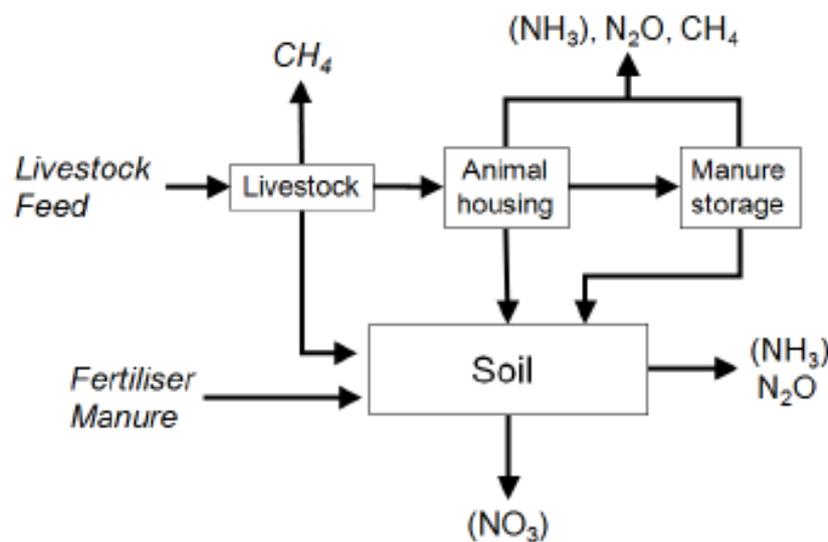
NB: data from 2007

Source: Eurostat (2010)

Figure 1.15. The contribution of agriculture towards EU GHG emissions, and the breakdown of emissions within the agricultural sector (inset)

Contrary to the majority of economic sectors where carbon dioxide is the principal greenhouse gas emitted, GHG emissions from the agricultural sector are largely composed of nitrous oxide (N₂O) (56.3 %) and methane (43.7 %) (IPCC, 2001; Paustian et al., 2004; Eurostat, 2011). Methane emissions are produced during the decomposition of organic material under oxygen-depleted

conditions, and originate largely from enteric fermentation by ruminant livestock, from stored manure and from rice cultivation under flooded conditions. N_2O , a GHG that is 298 times stronger than CO_2 at the 100-year time horizon, originates within agriculture largely from the application of nitrogen (N) fertilizers (mineral and organic) to soils. Following the application of N, microbially mediated nitrification and denitrification reactions occur in the soil, leading to the formation of N_2O . Agricultural emissions represent about 60% of global anthropogenic N_2O emissions, and were seen to increase by 17% from 1990 to 2005 and further projected to increase by 35-60% up to 2030 (Smith et al., 2007). Although CO_2 emission is not a major direct aspect of agricultural production, though it does arise from fuel combustion to power mechanised field operations, it is an important indirect aspect arising from the production of inputs such as fertilisers and extensive transportation of agricultural produce (Bellarby et al., 2008). Figure 1.16 displays major environmentally relevant emissions arising from agricultural processes. Note that ammonia (NH_3) and nitrate (NO_3) emissions not only contribute to acidification and eutrophication, respectively, but are also precursors to N_2O and thus important indirect GHGs.

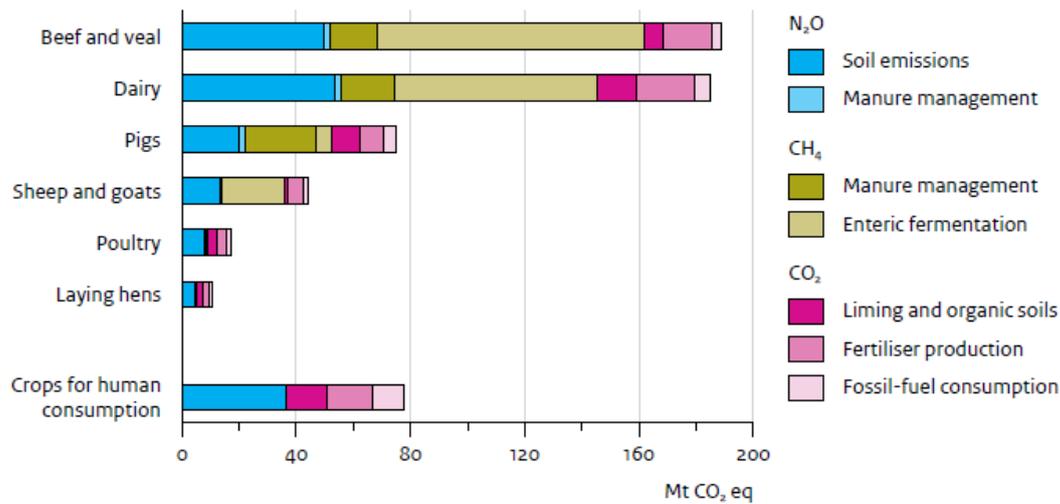


Source: Eurostat (2011a)

Figure 1.16. Major environmentally relevant emissions from the agricultural sector

The livestock sector alone accounts for approximately 10% of European GHG emissions (PBL, 2011) and 18% of global GHG emissions (IPCC, 2007; FAO, 2006). However, within the livestock sector if the emissions from the transport of livestock and feed are included, the sector is estimated to account for nearly 80% of the agricultural sectors emissions. Beef and dairy enterprises account for more than 70% of livestock GHG emissions, the majority of which arise from enteric fermentation. Pig production accounts for around 18% and poultry just 4% (with low digestive emissions and relatively high feed conversion rates) (Figure 1.17) (PBL, 2011).

Considering both direct and indirect emissions from the agricultural sector, including those from imported food, over 30% of the European Union's greenhouse gas emissions come from the food and drink sector (ESTO, 2005). Indirect emissions arise from processes including freezing and cooling, requiring large amounts of electricity for machinery, fans, pumps and cooling units in addition to giving rise to the leakage of refrigerant gases such as HCFCs with high global warming potentials (GWPs). Heating processes however account for the dominant part of the sector's overall energy requirements, comprising high temperature processing such as boiling, drying, pasteurisation and evaporation. In the UK, the transportation of food is reported to account for one quarter of all heavy-goods vehicle miles, with the average number of miles that UK food travels reported to have doubled over 30 years (DEFRA, 2005).

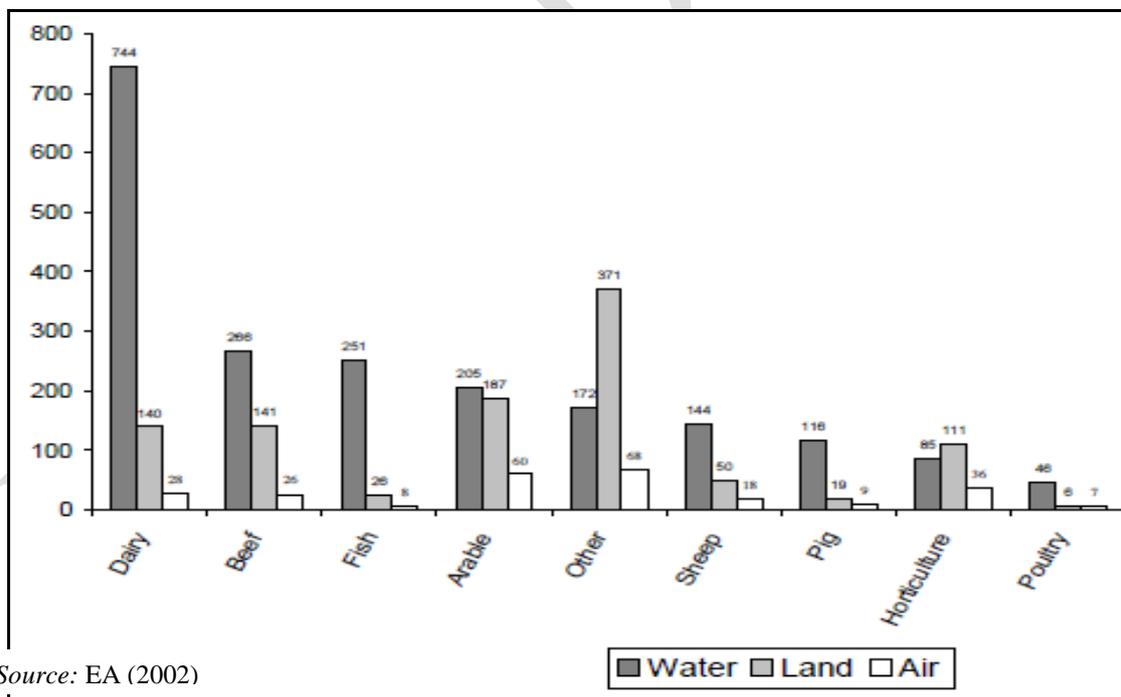


Source: PBL, (2011)

Figure 1.17. Greenhouse gas emissions per sector in the EU27 (reference year 2005)

Eutrophication, Water Quality and Acidification

In addition to the contribution towards climate change, agriculture contributes to a range of other environmental burdens. For example, in 2000 in the UK, agricultural sources accounted for 12.5% of substantiated air and water pollution incidents, representing 27% of the Category 1 (the most serious) and Category 2 incidents. The distribution of water, land and air pollution incidents by agricultural source in the UK in the 2000 is shown in Figure 1.18.



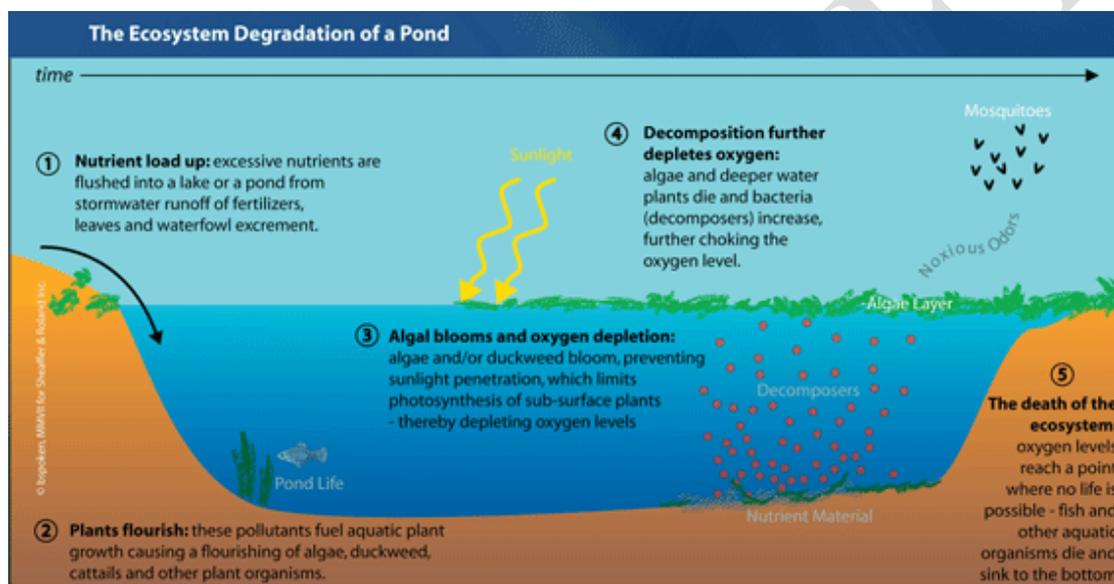
Source: EA (2002)

Figure 1.18. Substantiated agricultural pollution incidents by source in 2000

Eutrophication is the main driver of water quality deterioration globally and is caused largely by the addition of fertilisers and animal waste to agricultural land mostly in the form of N and phosphorus (P) compounds. Crops and animals however, are often unable to absorb all the external inputs and the N output/input efficiency of European agriculture is only 19%, and the rest of the nitrogen is lost into

ground-, inland-, coastal-waters via leaching and runoff from agricultural soils (UN-Water, 2009; PBL, 2011). The subsequent nutrient enrichment of water bodies stimulates algal blooms resulting in plant death and decay through oxygen depletion, therefore reducing aquatic biodiversity and ecosystem functioning (Figure 1.19). Water quality can further be impacted through the addition of animal waste and toxic faecal coliforms that may contaminate water runoff from livestock facilities and enter water systems, becoming a potential threat to public health and biodiversity, as well as requiring considerable financial resources to treat. The financial impact on farmers of nutrient losses in the UK is reported to be around £500 million (600 million EUR) a year through fertiliser losses, whilst around £200 million (240 million EUR) per year is estimated to be spent by the UK water industry treating agriculturally-derived pollution (EA, 2008).

The FAO (2006) estimated that livestock agriculture is responsible for a third of N and P losses to freshwaters globally. The sector is subject to restrictions on N and P inputs in some areas, in particular through EU member state implementation of the Nitrates Directive (91/676/EEC) and Water Framework Directive (2000/60/EC).

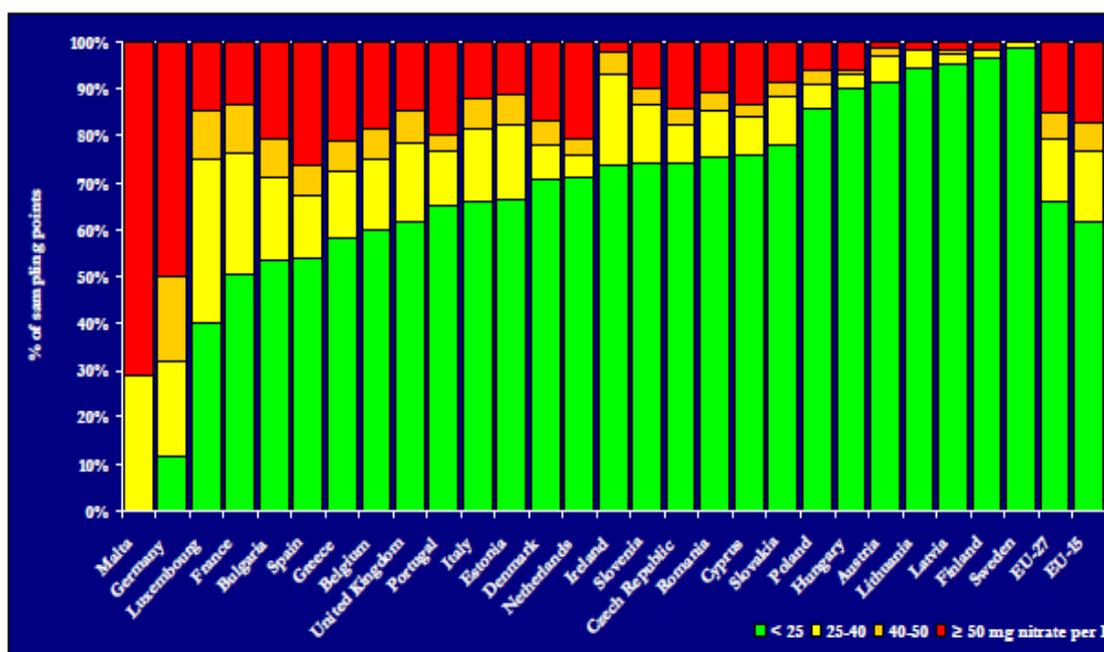


Source: UN-Water 2009

Figure 1.19. The eutrophication process and associated environmental effects

Water contamination by nitrates is one of the main problems associated with agricultural activities, largely attributable to their high solubility and rapid migration into groundwater through soil. One of the major causes of eutrophication is consequently the excessive addition of Nitrogen to agricultural soil. In the EU-27, 11.4 Mt N were applied to agricultural soils in 2004, increasing by 6% to 12.1 Mt N in 2007 (EC, 2010).

It is estimated that 70% of N entering inland surface waters in the EU is from agricultural sources (EA, 2002), whilst the relative contribution of agricultural sources to N loading to surface water is greater than 50% in most members states of the EU-27. Within the EU-27, 15% of groundwater monitoring stations have been reported as having nitrate levels over 50mg of nitrates per litre (the upper trigger value set in the Nitrates Directive), 6% were in the range of 40-50 mg/l and 13% were in the range 25-40mg/l. Approximately 66% were reported to fall under the 25mg/l mark. Malta and Germany have the highest rates of groundwater nitrate contamination with 70% of Malta's ground water monitoring sites registering nitrate levels of over 50mg/l, followed by 50% of sites in Germany. Within both countries, less than 10% of monitoring sites registered levels below 25mg/ml (Figure 1.20). The proportion of fresh surface water monitoring stations measuring 50mg/ml was also highest in Malta (43%), followed by Belgium (10%) and the United Kingdom (7%) within Europe (EC, 2010). However, stimulated by national and European policies, farmers have been reported to have significantly reduced fertiliser use and nitrogen losses over the last 20 years (PBL, 2011).



Source: EC, (2010)

Figure 1.20. Frequency diagram of groundwater classes within each MS, showing the percentage of sampling points where nitrate concentrations were: (i) below 25 mg/l; (ii) between 25 and 40 mg/l; (iii) between 40 and 50 mg/l; (iv) above 50 mg/l

Phosphorus, an essential element for plant growth, is the main cause of eutrophication and of water quality deterioration. Even a low phosphorus concentration (some tens of $\mu\text{g/l}$) in fresh water can represent significant pollution. Phosphorus loading to waters is reported to arise mainly from industrial and domestic wastewater discharges. In the UK, the agricultural sector has been reported to be responsible for 40% of total phosphorus loading to freshwaters (DEFRA, 2006).

A further impact to water courses is that of acidification, caused by emissions of ammonia (NH_3) and oxides of sulphur (SO_x) and N (NO_x) to air, reacting with water in the atmosphere to form acidic compounds that become deposited upon, and subsequently damage, both terrestrial and aquatic ecosystems. Agriculture is the main source of NH_3 emissions, accounting for 94% of European NH_3 emissions (EEA, 2012a). The livestock sector dominates NH_3 emissions, which arise mainly from volatilisation of ammoniacal N contained in manures, during storage, and after excretion or application on fields. Globally 64% of NH_3 emissions are reported to arise from livestock production, whereas in Europe the figure rises to 80%. The remaining 10-20% of NH_3 emissions in Europe is estimated to result from the volatilisation of ammonia from nitrogenous fertilisers and from fertilised crops (FAO, 2006).

Biodiversity

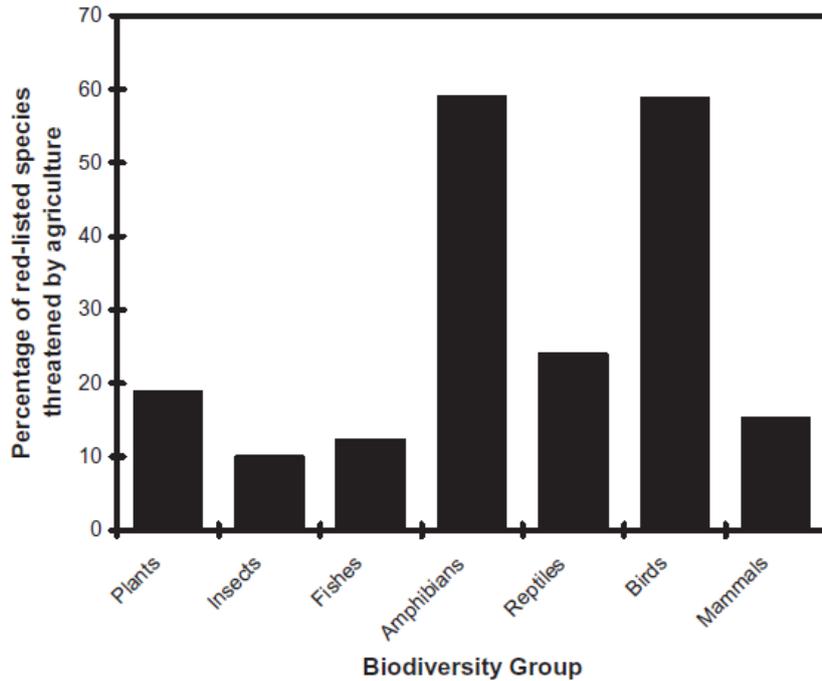
The interactions between biodiversity and agriculture are complex, as agricultural practises can both provide an essential habitat for a variety of species, as well as cause the depletion of natural resources upon which many species rely. Agriculture is at the origin of many ecosystems with high biodiversity and contributes to the maintenance of a diversity of species and a large gene pool. The preservation of biodiversity (as well as other natural resources) and sustainable agricultural activity are inextricably linked as agriculture relies on healthy ecosystems for a variety of ecosystem services such as pest removal and pollination. One of the best known examples of habitat creation for biodiversity within agriculture is the use of semi-natural grasslands, but also traditional irrigation systems and water reservoirs are the origin of diverse and complex landscapes able to support a variety of wildlife.

The loss of biodiversity occurs as a consequence of multiple environmental pressures, including climate change (especially if this occurs at a faster rate than species can migrate, and in combination with habitat fragmentation that blocks migration pathways in response to climate change), acidification, eutrophication, ecotoxicity, water stress and soil degradation. However, one of the major direct causes of biodiversity loss attributable to agriculture is land clearing for agricultural expansion – specifically, the removal of natural or semi-natural vegetation with High Nature Value (HNV).

In Europe, past production-linked subsidies offered to farmers under the Common Agricultural Policy (CAP) encouraged overproduction and have been blamed for biodiversity loss through habitat destruction and over intensification (Henle et al., 2008). Diverse natural habitats have been converted into simplified monocultures of cropland or intensively grazed pastures, replacing systems rich in diversity with a largely fragmented landscape, often acting as barriers to some vulnerable and rare species (Groombridge & Jenkins, 2002). Intensive use of external outputs such as agrochemicals and fertilisers, intensive grazing regimes, crop rotations and small-scale habitat removal, lead to further detrimental impacts on natural resources and subsequently cause a reduction in wildlife. A report by Kleijn et al. (2009), demonstrates a strong inverse relationship between N application rate and species richness on grasslands and arable fields, such that species richness declined exponentially with increasing N application.

Following the Mid-Term review of the CAP in 2003, the emphasis on production shifted to regulatory compliance and better environmental practices. However in order to meet the rising demand for animal products, the on-going shift from traditional extensive and mixed farming, to industrial and intensive farming systems is likely to continue (Bouwman et al., 2011, Galloway et al., 2007). Therefore the challenge in Europe will be to protect low productivity and extensive agricultural land uses associated with HNV in order to maintain vital habitat for biodiversity (Henle et al., 2008).

Despite its crucial role in feeding the world population, agriculture remains the largest driver of genetic erosion, species loss and conversion of natural habitats. According to the IUCN data, agriculture is a major cause of global species endangerment, and those groups which are most affected include amphibians and birds (Figure 1.21). An estimated 4,000 assessed plant and animal species are thought to be threatened by agricultural intensification (IUCN, 2008). In the EU, a 48% decline has been recorded in common farmland birds over the last 26 years, a trend not shared by bird assemblages of other habitats over the same period. Agricultural intensification, such as the loss of crop diversity, destruction of grasslands and hedgerows, and excessive use of pesticides and fertilizers, has been widely recognised as one of the main driving forces behind this dramatic decline of common farmland birds. A 60% decline has also been seen in grassland butterflies since 1990 (Figure 1.22) and only an estimated 3% of key species and 7% of habitats that are reliant on agriculture are currently reported to be in favourable conservation status (EEA, 2010a).

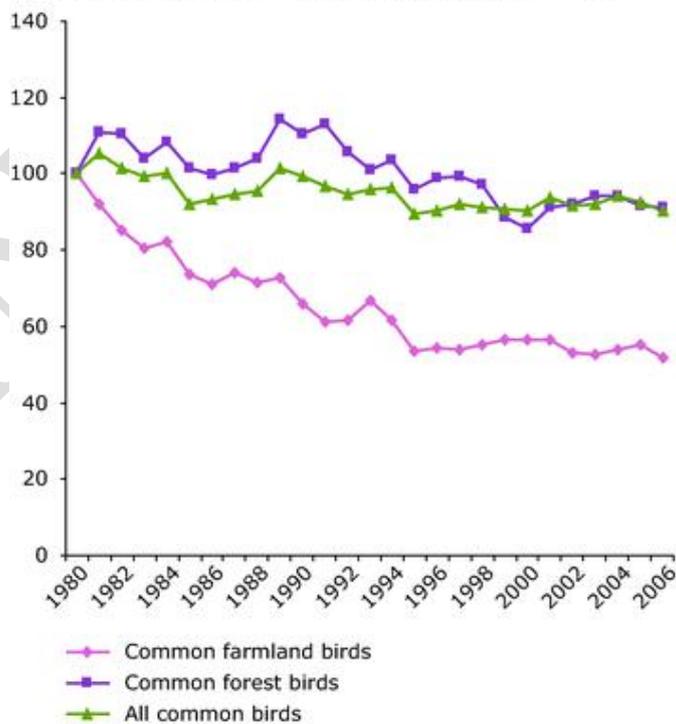


Source: Norris (2008)

N.B.: Data are from the World Conservation Union (IUCN) Red List database (<http://www.iucnredlist.org/search/search-basic>). Least concern (LC) species were excluded from the analysis. IUCN threat codes used to assess agricultural threats were 1.1, 6.2.1, 6.3.1, and 6.3.7.

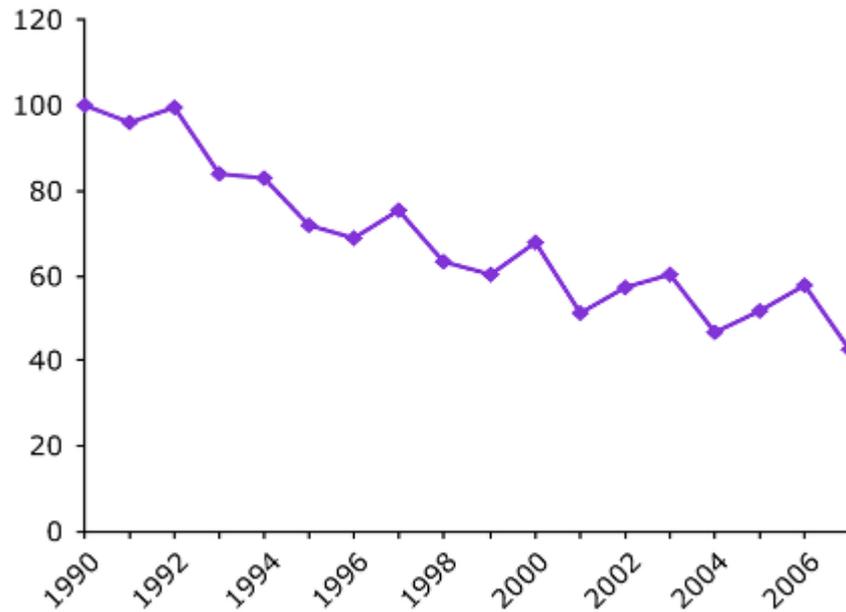
Figure 1.21. The percentage of red-listed species threatened by agriculture in a range of biodiversity groups.

Common birds in Europe — population index (1980 = 100)



Source: EEA (2010b)

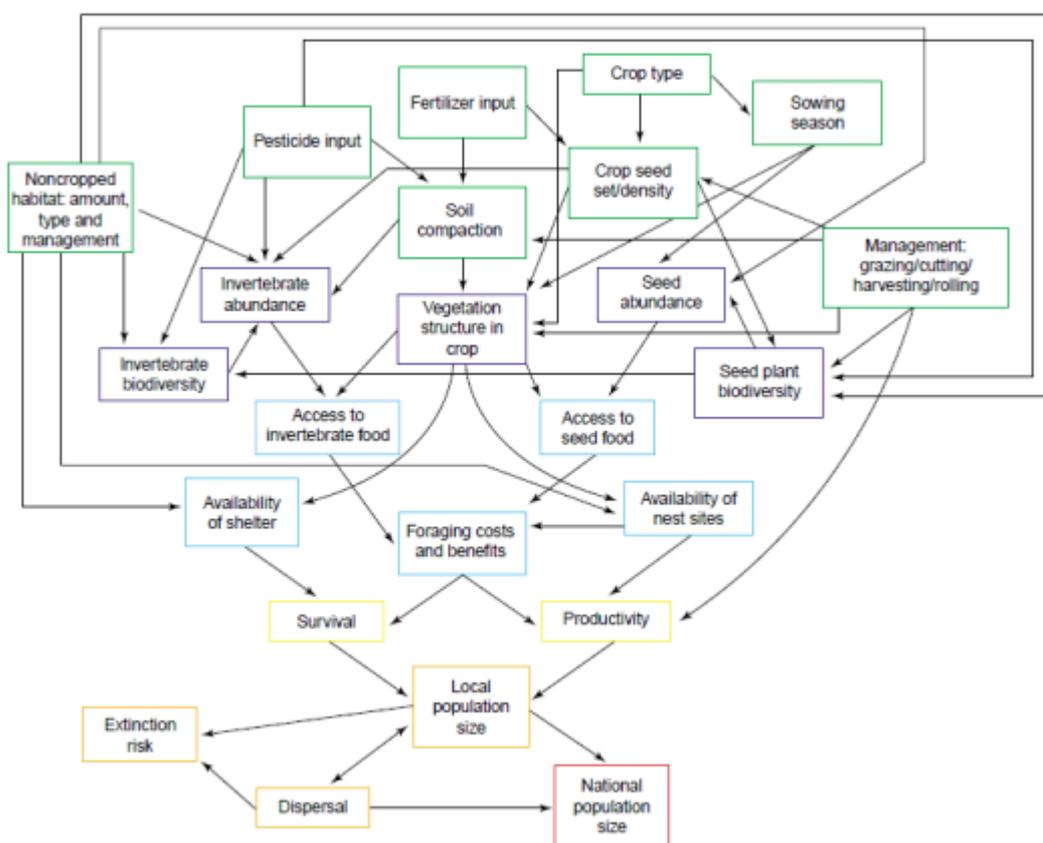
Grassland butterflies — population index (1990 = 100)



Source: EEA (2010b).

Figure 1.22. Declines in European biodiversity; bird populations (above) and grassland butterfly populations (below) between 1990 and 2006.

In the UK, the agriculture-related decline in biodiversity has included a 67% decline in 333 farmland species (broadleaved plants, butterflies, bumblebees, birds and mammals) between 1984 and 1990 due to agricultural practices, and a decline in woodland and farmland bird populations of 14% and 47% respectively (UK National Ecosystem Assessment, 2011). Figure 1.23 displays the variety of direct and indirect impacts that agricultural practices place on farmland bird populations. Arrows indicate known routes by which farming practices (green boxes) indirectly (dark-blue boxes) or directly (light-blue boxes) affect farmland bird demography (yellow boxes), and therefore local population dynamics (orange boxes) and finally total population size (red box). The goal of manipulating farming practice is to impact on population size. Rather than identifying key routes through this web to change in a piece-meal fashion (e.g. insecticide usage), Benton et al. (2003) suggest that management designed to increase habitat heterogeneity is likely to benefit the organisms in such a way as to meet the management goals. For example the rate at which the birds will feed is determined both by the amount of food (abundance) and its accessibility (access) within the habitat, which can both be enhanced through increased heterogeneity.



Source: Benton et al. (2003)

Figure 1.23. The interacting nature of farming practices and some of the routes by which practices impact on farmland birds

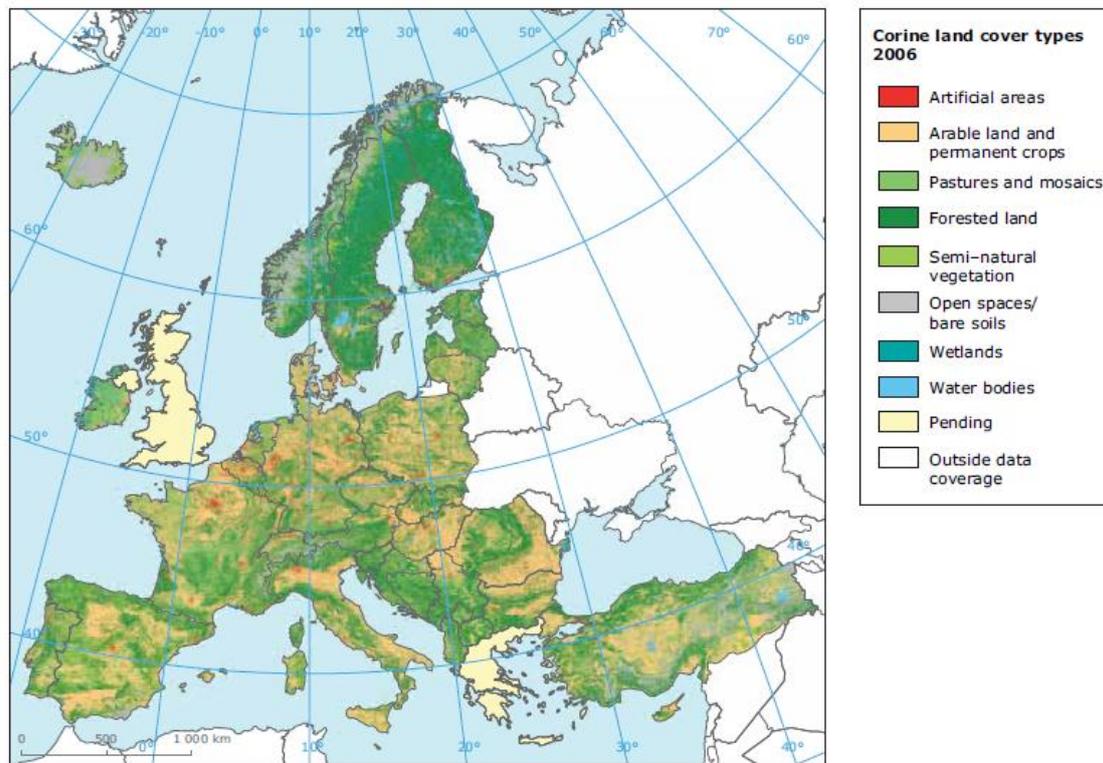
Due to the concentration of biodiversity in tropical regions, with around half the global species thought to reside in tropical forests, these areas are now the focus point for biodiversity loss and protection programmes. Livestock agriculture is thought to be a major direct driver of their destruction, as 70% of previously forested land in the Amazon is now used for pasture agriculture (FAO, 2006), whilst European livestock agriculture contributes indirectly to their destruction through feed production. It is estimated that the expansion of livestock production (pasture and feed) is responsible for the loss of 3 million hectares per year (2000-2010 average) in Latin America, accounting for over 80% of deforestation in that region (timber production being another significant driver). Not only does this have a drastic impact on biodiversity, but land conversion further contributes towards climate change through the release of carbon to the atmosphere from biomass and soils.

Another important driver of biodiversity loss within European agricultural systems is the use of plant protection products. The use of these products can provide economic and eco-efficiency benefits to the sector through crop protection and by enabling a reduction in tillage cultivation, thus reducing soil erosion. However, both terrestrial and aquatic biodiversity losses can be incurred especially through uncontrolled use of plant protection products, where excessive quantities are released into the wider environment via spray drift, leaching or run-off, therefore contaminating non-target organisms either directly or through agricultural soils, groundwater, rivers, lakes and the food chain.

Land Occupation

Land is a vital limited resource central to agricultural production. Agriculture covers around 40-50% of the global land surface and around 47% (184 million ha) of the European land surface (DG AGRI, 2012). Increasing demand for food has therefore led to a concurrent increase in the requirements for agricultural land, despite significant increase in areal yields. According to FAO statistics, between

1961 and 2007 global cultivated land area increased by around 13% from 1,370 million ha to 1,559 million ha and permanent meadows and pastures increased by almost 10% throughout the same period. Figure 1.24 displays land cover classes and their locations within the EU.

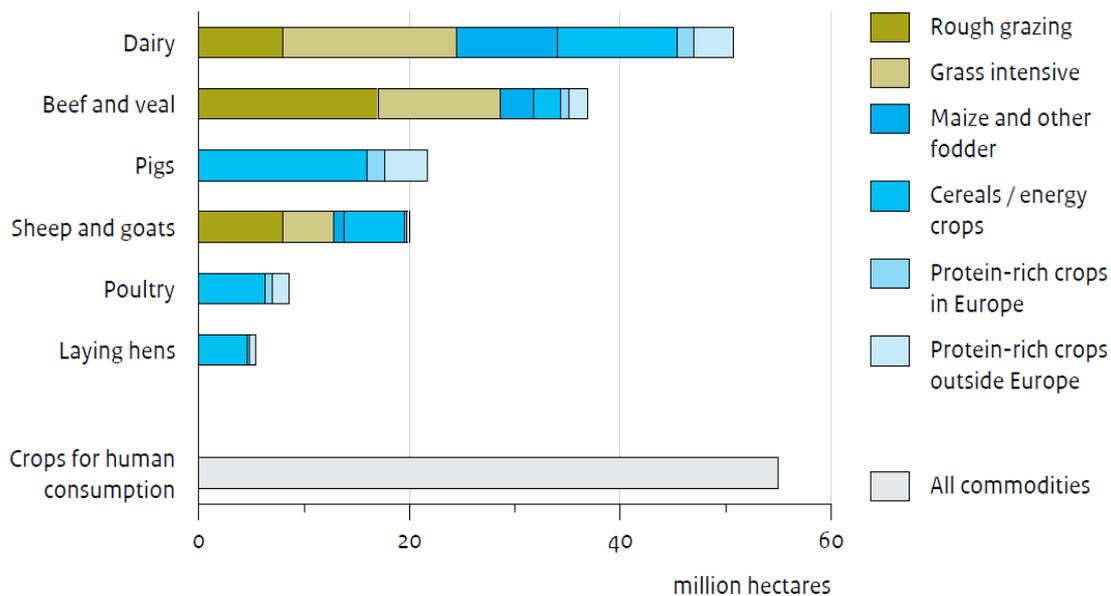


Source: EEA (2010c)

Figure 1.24. European land cover classes identified through satellite imagery

The appropriate and sustainable management of land through agriculture can have a positive effect on land quality, protecting and enhancing the ecosystem services that land provides to society. In good condition, land managed for agriculture can enhance biodiversity, help to prevent flooding and landslides, and act as an important carbon sink (Bowyer et al., 2009). However, the degradation of land through agricultural practices is common both across Europe and the globe, as a consequence of physical, chemical and biological shifts driven by environmental, social and economic pressures. A global assessment of land degradation due to agricultural activities estimated that about 12,400,000 km², has been degraded, mainly as a consequence of erosion, nutrient loss, salinisation (improper irrigation and drainage practices) and physical compaction (Bot et al., 2000). As a consequence of land degradation and subsequent reductions in productivity, as well as the economic viability of farming, around one quarter to one third of cultivated land globally is estimated to have been abandoned (Campbell et al., 2008).

Land use within agriculture directly supports the production of crops for human consumption; however, almost 80% of all agricultural land is dedicated to the production of livestock, either through feed production or as grazing land (FAO, 2009). The dairy sector utilises the largest quantity of land within the EU, using over 50 million hectares, almost as much as the total required to grow crops for human consumption (~55 million ha) (Figure 1.25). Together beef and dairy production utilise around 87 million hectares, around 53 million of which is grassland, not including temporary grasslands (PBL, 2011). In comparison to for example rice or potatoes the land use efficiency for the livestock sector is extremely inefficient. One hectare of land is able to produce rice or potatoes for 19-22 people per annum however this same area will only produce enough lamb or beef for only one or two people (Fox, 2013).



Source: PBL, (2011)

Figure 1.25. Land use per agricultural sector, reference year: 2005

The production of animal products is increasing globally, and has almost doubled between 1980 and 2004 (FAO, 2005). The upward trend is further expected to continue given the projected doubling of meat demand by 2050 (FAO, 2006). The projected rise in demand is attributed to increases in population and an increase in affluence in many countries. The expected rise in demand for meat products is anticipated to increase agricultural land requirements by as much as 200-400 million ha globally (Fischer et al., 2008). In the EU, the livestock sector uses around 500 million tonnes of animal feed, around 40% of which is grass (expressed as dry matter), 28% is cereals and the rest consists of a range of products. Around 60% of the total cereal production in the EU is used within animal feed, whilst the dairy sector alone uses 220 million tonnes annually. As well as using land within Europe, the requirement for cheap feed has led to the importation of around 35 million tonnes of soybean meal equivalents, mainly from Brazil and Argentina, thus driving associated land conversion and deforestation in these areas (PBL, 2011).

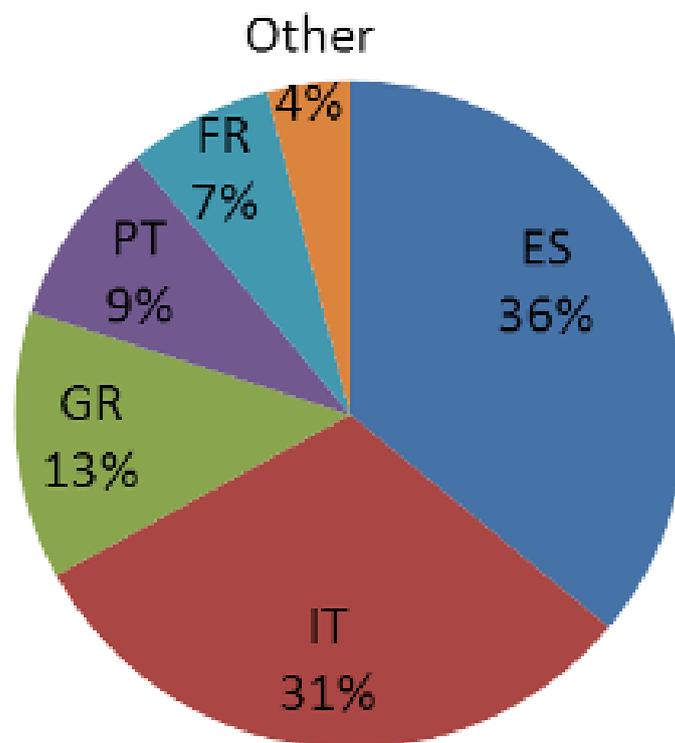
Water Use

The agricultural sector is the single largest user of freshwater resources, accounting for a global average of 70% of total anthropogenic water consumption and 93% of water depletion worldwide. In Europe, on average 44% of total water abstraction is used for agriculture, totalling about 247,000 million m³/year (EC, 2012). The irrigation of crops accounts for 40% of the world's water use, although this share varies markedly across regions. From a total of 332 regions within the EU, the 41 regions with the highest recorded water use for agricultural purposes (over 500 million m³/year) are located in southern Europe. In the South, irrigation accounts for over 60% of water use in most countries, reaching up to 80% in Spain, whilst in Northern Member States the share ranges from almost zero in a few countries to over 30% in others. Water demand for irrigation is relatively insignificant in Ireland, Finland, Sweden, Luxembourg and Denmark, of increasingly regional importance in the UK, Belgium, the Netherlands, Germany, Austria and France, and nationally significant in Portugal, Spain, Italy and Greece (Institute for European Environmental Policy, 2000; EC, 2002).

Irrigation enables greater agricultural production than would be possible with rainfed agriculture alone. The additional food production obtained with irrigation is essential for food security on a global level, and on a national level for some countries. However, some methods of irrigation such as boon irrigation, lead to high evaporative losses especially in hot climates where water is more likely to be scarce. The area of irrigated land has multiplied nearly fivefold over the last century, and in

2003 reached 277 million hectares (FAO, 2006). Turner et al. (2004) estimated that 3,000 litres a day are required in order to grow sufficient food for the daily intake of one person. The environmental impacts, however, of the irrigation of crops include water stress, water pollution, damage to habitats through the extraction of water, increased soil erosion and the salinisation of soils and ground water sources (Institute for European Environmental Policy, 2000). Vanham et al. (2013) calculate that the average EU28 diet has a water footprint (green plus blue components) of 3871 L per person per day; although the blue (extracted water) component is 299 L per person per day (includes a minor contribution from non-food agricultural products). Of the total average EU28 water footprint, 37% is attributable to the production of crop products and 46% to the production of animal products.

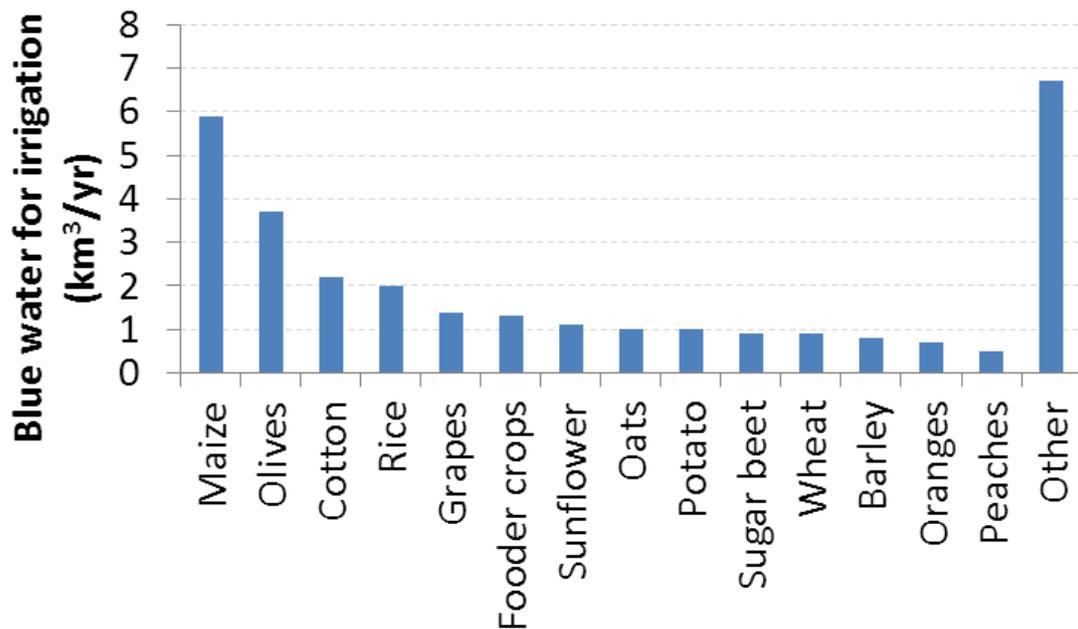
Vanham and Bidoglio (2013) quantified the blue water extracted by different countries within the EU (Figure 1.26) and for different crop types (Figure 1.27). It is striking that Spain and Italy between them account for 67% of blue water extraction for irrigation, with Greece and Portugal accounting for a further 22%. Mediterranean countries therefore clearly dominate the water footprint of European agricultural production.



Source: Data from Vanham & Bidoglio (2013)

Figure 1.26. Blue water withdrawal for irrigation across the EU28 by country

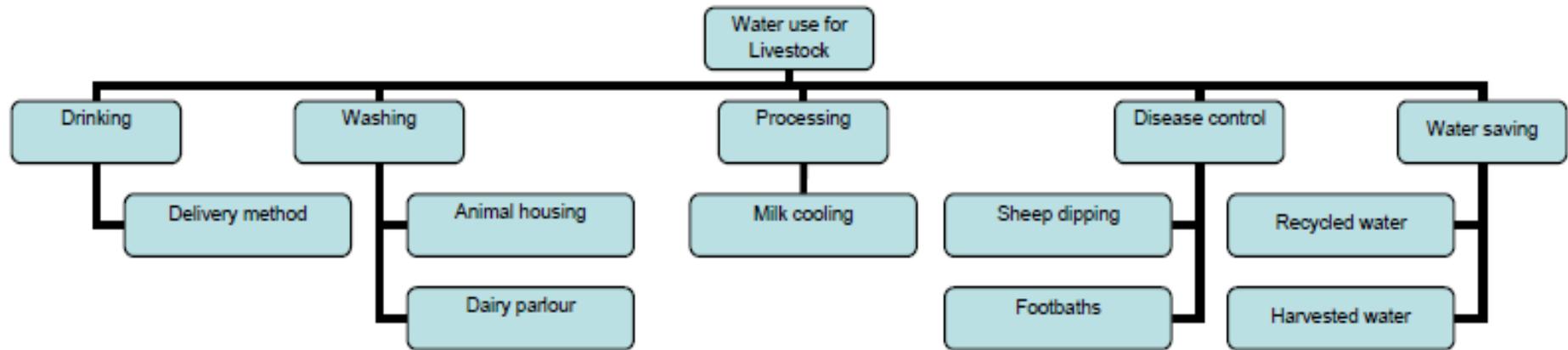
Across the major crop types, maize and olives are responsible for the largest shares of blue-water extraction for irrigation in the EU 28 (20% and 12% of total irrigation water, respectively) (Figure 1.27). Cotton, rice, grapes, fodder crops, sunflowers, oats, potatoes, sugar beet, wheat, barley oranges and peaches also make significant, though lesser, contributions. Presumably tomatoes and strawberries are significant contributors to the “others” categories.



Source: Data from Vanham & Bidoglio (2013)

Figure 1.27. Blue water withdrawal for irrigation across the EU28 by crop type

In addition to direct use for crop irrigation in the arable and horticultural sub-sectors, large quantities of water consumption can be attributed to the livestock sub-sector. The four main purposes of direct water consumption within the livestock sector include drinking water for livestock, washing, processing and disease control (Figure 1.28). However, the vast majority of water consumed by the livestock sector is consumed indirectly for livestock feed production, currently utilising over 8% of the global water usage and accounting for 15% of all irrigated water, with levels projected to increase by 50% by 2025. The water footprint of UK milk production has been estimated at 67 L per L milk (FAO, 2006).

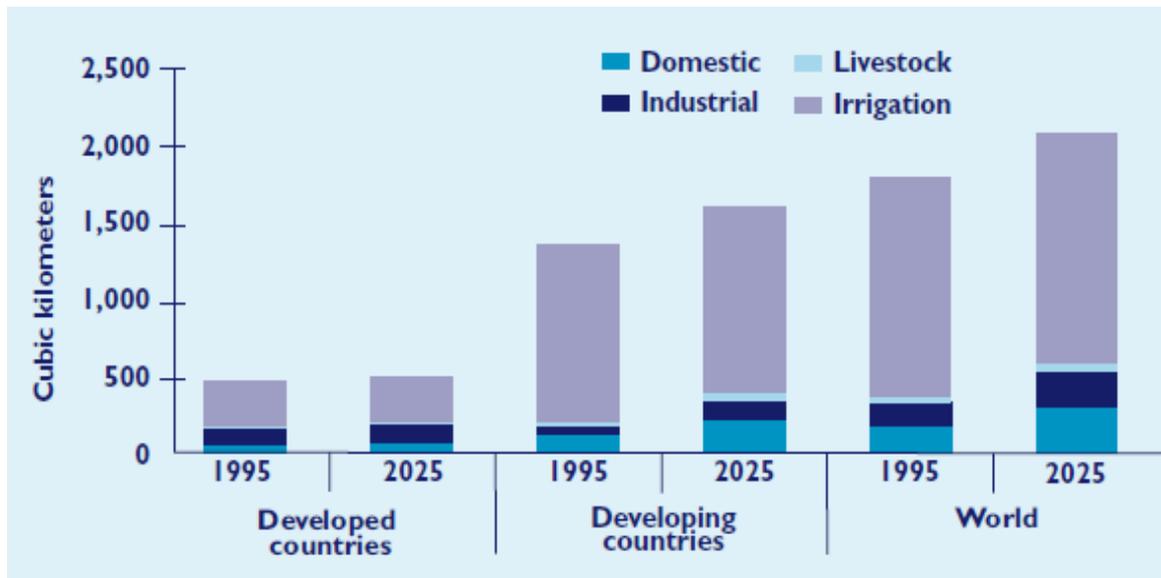


Source: Warwick Crop Centre (2013)

Figure 1.28. Water use pathways within the livestock sector

FINAL

The major impact from increasing water use within the agricultural sector is that of water stress on valuable water resources. As a direct consequence of the expected increase in the livestock sectors demand for water, Rosegrant et al. (2002) project that by 2025 64% of the world's population will live in water-stressed basins (against the 38% currently estimated). Figure 1.29 displays the projected increase in water consumption by sector, displaying that in comparison to irrigation the direct water consumption by livestock is relatively small. However the rapid increase in livestock production expected, particularly in developing countries, means that livestock water demand is projected to increase by 71% between 1995 and 2025 in comparison to the projected 19% in the developed world.



Source: Rosegrant et al. (2002)

Figure 1.29. Water consumption by agricultural sector, 1995 and projected levels for 2025

Soil Erosion and Degradation

Soil erosion is an environmental impact which has led to one of the major and most widespread forms of land degradation. The erosion of soil is estimated to affect about 17% of the total land area in Europe, affecting around 27 million ha in the EU (Oldeman et al., 1991). Soil erosion is most serious in central Europe, the Caucasus and the Mediterranean region, where 50-70 % of agricultural land is at moderate to high risk of erosion (UNECE, 2001).

The process of soil erosion is gradual, occurring when the impact of water or wind detaches and removes soil particles, causing the soil to deteriorate and therefore reducing the performance and productivity of the land and ecosystem. In Europe, the major cause of erosion is by water (around 92% of the affected area) (EEA, 2002). A report for the Council of Europe, using revised GLASOD data (data compiled in cooperation with soil scientists throughout the world) provides an overview of the area affected by soil erosion in Europe. Some of the findings are shown in Table 1.8 (Oldeman et al., 1991). Soil erosion is a natural process; however agricultural practices are able to significantly accelerate the natural rate of soil erosion. The removal of trees and vegetation for the extension of agricultural land and overgrazing, as well as tillage practices are able to leave soil exposed to natural elements such as wind and water therefore leading to the erosion of topsoil. An estimated 75 billion tonnes of fertile topsoil is lost worldwide from agricultural systems every year, and with such substantial losses arises the un-sustainable use of an important natural resource. The formation of soil is slow (100-400 years/cm of topsoil); therefore any soil loss of more than 1 tonne/ha/year can be considered as irreversible within a time span of 50–100 years (Pimentel et al., 1976, EEA 1999). In parts of the Mediterranean region, erosion has reached a stage of irreversibility and in some places erosion has practically ceased because there is no more soil left.

Topsoil contains most of the soils nutrients as well as pesticides and further agricultural pollutants; therefore its passage into waterways is able to lead to both silting and water pollution therefore

impacting biodiversity and disrupting the ecosystem. Furthermore, due to the topsoil's removal there is an on-site loss of agricultural potential, reducing both the fertility and productivity of the remaining soil. This often leads to the increasing reliance of farmers on the addition of fertilisers and soil amendments in order to compensate for potential yield losses through unproductive soil qualities. Such a loss in agricultural potential is therefore able to have a large impact on the economic potential of the land and annual financial losses in agricultural areas of Europe are estimated at around 53 EUR/ha, whereas the costs of indirect effects on for example public infrastructures such as road damage and siltation of dams reaches 32 EUR/ha (García-Torres et al., 2001).

Table 1.8. Human-induced soil Erosion in Europe (Million ha)

WATER EROSION	Light	Moderate	Strong	Extreme	Total
Loss of topsoil	18.9	64.7	9.2	-	92.8
Terrain Deformation	2.5	16.3	0.6	2.4	21.8
Total	21.4	81.0	9.8	2.4	114.5 (52.3%)
WIND EROSION					
Loss of topsoil	3.2	38.2	-	0.7	42.2
Total	3.2	38.2	-	0.7	42.2 (19.3%)
Includes European part of the former Soviet Union Source: Oldeman et al. (1991)					

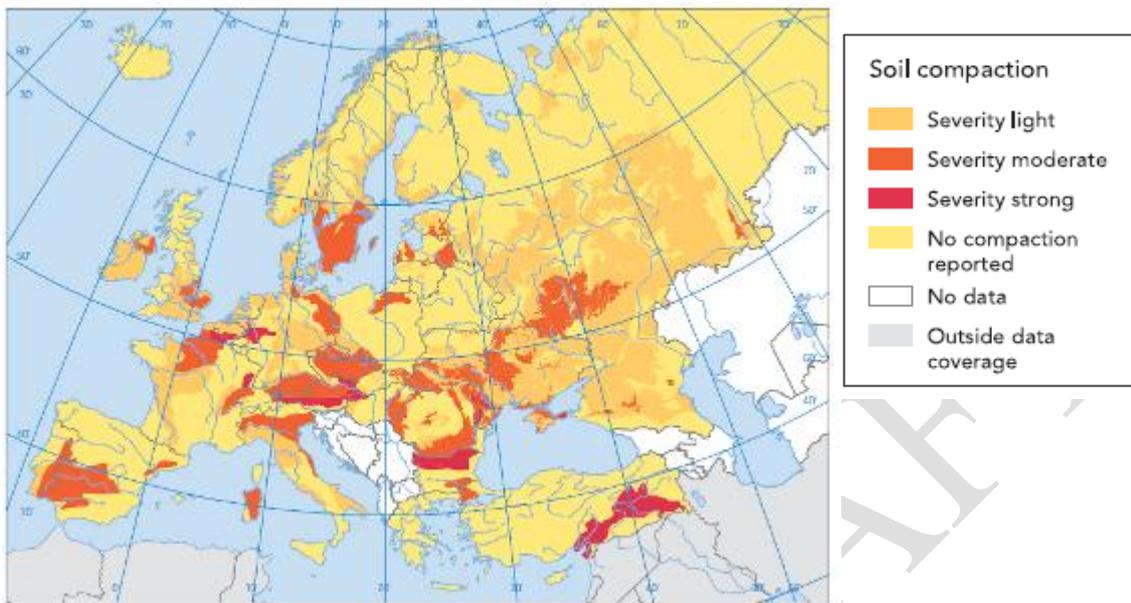
The compaction of soil is further a major threat to agricultural productivity as well as enhancing runoff and therefore enhancing the process of soil erosion (EEA, 1995a). The compaction of soil can occur through overstocking areas of agricultural land as well as the repetitive use of heavy machinery, causing the compression of soil particles and therefore slowing infiltration rates and enhancing surface runoff. Compaction is further able to alter the quantity and quality of biochemical and microbial activity in the soil. Whilst compaction of top soil can be relatively easily countered by re-working the soil, the deep compaction of subsoil is persistent and cannot be easily reversed (EEA, 1995b). In Central and Eastern Europe, soil compaction has affected over 62 million ha or 11% of the total land areas in the surveyed countries (Figure 1.30.).

Resource depletion

Aside from water and land depletion through agriculture further important resources are also used in order to produce sufficient quantities of food. Within the livestock sector around half of the world's antibiotic production is used for farm animals due to the stressful and often crowded livestock living conditions within factory farms encouraging the prevalence of infectious disease. However, in the EU treatment with antibiotics is not only provided to cure disease but it is also common for pigs and poultry to be fed antibiotics with their feed and water in order to suppress likely infections. Not only using up valuable resources in the production of antibiotics, this use also creates a risk of bacterial resistance to a variety of antibiotics, ensuring their lowered potential for use in human medicine (CIWF, 2011).

Phosphorus is essential within agriculture, providing an irreplaceable growth nutrient to crops. Approximately 90% of all phosphate demand is for food production, primarily for the production of agricultural fertiliser (82%) and a smaller fraction for animal feed additions (7%) and food additives (1-2%). The remaining 9% goes to industrial uses such as detergents and metal treatment and other industrial applications (Figure 1.31). The source of phosphate from which fertilisers are produced however, are from finite resources of phosphate rich rock (current proven reserves equate to less than 100 years' supply at current use rates). Richard and Dawson (2008) estimate that in the EU-27, 3.69 Mt P is added to agricultural soils, of which 1.32 Mt P are from mineral fertilisers and 2.06 Mt P are from manures. Levels of phosphorus use are further expected to rise due to increasing demands for food production. According to Rosegrant et al. (2001) an additional 650 Mt of cereals will be produced in 2020, most of which is likely to be used in cattle feed, requiring an additional input of a

minimum of 1.95 Mt/a of P to compensate for the phosphorus removed from fields with the harvested cereals (assuming a P content of 0.3%). This additional phosphorus is equivalent to more than 10% of the current world use of fertiliser phosphorus (Schroder et al., 2009).



Source: EEA, (2012)

Figure 1.30. The degree and extent of soil compaction in Europe

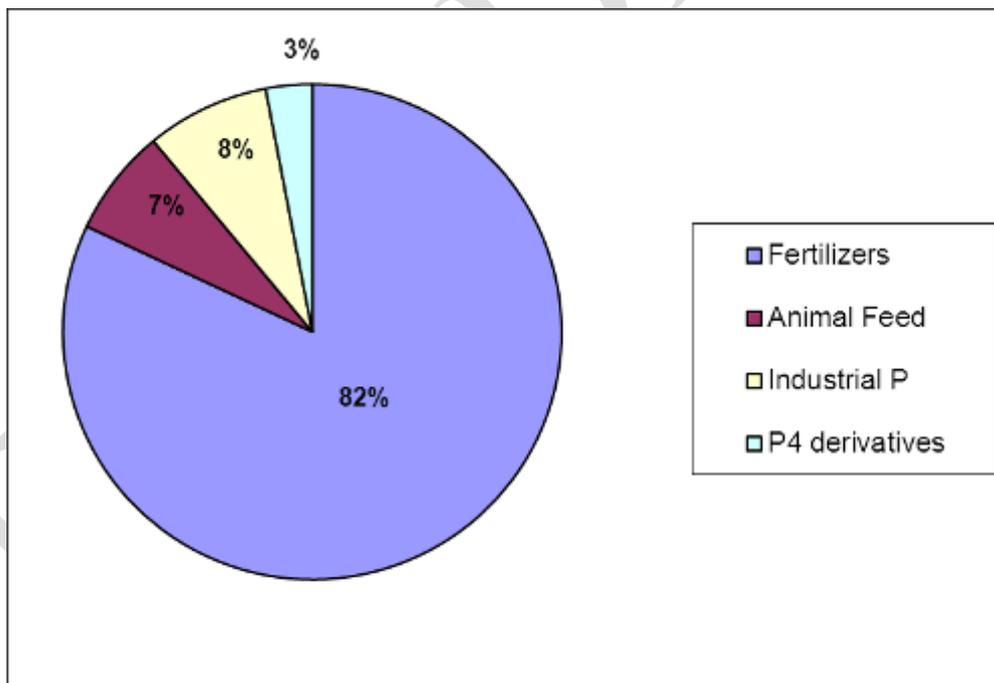


Figure 1.31. Breakdown of phosphorus end uses, indicating the large use for fertilisers

Energy is an essential resource across the entire food production cycle, with estimates showing an average of 7–10 calories of input being required in the production of one calorie of food, most of which comes from the utilisation of fossil fuels. This varies dramatically depending on crop, from three calories for plant crops to 35 calories in the production of beef.

The agricultural sector currently relies heavily on N fertilisers and pesticides in order to produce sufficient yields; therefore the energy used in their production and distribution represents the largest component of energy use within the sector. The production of these additional inputs requires large quantities of fossil fuel-derived energy and on a global scale fertiliser manufacturing consumes about 3-5% of the world’s annual natural gas supply. The production and distribution of N fertilisers currently require an average of 62 litres of fossil fuels per hectare, a demand expected to further increase with the expansion of agricultural land and the use of advanced technologies in the developing world. The estimated demand for fertiliser is thought to increase 25% by 2030 to 223 million tonnes, sustainable energy sourcing will therefore become an increasingly major issue (FAO, 2002; FAO, 2008; Fox, 2013).

1.2.4 Environmental Burden Overview

Figure 1.32 provides an overview of the extent to which agriculture contributes towards some of the major environmental impacts in Europe, based on data derived from European reports. The largest contribution of the sector is estimated to be towards total soil erosion within Europe (95%) followed by NH₃ emissions (94%) and Nitrogen water pollution (65%). The lowest contribution of the sector is estimated to be towards CO₂ equivalents (10%) however it must be noted that this figure excludes indirect emissions from for example fertiliser and pesticide manufacture.

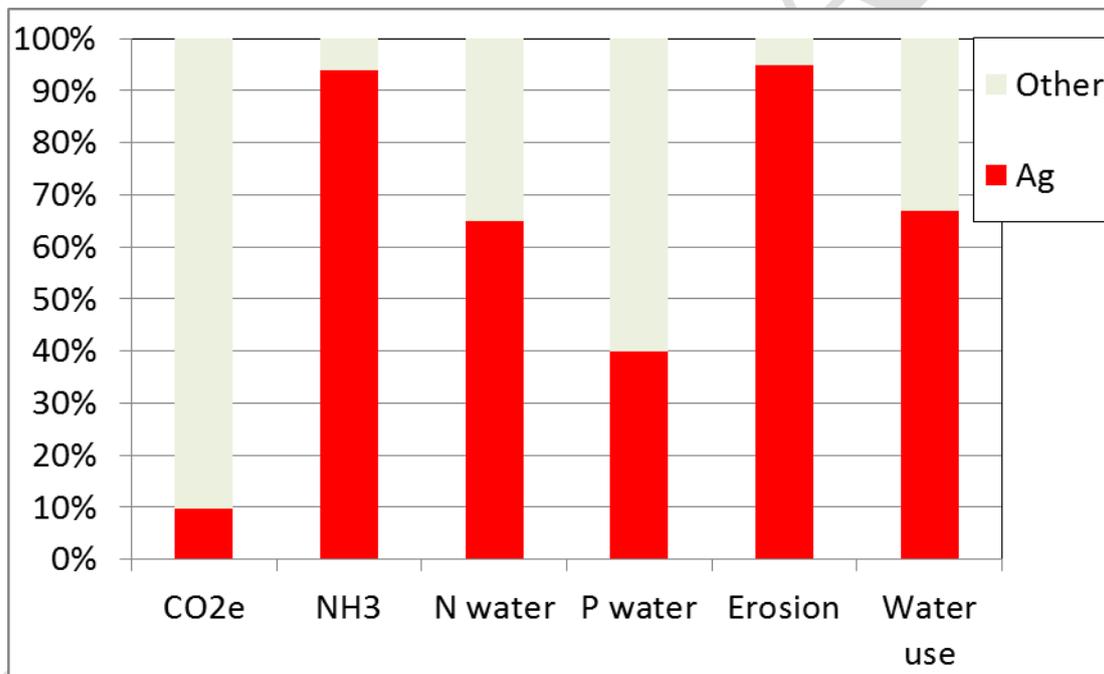
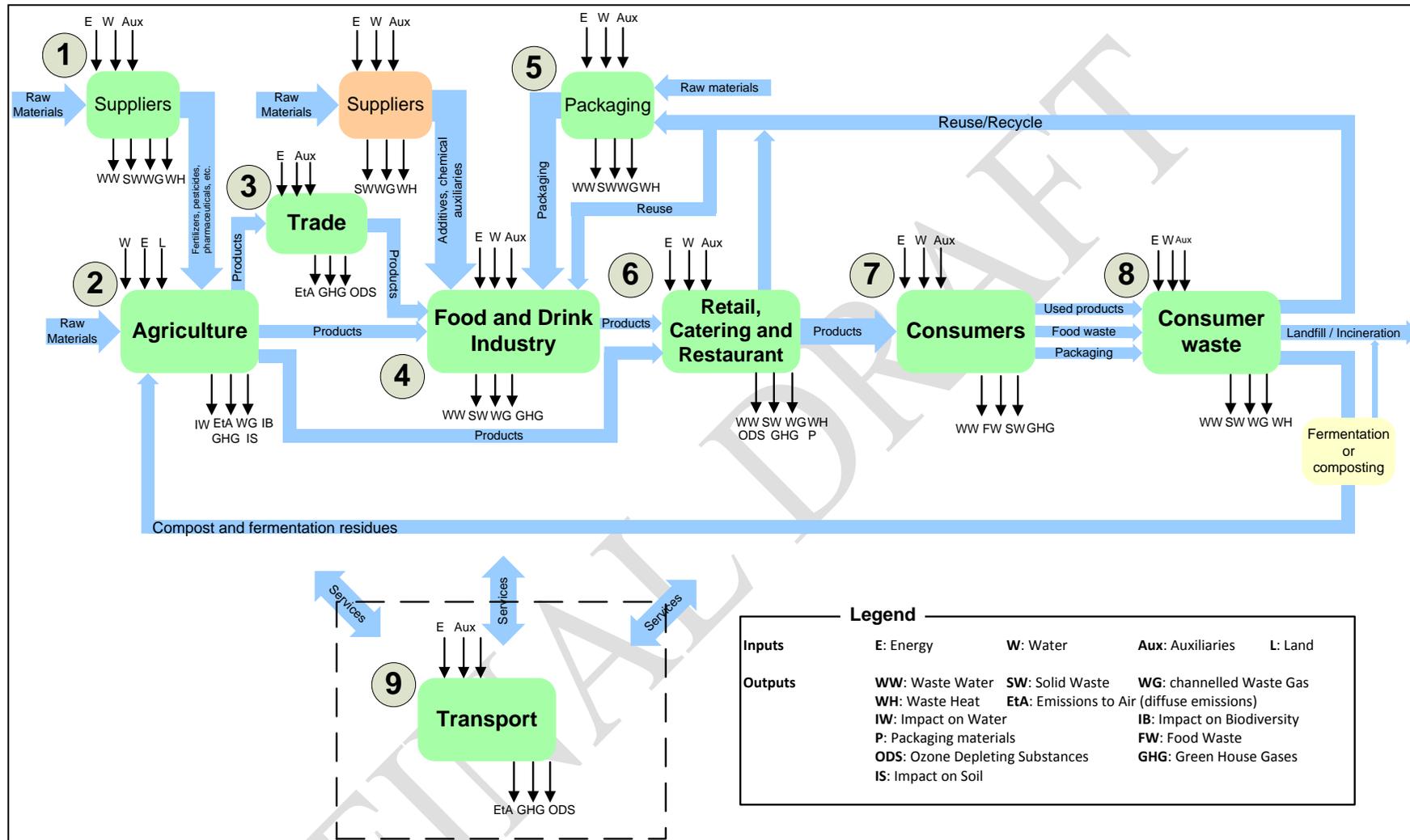


Figure 1.32. The major environmental impacts of the agricultural sector and their relative importance

Agriculture is just one stage in the life cycle of food production and consumption. Figure 1.33 displays a generic schematic of a food value chain, showing nine stages from agricultural suppliers to waste management after consumer disposal, with transport occurring between most of these stages. Although the specific processes occurring within each stage (e.g. enteric fermentation from animal husbandry) are not shown, the environmentally important inputs and outputs are shown.



Source: EC (2012)

Figure 1.33. A basic systems schematic of the food chain

1.2.5 Reference literature

- Bellarby, J., Foereid, B., Hastings, A., Smith, P. 2008, *Cool Farming: Climate Impacts of Agriculture and Mitigation Potential*. Cambridge University Press, Cambridge.
- Benton, T., Vickery, J.A. & Wilson, J.D. 2003, *Farmland biodiversity is habitat heterogeneity the key?* Trends in Ecology and Evolution, Vol.18 No.4.
- Bot, A.J, Nachtergaele, F.O., Young, A. 2000, *Land Resource Potential and Constraints at Regional and Country Levels*. FAO, Land and Water Development Division, Rome, Italy.
- Bouwman, L., Goldewijk, K.K., Van Der Hoek, K.W., Beusen, A.H.W., Van Vuuren, D.P., Willems, J., Rufino, M.C., Stehfest, E. 2011, *Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900-2050 period*. Proceedings of the National Academy of Sciences.
- Bowyer, C., Withana, S., Fenn, I., Bassi, S., Lewis, M., Cooper, T., Benito, P., Mudgal, S. 2009, *Land Degradation and Desertification*. Policy Department Economic and Scientific Policy.
- Campbell, J.E., Lobell, D.B., Genova, R.C. & Field, C.B. 2008, *The global potential of bioenergy on abandoned agriculture lands*. Environmental Science & Technology. Vol. 42, pp. 5791
- CIWF, (Compassion In World Farming). 2011, *Antibiotics in animal farm production*, Public Health and Animal Welfare.
- DEFRA. 2005, *The validity of food miles as an indicator of sustainable development*. Food Miles Final Report Issue 7.
- DEFRA, 2006, *Inland Water Quality and Use*, (Accessed; 2012, Available at; <http://archive.defra.gov.uk/evidence/statistics/environment/inlwater/iwnutrient.htm>)
- DG AGRI, 2012. *Agriculture in the European Union: Statistical and economic information 2011*.
- EA, (Environment Agency). 2002, *Agriculture and natural resources benefits, costs and potential solutions*.
- EA, (Environment Agency). 2008, *Best practice guide*.
- EC, (European Commission). 2002, *Sustainability of European irrigated agriculture under water framework directive and agenda 2000 (WADI)*. Analysis of European Water Policy.
- EC, (European Commission). 2006, *Environmental impact of products (EIPRO): analysis of the life cycle environmental impacts related to the final consumption of the EU-25*. IPTS, Seville. Technical Report EUR 22284 EN.
- EC. 2008, *Environmental Improvement Potentials of Meat and Dairy Products*. IPTS, Seville. Technical Report EUR 23491 EN.
- EC, 2009. *Regulation (EC) No 1221/2009 of the European Parliament and the Council of 25 November 2009 on the voluntary participation by organisations in a Community ecomanagement and audit scheme (EMAS), repealing Regulation (EC) No 761/2001 and Commission Decisions 2001/681/EC and 2006/193/EC*, OJEU L 342 (2009).
- EC, (European Commission). 2010, *On implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources based on Member State reports for the period 2004-2007*. Brussels.
- EC, (European Commission). 2012, *Agriculture and water*. (Accessed; Jan 2013, Available at; http://ec.europa.eu/agriculture/envir/water/index_en.htm).
- EEA (European Environment Agency). 1995a, *Corine soil erosion risk and important land resources in the southern regions of the European Community*. Office for Official Publications of the European Communities, Luxembourg.

- EEA (European Environment Agency) 1995b, *Europe's environment: The Dobbris assessment*. Office for Official Publications of the European Communities, Luxembourg.
- EEA (European Environment Agency) 1999, *Environment in the European Union at the turn of the century*. Environmental Assessment Report. No 2. Office for Official Publications of the European Communities, Luxembourg.
- EEA (European Environment Agency) 2002, *Assessment and reporting on soil erosion*. Technical report No 94. EEA.
- EEA, (European Environment Agency) 2010a, *Biodiversity Baseline*, Technical report No 12/2010.
- EEA, (European Environment Agency) 2010b, *Abundance and Distribution of selected species (SEBI 001)* (Accessed at; Jan 2013, Available from; <http://www.eea.europa.eu/data-and-maps/indicators/abundance-and-distribution-of-selected-species/abundance-and-distribution-of-selected>)
- EEA, (European Environment Agency). 2010c. *The European Environment. State and Outlook 2010. Land use*. EEA, Copenhagen.
- EEA (European Environment Agency). 2012, *Soil compaction in Europe* (Accessed; Jan 2013, Available at; <http://www.eea.europa.eu/data-and-maps/figures/soil-compaction-in-europe>)
- EEA, 2012a. Ammonia emissions, webpage accessed November 2012: <http://www.eea.europa.eu/data-and-maps/indicators/eea-32-ammonia-nh3-emissions-1/assessment-1>.
- ESTO. 2005, *Environmental Impacts of Products, (EIPRO) Analysis of the life cycle environmental impacts related to the final consumption of the EU-25*. European Science and technology Observatory and Institute for Prospective Technological Studies.
- Eurostat, 2010. *Using official statistics to calculate greenhouse gas emissions. A statistical guide 2010 edition*. (Available at http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-31-09-272/EN/KS-31-09-272-EN.PDF)
- Eurostat. 2011, *Climate change statistics*. (Available at http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Climate_change_statistics)
- Eurostat, 2011a. *Farm data needed for agri-environmental reporting*. Eurostat, Luxembourg. ISBN 978-92-79-19648-5.
- FAO (Food and Agriculture Organisation). 2002, *World agriculture: Towards 2015/2030*. (Accessed, Jan 2013; Available at, <http://www.fao.org/docrep/004/y3557e/y3557e00.htm>)
- FAO, (Food and Agriculture Organisation). 2005, *Livestock policy brief 02*. Rome. Food and Agriculture Organization.
- FAO, (Food and Agriculture Organisation), 2006. *Livestock's Long Shadow: Environmental issues and options*. Rome: UN FAO. ISBN 978-92-5-105571-7.
- FAO (Food and Agriculture Organisation). 2008, *Forecasting Long-term Global Fertilizer Demand* (Food and Agriculture Organization of the United Nations, Rome).
- FAO, (Food and Agriculture Organisation). 2009, *The state of food and agriculture, 2009*. Livestock in the balance. Rome
- FAO, (Food and Agriculture Organisation). 2012. *FAO Statistical Database*. Rome, (Available at <http://faostat.fao.org/default.aspx>)
- Fischer, J., Brosi, B., Daily, G.C., Ehrlich, P.R., Goldman, R., Goldstein, J., Lindenmayer, D.B., Manning, A.D., Mooney, H.A., Pejchar, L., Ranganathan, J., Tallis, H. 2008, *Should agricultural*

policies encourage land sparing or wildlife friendly farming? *Frontiers in Ecology and the Environment*, Vol. 6, pp. 380–385.

- Fox, T. 2013, *Global food waste not want not*, Institution of Mechanical Engineers,.
- Galloway, J., Burke, M., Bradford, G.E., Naylor, R., Falcon, W., Chapagain, A.K., Gaskell, J.C., McCullough, E., Mooney, H.A., Oleson, K.L.L., Steinfeld, H., Wassenaar, T., Smil, V. 2007, *International trade in meat: the tip of the pork chop*. *Ambio*, 36:622–9.
- García-Torres, L., Martínez-Vilela, A., & Norena, F.S. 2001, *Conservation agriculture in Europe: Current status and perspectives*. Conservation agriculture, a worldwide challenge. I World Congress on Conservation Agriculture. Madrid, 1–5 October
- Groombridge, B., & Jenkins, M. 2002, *World atlas of biodiversity: earth's living resources in 21st Century*, UNEP-WCMC, Cambridge.
- Henle, K., Alard, D., Clitherow, J., Cobb, P., Firbank, L., Kull, T., McCracken, D., Moritz, R.F.A., Niemela, J., Rebane, M., Wascher, D., Watt, A., Young, J. 2008, *Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe—A review*. *Agriculture, Ecosystems and Environment* 124: 60–71.
- Institute for European Environmental Policy. 2000, *The environmental impacts of irrigation in the European Union*, A report to the Environment Directorate of the European Commission.
- IPCC. 2001, *Climate change 2001: the scientific basis*. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change. Cambridge, UK.
- IPCC, 2007: *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.
- IUCN. 2008, *The IUCN Red List of threatened species* (Accessed; Jan, 2013, Available from; <http://www.iucnredlist.org/>)
- Johnson, J.M.F., Franzluebbers, A., Weyers, S.L., Reicosky, D.C. 2007, *Agricultural opportunities to mitigate greenhouse gas emissions*. *Environmental Pollution*, Vol. 150, pp. 107–124.
- Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Concepción, E.D., Clough, Y., Díaz, M., Gabriel, D., Holzschuh, A., Knop, E., Kovács, A., Marshall, E.J.P., Tschardtke, T., and Verhulst, J. 2009, *On the relationship between farmland biodiversity and land-use intensity in Europe*. *Proceedings of the Royal Society* 276: 903–909.
- Norris, K. 2008, *Agriculture and biodiversity conservation: opportunity knocks*, *Conservation Letters*, Vol. 1, pp. 2–11
- Oldeman, L. R. et al., 1991. *GLASOD world map of the status of human-induced soil degradation*. ISRIC, Wageningen and UNEP, Nairobi. (Available at; <http://www.isric.nl/ISRIC/webdocs/docs/explannote.pdf>)
- Paustian, K., Babcock, B., Kling, C., Hatfield, J., Lal, R., McCarl, B., McLaughlin, S., Post, W., Mosier, A., Rice, C., Robertson, G., Rosenberg, N., Rosenzweig, C., Schlesinger, W., Zilberman, D. 2004, *Agricultural mitigation of greenhouse gases: science and policy options*. Council on Agricultural Science and Technology (CAST) report p. 120.
- PBL, 2011. *The protein puzzle: The consumption and production of meat, dairy and fish in the European Union*. Netherlands Environmental Assessment Agency, The Hague. ISBN 978-90-78645-61-0
- Pimentel, D., Terhune, E. C., Dyson-Hudson, R., Rochereau, S., Samis, R., Smith, E. A., Denman, D., Reifschneider, D. & Shepard, M. 1976, *Land degradation: Effects on food and energy resources*. *Science*, 94:149–155.

- Prud'Homme, M. 2010, *World phosphate rock flows, losses and uses*. International Fertiliser Industry Association, Phosphates 2010 International Conference, March 2010 Brussels
- Richards, I.R. & Dawson, D.J. 2008, *Phosphorous imports, exports, fluxes and sinks in Europe*. Proceedings 638, International Fertilizer Society, York, UK: 1-28
- Rosegrant, M.W., Paisner, M.S., Meijer, S. & Witcover, J. 2001, *2020 Global food outlook trends, alternatives and choices*. International Food Policy Research Institute, Washington, D.C.
- Rosegrant, M. W., Cai, X. C. & Cline, S.A. 2002, *Global Water Outlook to 2025, Averting an Impending Crisis*. A 2020 vision for Food, Agriculture, and the Environmental Initiative. International Food Policy Research Institute.
- Schoenberger, H., Galvez-Martos, J.L., Styles, D., 2013. *Best Environmental Management Practice in the Retail Trade Sector: Learning from frontrunners*. JRC Scientific Report. IPTS, Seville. ISBN 978-92-79-30495-8. Available at: <http://susproc.jrc.ec.europa.eu/activities/emas/documents/RetailTradeSector.pdf>
- Schroder, J.J., Cordell, D., Smit, A.L. & Rosemarin, A. 2009, *Sustainable use of Phosphorous*. Plant Research International.
- Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B. & Sirotenko, O. 2007, Agriculture. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
- TFRN, 2011. *Draft Guidance document for preventing and abating ammonia emissions from agricultural sources*. WGSR Informal document no. 21.
- Turner, K., Georgiou, S., Clark, R., Brouwer, R. & Burke, J. 2004, *Economic valuation of water resources in agriculture*. From the sectoral to a functional perspective of natural resource management. FAO paper reports No. 27, Rome, FAO
- UK National Ecosystem Assessment. 2011, *The UK National Ecosystem Assessment: Synthesis of the Key Findings*. UNEP-WCMC, Cambridge.
- UN Water. 2009, *The United Nations World Water Development Report 3: Water in a changing world*. Paris and London, UNESCO and Earthscan, pp 127-149.
- UNECE (United Nations Economic Commission for Europe). 2001, *Assessment of progress in sustainable development since Rio 1992 for member states of the United Nations Economic Commission for Europe*. CEP/AC.12/3. UNECE, Geneva.
- Vanham, D., Bidoglio, G., 2013. A review on the indicator water footprint for the EU28. *Ecological Indicators* 26: 61–75.
- Vanham, D., Mekonnen, M.M., Hoekstra, A.Y., 2013. The water footprint of the EU for different diets. *Ecological Indicators* 32: 1– 8.
- Warwick Crop Centre (Accessed Jan; 2013, Available at; <http://www2.warwick.ac.uk/fac/sci/lifesci/wcc/research/resources/wateruse/technology/livestock.pdf>).

2 MAPPING BEST PRACTICE FOR PRODUCT GROUPS AND FARM TYPES

Best practice mapping

Based on environmental hotspots, Table 2.1 maps across the most relevant best environmental management practices (BEMPs) contained in this report to 12 major farm types. Simplification is inevitably involved, and farms may include features typical of multiple farm types (mix of intensive and extensive areas, mixed animal and crop production, etc).

Table 2.1. Priority best practices (BEMPs) described in this report for 12 major farm types (dark shading = high priority; medium shading = medium priority; white = not applicable or low priority)

BEMP	Intensive dairy ⁷	Extensive dairy	Intensive Beef ⁷	Extensive beef	Sheep	Intensive pigs ⁷	Intensive poultry ⁷	Extensive pig & poultry	Cereals and oils	Root crops	Field fruit & vegetables	Covered fruit & vegetables
3.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
3.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
3.3	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
3.4	Medium	Dark	White	Dark	Dark	White	White	Dark	Dark	Dark	Dark	Dark
3.5	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
3.6	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Dark	Dark	Dark	Dark	Dark
3.7	White	Medium	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
4.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
4.2	White	White	White	White	White	White	White	White	White	White	White	White
4.3	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
4.4	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
5.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
5.2	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Dark	Dark	Dark	Dark	Dark
5.3	Dark	Medium	Dark	Medium	Medium	Dark	Dark	Dark	Dark	Dark	Dark	Dark
5.4	Dark	Medium	Dark	Medium	Medium	Dark	Dark	Dark	Dark	Dark	Dark	Dark
6.1	White	White	White	White	White	White	White	White	White	White	White	White
6.2	White	White	White	White	White	White	White	White	White	White	White	White
6.3	White	White	White	White	White	White	White	White	White	White	White	White
6.4	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Dark	Dark	Dark	Dark	Dark
6.5	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
7.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
7.2	White	White	White	White	White	White	White	White	White	White	White	White
7.3	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
7.4	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.1	Dark	Dark	White	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.3	Dark	Medium	Dark	Medium	Medium	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.4	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.5	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.6	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.7	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.1	Dark	Medium	Dark	Medium	Medium	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.2	Dark	Medium	Dark	Medium	Medium	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.3	Dark	Medium	Dark	Medium	Medium	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.4	Dark	Dark	White	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.5	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.6	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.7	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
10.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
10.2	White	White	White	White	White	White	White	White	White	White	White	White
10.3	White	White	White	White	White	White	White	White	White	White	White	White
10.4	White	White	White	White	White	White	White	White	White	White	White	White
11.1	White	White	White	White	White	White	White	White	White	White	White	White
11.2	White	White	White	White	White	White	White	White	White	White	White	White

⁷ Arable best practice may apply to areas of the farm for feed production, or to farms receiving pig and poultry manure in terms of slurry application

BEMP	Intensive dairy ⁷	Extensive dairy	Intensive Beef ⁷	Extensive beef	Sheep	Intensive pigs ⁷	Intensive poultry ⁷	Extensive pig & poultry	Cereals and oils	Root crops	Field fruit & vegetables	Covered fruit & vegetables
12.1												
12.2												
12.3												

Particular systems within the broad categories above may have particular environmental hotspots that should be addressed, such as soil erosion for olive production, copper accumulation in soils for vineyards, etc. This report cannot be exhaustive, but attempts to address the major areas of environmental improvement potential within European agriculture.

Measuring resource efficiency

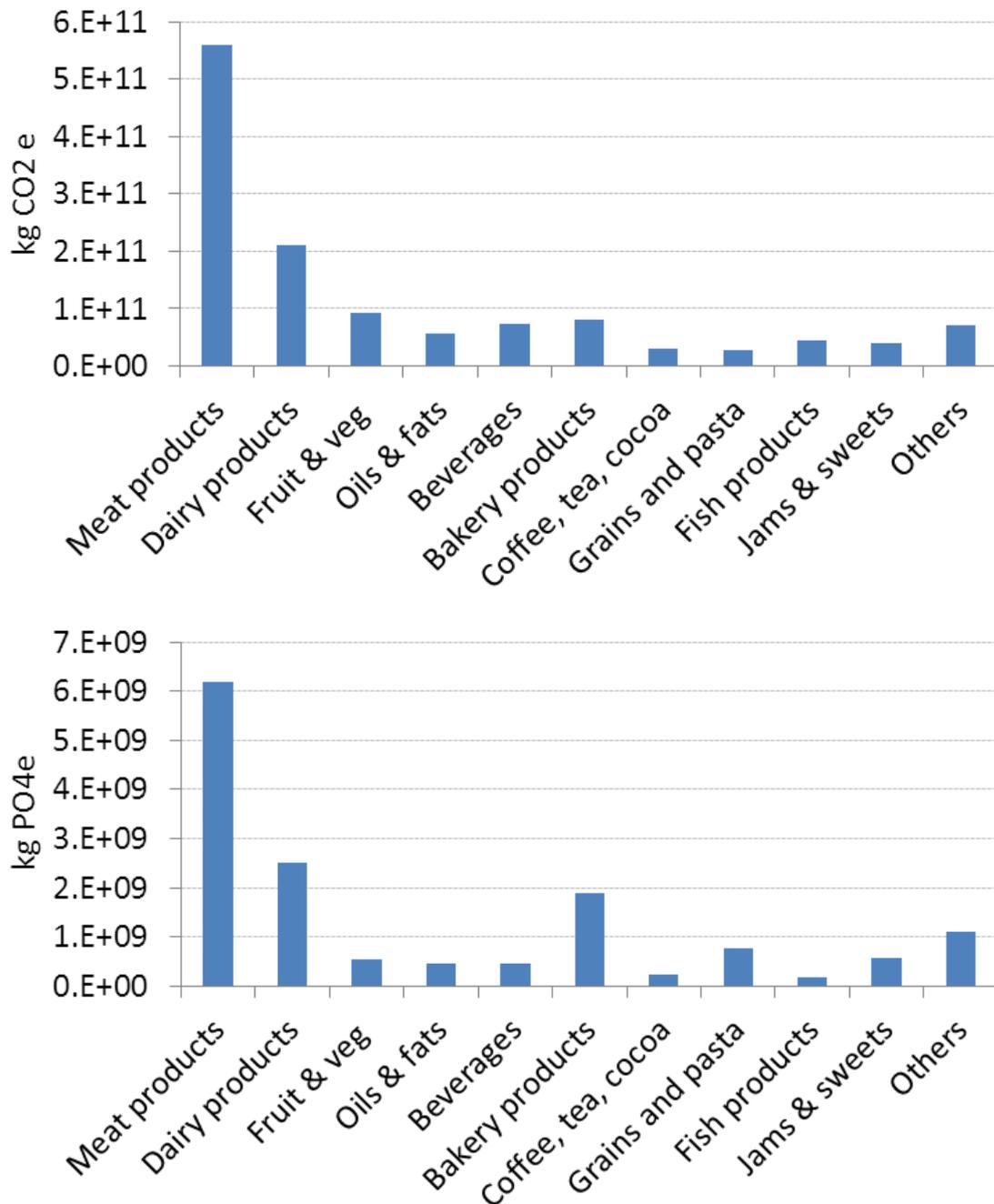
This chapter provides a brief overview of the environmental burdens arising from production and consumption of major food and drink product groups within Europe, in order to identify environmental hotspots and effective improvement options across product groups. In the first instance, a life cycle assessment (LCA) approach is used, including life cycle impact assessment (LCIA) indicators to express environmental burdens (Table 2.2). Note that whilst the CML LCIA method is one of the most commonly used, in some cases environmental burden data reported from other studies may be derived using different methodologies.

Table 2.2. Environmental impact categories, abbreviations, selected characterisation factors and indicators used in this report based on CML (2010) methodology

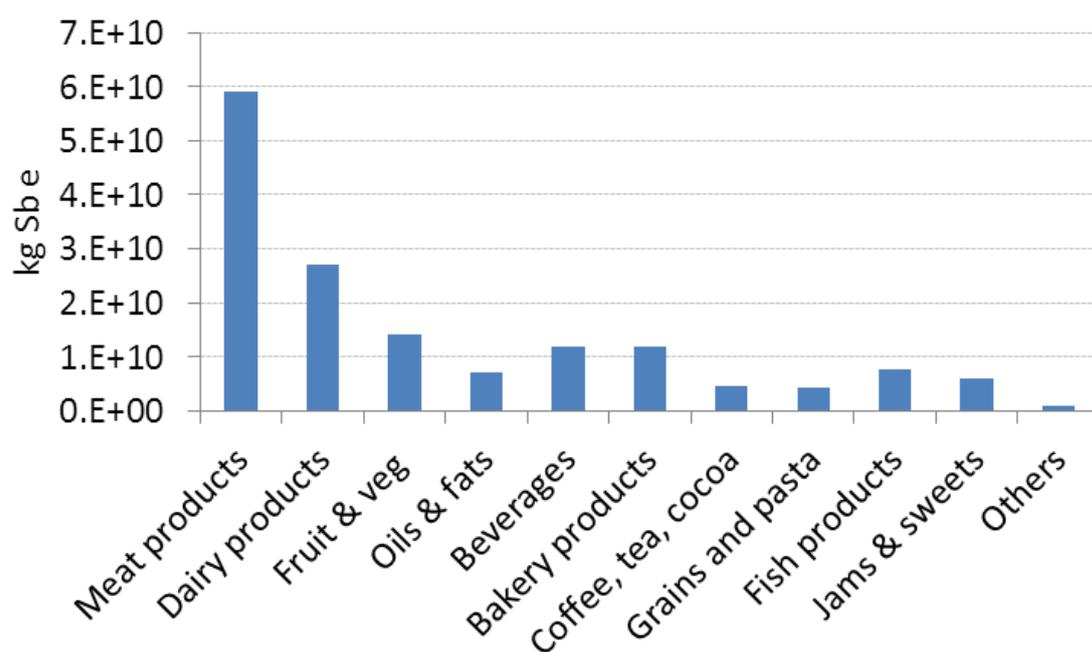
Impact category	Abbreviation	Interventions (characterisation factors for indicator loading; kg per kg intervention)	Indicator
Global warming potential	GWP	<ul style="list-style-type: none"> – CO₂ (1) – N₂O (298) – CH₄ (25) 	CO ₂ e
Eutrophication (RER)	EP	<ul style="list-style-type: none"> – NO₃ (1 x 10⁻¹) – P (3.06) – NH₃ (3.5 x 10⁻¹) – NO_x (1.3 x 10⁻¹) – N (4.2 x 10⁻¹) 	PO ₄ e
Acidification (RER)	AP	<ul style="list-style-type: none"> – NH₃ (1.6); – NO_x (5 x 10⁻¹) – SO_x (1.2) 	SO ₂ e
Resource depletion (fossil fuels)*	RDP	<ul style="list-style-type: none"> – Hard coal (27.91) – Soft coal (13.96) – Natural gas (38.84 per m³) – Crude oil (41.87) 	MJe

Abiotic Resource depletion (elements)*	ARDP	– See CML (2010); e.g. P (5.52 x 10 ⁻⁶)	Sb e
Eco-toxicity potential	ETP	– See CML (2010)	1,4-DCBe
*RDP and ARDP correlated via CML (2002) equation			

Figure 2.1 provides an overview of environmental burdens for major product groups, in terms of GWP (CO₂e), EP (PO₄e), ARDP (Sb e) and ecotoxicity and human toxicity (1,4-DCBe).



Source: Data reported in EC (2008), based on EIPRO study results



Source: Data reported in EC (2008), based on EIPRO study results

Figure 2.1. Environmental burdens of food production and consumption in the EU27, expressed across major product groups as LCA impact category burdens for: (i) global warming potential (top); (ii) eutrophication (second down); (iii) abiotic resource depletion (third down); (iv) human- and eco- toxicity (bottom).

The data above relate to entire production and consumption chains, as per the environmental-economic coupling methodology used in the input-output analyses of the EIPRO study (EC, 2008). For many products, such as meat and dairy products, the agricultural production stage (including upstream processes such as fertiliser manufacture) accounts for the major share of environmental burdens. For other products, such as bakery products, processing and cooking may account for a large share of the environmental burdens.

For the purposes of this report, it is important to provide an overview of the environmental profile, and contributory stages (ideally processes), for the major food and drink products to:

- (i) provide context for agricultural environmental improvement potential;
- (ii) direct policy makers towards priority sustainability actions for particular product groups;
- (iii) identify the upstream consequences of food waste;
- (iv) identify priority best practices within the agricultural sector.

A DEFRA funded project in assessed the environmental burdens arising from the agricultural production of some major food products in the UK. The results are summarised in Table 2.3.

Table 2.3. Main burdens of animal products per functional unit produced (one tonne dead weight, 20 000 eggs, and 1000 L milk) in the UK, based on national average production systems

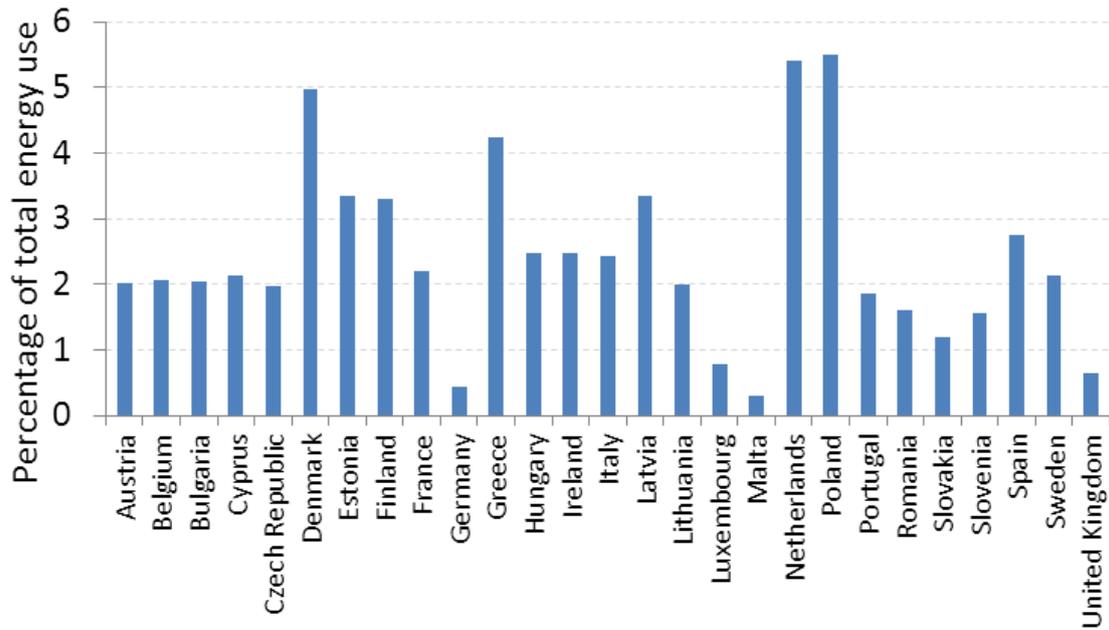
Impacts & resources used	Beef	Pig Meat	Poultry Meat	Sheep Meat	Eggs	Milk
Primary energy used, MJ	27,700	16,700	12,000	23,100	14,100	2,510
Global warming potential, kg CO ₂ e	15,800	6,350	4,580	17,400	5,540	1,060
Eutrophication potential, kg PO ₄ e	158	100	49	200	77	6.4

Impacts & resources used	Beef	Pig Meat	Poultry Meat	Sheep Meat	Eggs	Milk
Acidification potential, kg SO ₂ e	471	394	173	380	306	16.3
Pesticides used, dose ha	7.1	8.8	7.7	3.0	7.7	0.35
Abiotic resource depletion, kg Sb e.	36	35	30	27	38	2.8
Land use						
Grade 2, ha	0.04	0.00	0.00	0.05	0.00	0.022
Grade 3a, ha	0.79	0.74	0.64	0.49	0.67	0.098
Grade 3b, ha	0.83	0.00	0.00	0.48	0.00	0.00
Grade 4, ha	0.67	0.00	0.00	0.38	0.00	0.00
N losses						
NO ₃ -N, kg	149	48	30	287	36	7.2
NH ₃ -N, kg	119	97	40	106	79	4
N ₂ O-N, kg	11	6.4	6.3	9.0	7.0	0.71
<i>Source: Williams et al. (2006)</i>						

A subsequent DEFRA-funded project used LCA to compare the relative environmental burdens of food products commonly imported to the UK with equivalent products grown in the UK, up to the point of UK retail distribution centres (DEFRA, 2008). That report cites Foster et al. (2006) who defined the concept of “ecological comparative advantage” for some countries or regions in relation to certain types of products – the eco-efficiency of production for particular products in particular countries (e.g. related to climate) outweighs the environmental burden of transport from those countries to the UK (or other northern European countries). Conclusions from that report included:

- Greenhouse gas emissions per tonne product were not necessarily less for UK produce than for imports from the countries considered in the project
- Total pre farm gate carbon footprint was estimated to be smaller for UK production of potatoes and beef
- Up to the retail distribution centre, total carbon footprint was less for potatoes, beef and apples from the UK than imports
- Carbon footprints for tomatoes and strawberries from Spain, poultry from Brazil and lamb from New Zealand were smaller than from the same foods produced in the UK despite the GHG emissions from transport.

The agricultural sector is responsible for a relatively small share of overall energy use, compared with its contribution to other burdens (Figure 2.2), and a large share of the energy burdens for many food and drink products are imposed downstream of the farm gate, during storage, transport, processing and cooking. Other documents on best environmental management practice cover the environmental burdens of food processing and distribution (Schoenberger et al., 2013).



Source: FAOStat (2013)

Figure 2.2. Agricultural energy use expressed as a percentage of total national energy use across EU member states

In the sections below, the environmental profiles of major agricultural commodities and their derivative products are summarised, along with some proposed priority improvement options. This chapter provides a framework for BEMP techniques described within this report. Finally, relevant product standards and agricultural certification schemes are summarised, to provide further guidance on BEMP implementation for both farmers and farm advisors, and supply chain managers.

Ecosystem services assessment

Half of European land area is subject to agricultural management. Extensive management, such as low intensity grazing, can maintain particular valued plant and animal species recognised as High Nature Value (HNV) areas. Thus, extensive livestock agriculture can have a positive effect on the environment through landscape management, although the efficiency of such farming systems may be low from a resource-efficiency perspective measured using LCA metrics. In addition, many environmental impacts occur locally or regionally, including eutrophication, biodiversity loss, soil degradation, etc. The LCA approach may be of less relevance to such impacts: food production may become more “efficient” on a per kg basis whilst local environmental thresholds are exceeded. Thus, it is important to combine LCA with additional measures of environmental impact assessment, especially at the landscape scale. One such approach is the Ecosystem Services Assessment framework, as proposed by the Millennium Ecosystem Assessment (MEA) report (MA, 2005).

Alternative “best practice” strategies

Depending on the local context, intensification or extensification could be regarded as best practice. Livestock production systems can broadly be classified into:

- grazing systems
- mixed systems
- fully confined landless/industrial systems.

Grazing systems typically have stocking rates less than one or two livestock unit per ha, depending on grassland productivity. Mixed systems produce multiple outputs and typically import some animal feed. Industrial systems have stocking rates greater than 10 livestock units per ha and import typically 90-100% of animal feed (TFRN, 2011). Industrial confinement systems can be more resource efficient, through higher feed conversion ratios and careful management of nutrient flows, but require large areas of surrounding arable land to provide feed. Grazing systems may provide an opportunity to manage large areas of HNV land.

According to EC (2008), “*The reduction of land use for crop production through intensification of cereal production is largely considered an autonomous development. If this development should be furthered, it could be done through regulation or subsidies that stimulate the setting aside of arable land more permanently. Increasing arable land set-aside makes the costs of using land for cereal production more expensive and consequently stimulates intensification.*” The authors go on to report that countries in eastern Europe such as Poland and Hungary obtain only half the cereal yield per ha compared with EU15 countries, reflecting smaller inputs of N and plant protection agents, restructuring of the farms, and similar socioeconomic reasons. The biophysical production potential is similar in eastern and Western Europe, implying considerable improvement potential.

EC (2008) conclude in favour of an intensification of arable production but not of cattle and dairy farming owing to the larger area requirement for feed that the latter intensification would entail, and also for intensified dairy production a reduced meat output which would require compensating dedicated meat production with greater environmental burdens. The authors assume that extensive grazing land area would not be reduced by an intensification of cattle farming, therefore yielding no benefits in terms of reduced nature occupation. They go on to suggest it would be environmentally beneficial to restrict further specialisation in dairy farming, or at least to remove any existing incentives for such specialisation. EC (2008) assumed that the 10 million ha of barley and wheat grown in eastern Europe, with an average yield of 2.8 t/ha, can be intensified to yield the western European average of 5.2 t/ha (EU15 less Spain, Portugal, Italy and Greece, where crop yields are lower). This would reduce the area required to produce one tonne cereal from 3 570 m² to 1 923 m² (EC, 2008). N fertilisation would need to increase from 70 to 130 kg/ha/year but overall emissions per tonne grain should reduce (Table 2.4). EC (2008) calculated that the overall effect on EU cereal production would be a 9% reduction in land use and ammonia emissions with only small changes in other emissions. They note that intensification may reduce erosion through the increased amount of crop residues.

Assuming that the N use efficiency of cereal production can be held constant whilst cereal yields are increased through use of higher yielding varieties and higher N inputs, the overall environmental burdens of producing one tonne of grain can be reduced (Table 2.4) and land can be spared for other purposes, including conservation and carbon sequestration.

Table 2.4. Inputs and emissions per tonne grain produced at different intensities (areal yields)

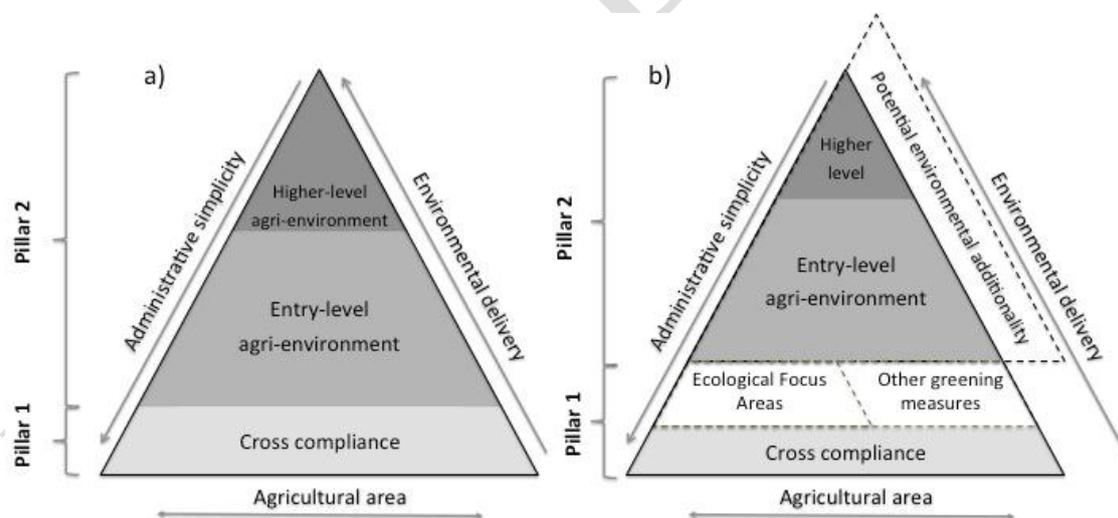
Factor	Extensive (2.8 t/ha/yr)	Intensive (5.2 t/ha/yr)
Fertiliser-N (kg)	21.46	21.46
Manure-N (kg)	2.93	2.93
Fertiliser-P (kg)	3.90	3.90
Fertiliser-K (kg)	12.68	12.68
Area (ha)	0.24	0.22
NH ₃ (kg)	2.37	2.22
N ₂ O (kg)	1.12	1.10
NO ₃ (kg)	48.54	47.80
<i>Source: EC (2008)</i>		

Regional prioritisation

It is clear from the above that different strategies for global environmental improvement are required depending on local or regional land, ecosystem and climate characteristics. Different regions will have different environmental hotspot pressures, such as water stress in Mediterranean areas, eutrophication and acidification in NW Europe. These may be locally acute owing to the presence of pristine and sensitive water bodies, HNV habitats, etc. Based on an experienced overview of European environmental pressures Hamell (2013) proposed the following regionally differentiated priority topics for environmental improvement in relation to agricultural production:

- Water quality in NW Europe (good examples of Nitrate Action Programme implementation include Northern Ireland, Ireland, Denmark, Emilia Romagna region of Italy, Catalonia)
- Water management in southern Europe (poor regulation of abstractions). Agri-environmental measures will require a 25% reduction in water consumption in southern European agriculture.
- Pesticide residues in waters in France owing to poor control and historical high application rates on vines. Copper toxicity is a problem in soils.
- Biodiversity everywhere, but especially southern Europe where there are very few “natural” field margins. One of the proposals for CAP reform addresses the issue by introducing an Ecological Focus Area (7% of all arable land should be dedicated to more natural habitat such as trees, edges, margins, dedicated crops from bees (IEEP, 2012).

However, implementing regionally differentiated strategies for environmentally sound farming is challenging (Figure 2.3). Bottom-up initiatives driven by farmers and farm consultants have the potential to overcome some of these challenges (see BEMP 3.1), though obviously will be most effective when coupled with well-designed regulation and incentives within a coherent agri-environmental policy.



Source: IEEP (2012)

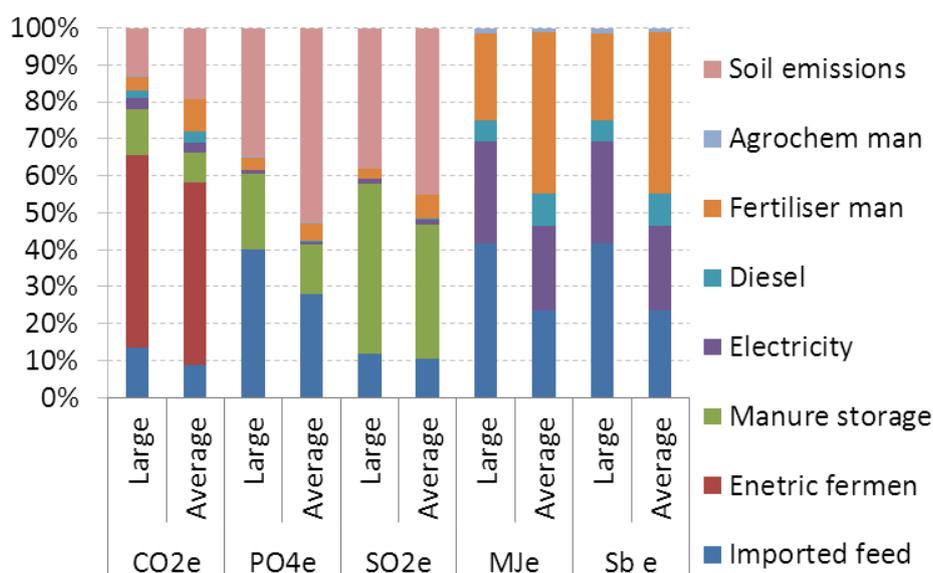
Figure 2.3. Integration of spatially targeted measures into European agri-environmental policy (IEEP, 2012)

2.1 Dairy production

Figure 2.4 displays the contribution of eight groups of processes to four environmental burdens for milk production, up to the farm gate, based on the Bangor University agricultural LCA tool. Results are displayed for:

- a large, intensive farm where cows are indoors for 10 months of the year
- an average-sized (UK) dairy farm where cows are grazing for 6 months of the year.

The latter system is more representative of European pasture-based dairy farms. The former system is closer to a typical European intensive dairy farm, although most feed (grass and fodder maize silage) is still grown on-farm, with approximately 2.2 tonnes concentrate feed per milking cow per year imported to the farm (average yield per cow of 8626 L/yr). The model farms are economically optimised in terms of feed rations and fertiliser application rates using the Farm-Adapt model (Gibbons et al., 2006), so may be more efficient than “average” farms. However, these farm systems use “conventional” slurry storage (open tanks) and spreading (splash-plate) methods, so can provide a useful baseline for improvement potential associated with BEMP. Enteric fermentation, manure storage and soil emissions (related to fertiliser and manure applications) dominate climate change, eutrophication and acidification burdens (Figure 2.4). Environmental burdens allocated to milk based on the relative energy outputs of milk and animal liveweight (89% of farm burdens allocated to milk) are summarised in Table 2.5.



Source: Bangor University farm LCA tool

Figure 2.4. Contribution of major processes to environmental burdens arising from milk production for an efficient 481- milking-cow (“Large”) and 125- milking-cow (“Average”) dairy farm

Table 2.5. Environmental burdens allocated per L milk produced on a large and average size dairy farm

	CO ₂ e	PO ₄ e	SO ₂ e	MJ e
	kg per L milk			
Large	0.90	0.0037	0.0076	1.55
Average	1.02	0.0039	0.0066	1.98

Source: Bangor University farm LCA tool

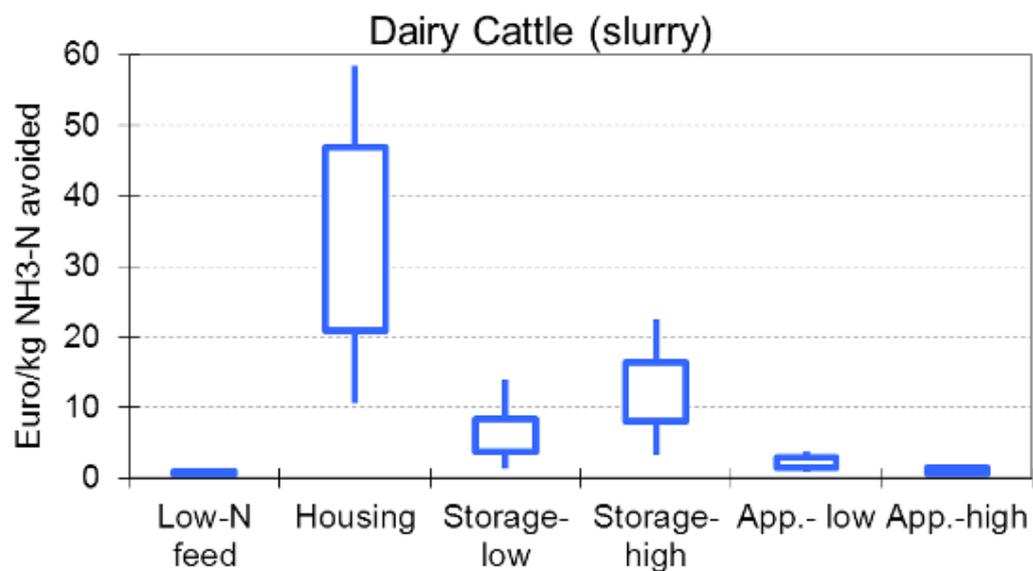
Very intensive dairy systems are more highly dependent on imported concentrate feed. The environmental burden associated with imported feed can increase considerably for such farms, especially if some of that concentrate is soybean meal extract to which indirect land use change is attributable (e.g. deforestation in Brazil or cultivation of grasslands in Argentina) (Hörtenhuber et al., 2011). This issue is dealt with in section 8.5, where the impact of soy feed is shown in relation to the intensive farm for which results are displayed in Figure 2.4.

The Scottish agricultural college (SRUC) have developed Marginal Abatement Cost Curves (MACC) for livestock GHG abatement options (Wall, CEUKF 2013). The main improvement options were determined to be:

- improved genetics (breeding)
- improved manure management
- improved nutrient management.

Profitable abatement options for farmers could reduce UK agricultural emissions by 10% by 2020. Breeding goals have expanded to include animal welfare, health and environmental considerations in addition to productivity.

The Task Force on Reactive Nitrogen (TFRN) have produced a guidance document on the prevention and abatement of ammonia (NH₃) emissions in agriculture, the latest version of which (TFRN, 2012) is used to underpin relevant BEMP in this report. Underpinning that document are NH₃ abatement costs derived from the European GAINS model and detailed in a publically-available spreadsheet (Winiwarter et al., 2011). Data from that spreadsheet are extracted and presented in this section, including in Figure 2.5.



NB: Bars display 25th to 75th percentile ranges, whilst lines display absolute range in GAINS values calculated across European countries. Excludes potential fertiliser replacement effects.

Source: Winiwarter et al. (2011), based on GAINS data

Figure 2.5. Range of European abatement costs for ammonia emissions from dairy systems with liquid slurry storage

Various agricultural organisations representing the dairy industry across Europe have developed road maps for more sustainable production, including e.g. Teagasc in Ireland, DairyCo in the UK, NZO in the Netherlands. Relevant sections will be referred to throughout this report.

Based on the environmental burden sources for dairy production referred to above, the most important BEMP techniques to reduce the overall burden of milk production are summarised in Table 2.6, below.

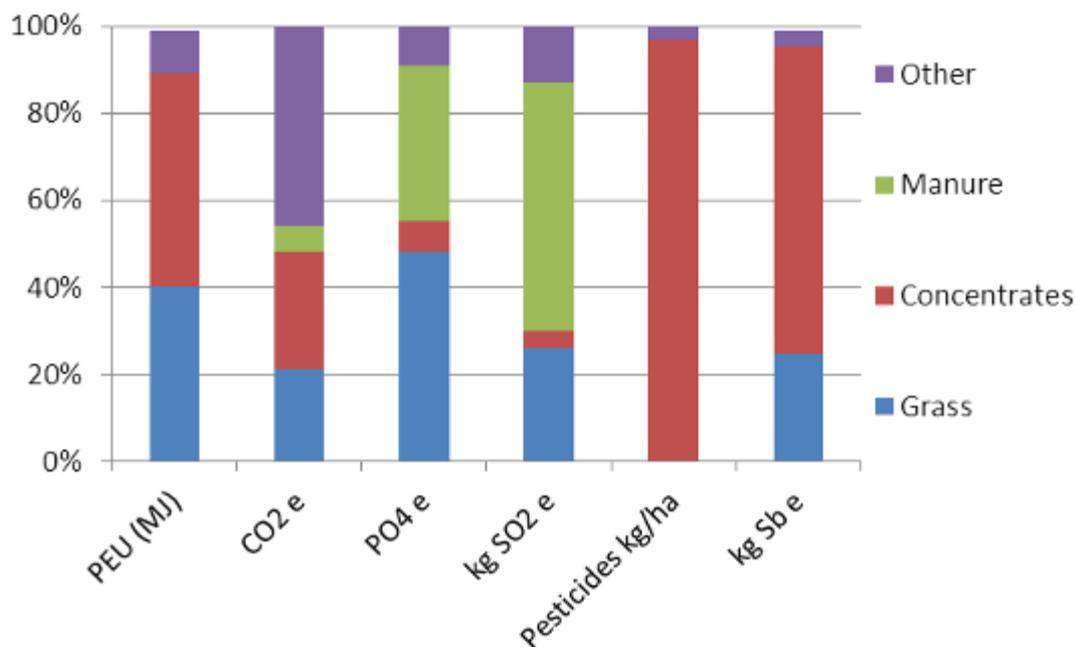
Table 2.6. Key BEMP measures to reduce the environmental burden of European dairy production, and priorities (P) for confinement and grazing based systems

Source	Key BEMP measures	Section	Confine-ment	Grazing
Enteric fermentation	Breeding for improved productivity	Section 8.1	P	P
	Maintaining animal health	Section 8.6	P	P
	Diet (feed conversion ratio)	section 8.4, 8.6	P	
Manure storage	Manure management in housing	Section 9.1	P	
	Storage	Section 9.3, 9.4, 9.5	P	
	Anaerobic digestion	Section 9.2	P	
Soil emissions (air and water burdens)	Soil Nutrient Management Planning	Section 4.1, 5.1	P	P
	Dietary optimisation of N intake (excretion)	Section 8.3	P	
	Precision fertiliser/manure application	Section 5.3, 9.6, 9.7	P	P
	Grass-clover swards	Section 7.3	P	P
	Efficient slurry application	Section 9.6, 9.7	P	
Feed production	Grazing management	Section 7.1,7.2		P
	Efficient silage production	Section 7.4	P	
	Green procurement of feed	Section 8.5	P	
Biodiversity burdens	Appropriate land use	Section 3.1, 3.3		P
	Habitat management	Section 3.4, 7.2		P
	Local breeds	Section 8.1		P
Resource consumption	Nutrient use efficiency	Section 3.2, 8.2	P	P
	Soil management	Section 3.3, 4.1, 4.4	P	P
	Energy management	Section 3.2, 3.5, 9.2	P	

2.2 Beef production

As shown in Table 2.3, each kg beef carcass requires 27.7 MJ primary energy input and gives rise to 15.8 kg CO₂e of GHG emissions and 0.158 kg PO₄ e of eutrophying emissions (to air and water). Subsequent processing and transport, including 25.5 kWh electricity per animal for slaughter and processing (DEFRA, 2008), accounts for a minor share of lifecycle impact up to the consumption stage. EBLEX (2009) reports that beef processing contributes 0.27 kg CO₂e per kg meat. The burdens in Table 2.3 are expressed per kg beef after non-edible portions (approximately 50% of the animal liveweight) is removed, and correspond with burdens expressed per kg liveweight calculated in the Bangor LCA tool used later in this report to calculate environmental benefits associated with specific BEMP techniques. Various methods may be used to allocate some of the production burden to by-products such as offal and pet-food.

Figure 2.6 shows that 41% of the energy burden comes from the production of grass and a similar amount comes from the production of various concentrate feeds for beef. Manure represents a negative energy burden as it replaces fertiliser, but causes significant emissions of GHGs and acidifying gases, as well as eutrophying substances, during storage and spreading.



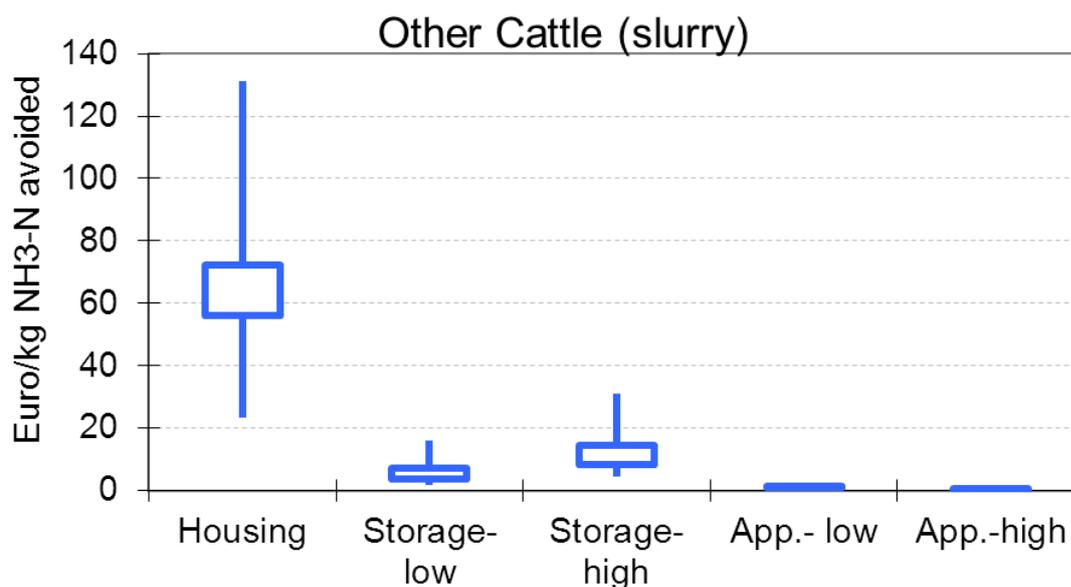
Source: Derived from data in Williams et al. (2006).

Figure 2.6. Contributions of main contributory sources to environmental burdens of beef production (in relation to 1 tonne dead weight beef carcass exported from the farm gate)

Cederberg (2013) shows that accounting for (indirect) land use change (LUC) in Brazilian beef production considerably increases its footprint. Care must be taken that measures to reduce the direct environmental footprint of beef production do not lead to higher indirect emissions through feed production or displacement of beef production to other countries, such as Brazil and Argentina, where such production is more likely to lead to land use change.

Williams et al. (2006) compare UK beef production with Brazilian beef production: a major source location for imported European beef. Although Brazilian production is extensive with low fertiliser inputs, it is often either based on recently cleared forest and native grasslands, or contributes indirectly to the expansion of agricultural production into those lands.

Figure 2.7 shows NH₃ abatement costs for various measures aimed at housing, manure storage and manure application for beef systems from Winiwarter et al. (2011).



NB: Bars display 25th to 75th percentile ranges, whilst lines display absolute range in GAINS values calculated across European countries. Excludes potential fertiliser replacement effects.

Source: Winiwarter et al. (2011), based on GAINS data.

Figure 2.7. Range of European abatement costs for ammonia emissions from non-dairy cattle systems with liquid slurry storage

Based on the environmental burden sources for beef production referred to above, the most important BEMP techniques to reduce the overall burden of beef production are summarised in Table 2-7 below (very similar to dairy production).

Table 2.7. Key BEMP measures to reduce the environmental burden of European beef production

Source	Key BEMP measures	Section
Enteric fermentation	Breeding for improved productivity	Section 8.1
	Maintaining animal health	Section 8.6
	Diet (feed conversion ratio)	section 7.1 and 8.4
	Optimised cull age	Section 8.7
Manure storage	Manure management in housing	Section 9.1
	Covered solid manure storage	Section 9.5
	Liquid slurry storage and anaerobic digestion	Section 9.4, 9.2
Soil emissions (air and water burdens)	Soil Nutrient Management Planning	Section 5.1
	Dietary optimisation of N intake (excretion)	Section 8.3
	Precision fertiliser/manure application	Section 5.3
	Grass-clover swards	Section 7.3
	Trailing shoe/banded slurry application	Section 9.6 and 9.7
Feed production	Grazing management	Section 7.1 and 7.2
	Efficient silage production	Section 7.4
	Green procurement of feed	Section 8.5

Source	Key BEMP measures	Section
Biodiversity burdens	Appropriate land use	Section 3.1, 3.3
	Habitat management	Section 3.4, 7.2
	Local breeds	Section 8.1
Resource consumption	Nutrient use efficiency	Section 3.2, 8.2
	Soil management	Section 3.3, 4.1, 4.4
	Energy management	Section 3.2, 3.5, 9.2

2.3 Sheep production

The overall environmental burdens of sheep production are shown in Table 2.8, in relation to one tonne of sheep meat (lamb or mutton) based on typical conventional or organic farm systems in the UK. As with milk and beef production, most emissions in the value-chain occur before the farm gate. However, electricity required for lamb slaughter and processing, 19.0 kWh/head, is significant relative to the animal liveweight and makes a small but significant contribution to lifecycle environmental burdens for lamb (DEFRA, 2008). EBLEX (2009) reported that lamb processing contributes 0.23 kg CO₂e per kg meat.

Table 2.8. Environmental burdens and resource use for the production of one tonne of sheep meat by typical conventional and organic systems in the UK

Impacts and resources	Conventional	Organic
Primary energy used, MJ	23,100	18,400
Global warming potential, kg CO ₂ e	17,500	10,100
Eutrophication potential, kg PO ₄ e	195	594
Acidification potential, kg SO ₂ e	368	1,511
Pesticides used, dose ha	3.0	0.0
Abiotic resource depletion, kg Sb e	27	19
Land use, ha	1.38	3.12
N losses		
NO ₃ -N, kg	282	700
NH ₃ -N, kg	100	618
N ₂ O-N, kg	8.9	13.4

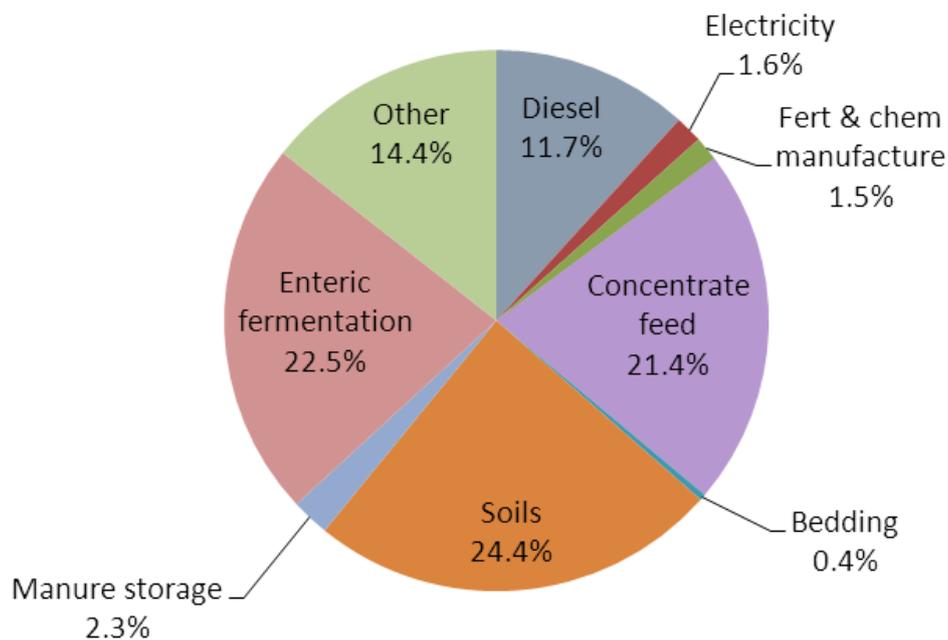
Source: Williams et al. (2006).

Figure 2.8 shows the main sources of GHG emissions from sheep production on a low-fertiliser-input farm. Compared with beef and milk production, concentrate feed production and soil emissions make larger relative contributions and manure storage a smaller relative contribution because animals are outdoors most of the year and enteric fermentation makes a smaller contribution.

Sheep production is often extensive, and is therefore associated with management of large areas of land and associated ecosystem service provisioning. It could be argued that an ecosystem services approach would be more relevant than an LCA approach to assess the overall environmental performance of extensive sheep farms, an issue pertinent to policy-level decisions on land designation (e.g. section 3.2). Ripoll-Bosch et al. (2013) demonstrate how ecosystem services provisioning can be regarded as a co-product of lamb production within carbon footprinting, improving the calculated eco-efficiency of extensive sheep systems relative to intensive systems.

Jones et al. (2013) short-listed the following six effective and practical measures to improve the environmental performance of sheep production, based on consultation with farmers and other expert stakeholders:

- include legumes in pasture reseed mix
- increase lamb growth rates for earlier finishing
- improve ewe nutrition in late gestation
- reduce mineral fertiliser use
- lamb as yearlings
- select pasture plants bred to minimise dietary nitrogen losses.



N.B.: "Other" includes bought-in ewes

Source: Data from Taylor and Edwards-Jones (2010)

Figure 2.8. Breakdown of the carbon footprint of sheep liveweight from a Welsh sheep farm (total footprint = 10.1 kg CO₂e per kg liveweight)

In terms of the comparative efficiency of sheep production in Europe versus other major producing countries such as New Zealand, DEFRA (2008) report that the overall burdens of sheep meat produced in the UK or imported to the UK from New Zealand were similar. New Zealand has a longer grazing season and lower soil and concentrate feed emissions than the UK (representative of European sheep production), but transporting the meat by ship leads to significant lifecycle eutrophication and acidification burdens via NO_x and SO_x emissions from heavy fuel oil used in ships.

Based on the environmental burden sources for sheep production referred to above, the most important BEMP techniques to reduce the overall burden of sheep production are summarised in Table 2.9.

Table 2.9. Key BEMP measures to reduce the environmental burden of European sheep production

Source	Key BEMP measures	Section
Enteric fermentation	Breeding for improved productivity	Section 8.1
	Maintaining animal health	Section 8.6
	Diet (feed conversion ratio)	section 7.1 and 8.4
	Optimised cull age	Section 8.7
Manure storage	Manure management in housing	Section 9.1
	Covered solid manure storage	Section 9.5
	Liquid slurry storage and anaerobic digestion	Section 9.4, 9.2
Soil emissions (air and water burdens)	Soil Nutrient Management Planning	Section 5.1
	Grass-clover swards	Section 7.3
	Trailing shoe/banded slurry application	Section 9.6 and 9.7
Feed production	Grazing management	Section 7.1 and 7.2
	Efficient silage production	Section 7.4
	Green procurement of feed	Section 8.5
Biodiversity burdens	Appropriate land use	Section 3.1, 3.3
	Habitat management	Section 3.4, 7.2
	Local breeds	Section 8.1
Resource consumption	Nutrient use efficiency	Section 3.2, 8.2
	Soil management	Section 3.3, 4.1, 4.4

2.4 Pig production

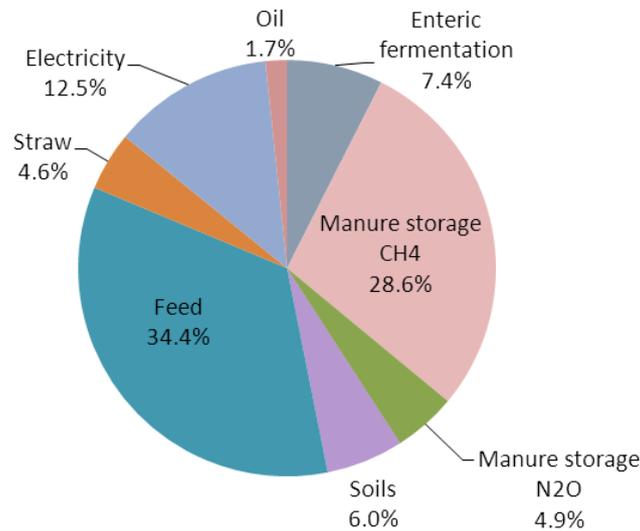
Environmental burdens of pork production are displayed in Table 2.10 for different types of system. Compared with beef and lamb production, pork production is associated with lower environmental burdens.

Table 2.10. Environmental burdens attributable to the production of one tonne of pig meat from alternative systems

Impacts and resources used	Non-organic	Organic	Heavier finishing	Indoor breeding	Outdoor breeding
Primary energy used, MJ	16,700	14,500	15,500	16,700	16,700
Global warming potential, kg CO ₂ e	6,360	5,640	6,080	6,420	6,330
Eutrophication potential, kg PO ₄ e	100	57	97	119	95
Acidification potential, kg SO ₂ e	395	129	391	507	362
Pesticides used, dose ha	8.8	0.0	8.2	8.6	8.8
Abiotic resource depletion, kg Sb e	35	33	33	40	33
Land use, ha	0.74	1.28	0.69	0.73	0.75
N losses					
NO ₃ -N, kg	48	71	43	40	51
NH ₃ -N, kg	98	40	98	119	91
N ₂ O-N, kg	6.4	6.8	5.9	6.1	6.5

Source: Williams et al. (2006)

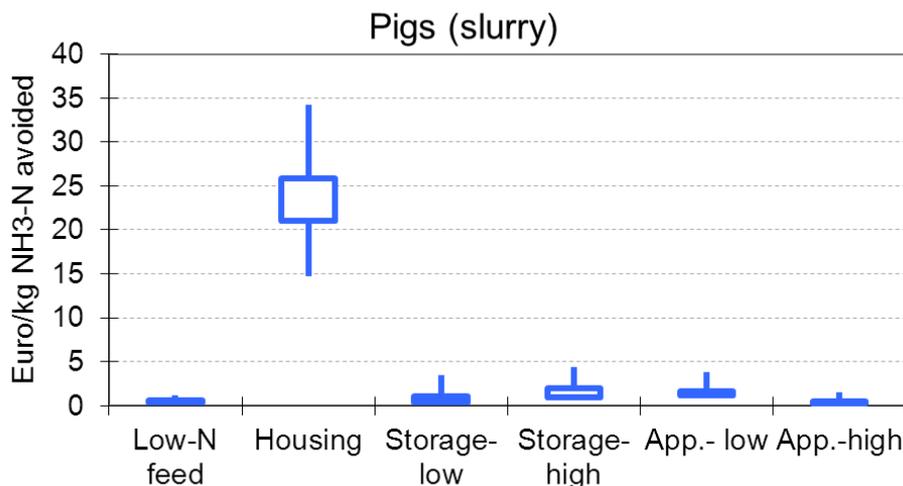
Figure 2.9 displays a breakdown of the main GHG emission sources for pig production, up to the farm gate, showing the importance of feed production and manure storage (mostly deep-bedding in the farms studied). Electricity use for heating, ventilation and air conditioning (HVAC) and lighting systems makes a significant (12.5%) contribution to the pig footprint. Soil direct N₂O emissions and indirect N₂O emissions via NH₃ volatilisation and NO₃ leaching make a comparatively small contribution to the carbon footprint, but are associated with significant eutrophication and acidification burdens.



Source: Footprints4Food (2013)

Figure 2.9. Breakdown of the carbon footprint of pig production across eight Welsh pig farms (average footprint = 4.5 kg CO₂e per kg liveweight)

Housing and storage management of manure also leads to considerable NH₃ emissions, the latter representing a low cost abatement opportunity (Figure 2.10).



NB: Bars display 25th to 75th percentile ranges, whilst lines display absolute range in GAINS values calculated across European countries. Excludes potential fertiliser replacement effects.

Source: Winiwarter et al. (2011), based on GAINS data

Figure 2.10. Range of European abatement costs for ammonia emissions from pig systems with liquid slurry storage

Most burdens from pork production arise up to the farm gate. Soil emissions may occur on neighbouring arable farms to which manures/slurries may be exported. Based on the environmental

burden sources for pork production referred to above, the most important BEMP techniques to reduce the overall burden of pork production are summarised in Table 2.11, below.

Table 2.11. Key BEMP measures to reduce the environmental burden of European pork production

Source	Key BEMP measures	Section
Enteric fermentation	Breeding for improved productivity	Section 8.1
	Maintaining animal health	Section 8.6
	Diet (feed conversion ratio)	section 8.4, 8.6
Manure storage	Manure management in housing	Section 9.1
	Storage	Section 9.3, 9.4, 9.5
	Anaerobic digestion	Section 9.2
Manure “disposal”	Efficient slurry application	Section 9.6, 9.7
Feed production	Green procurement of feed	Section 8.5
Resource consumption	Nutrient use efficiency	Section 3.2, 8.2
	Soil management	Section 3.3, 4.1, 4.4
	Energy management	Section 3.2, 3.5, 9.2

2.5 Poultry production

2.5.1 Broiler production

Table 2.12 displays the lifecycle environmental burdens arising from the production of one tonne of chicken meat from different types of poultry production system, from DEFRA (2008). Processing and transport make relatively minor contributions to life cycle environmental burdens (DEFRA, 2008).

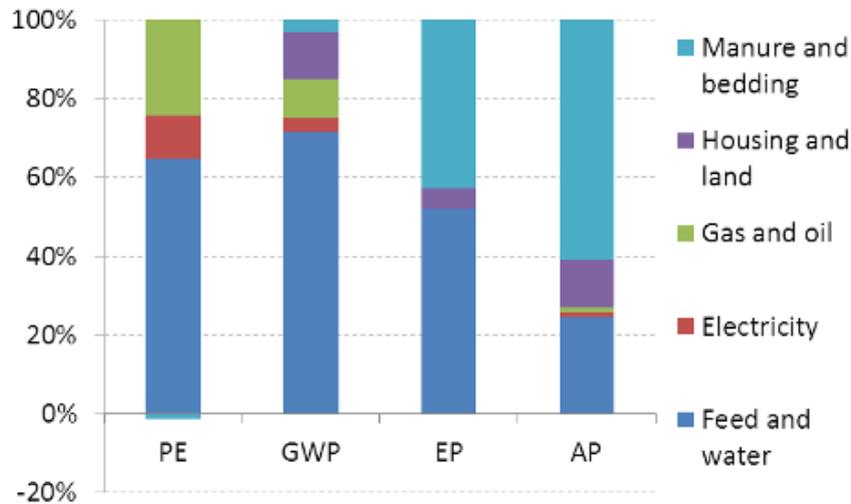
Table 2.12. Environmental burdens attributable to the production of one tonne of chicken meat in alternative broiler systems

Impacts and resources used	Non-organic	Organic	Free-range (non-organic)
Primary energy used, MJ	12,000	15,800	14,500
Global warming potential, kg CO ₂ e	4,570	6,680	5,480
Eutrophication potential, kg PO ₄ e	49	86	63
Acidification potential, kg SO ₂ e	173	264	230
Pesticides used, dose ha	7.7	0.6	8.8
Abiotic resource depletion, kg Sb e	29	99	75
Land use, ha	0.64	1.40	0.73
N losses			
NO ₃ -N, kg	30	75	37
NH ₃ -N, kg	40	60	53
N ₂ O-N, kg	6.3	9.3	7.6

Source: DEFRA (2008)

A subsequent study undertook further modelling based on these data, and reported the relative contributions of five main processes (Figure 2.11). Feed and water clearly dominate the GWP, PE and EP impact categories, reflecting the upstream burdens of soy and wheat production, whilst manure and bedding dominates the AP category, reflecting the high NH₃ emissions arising from broiler

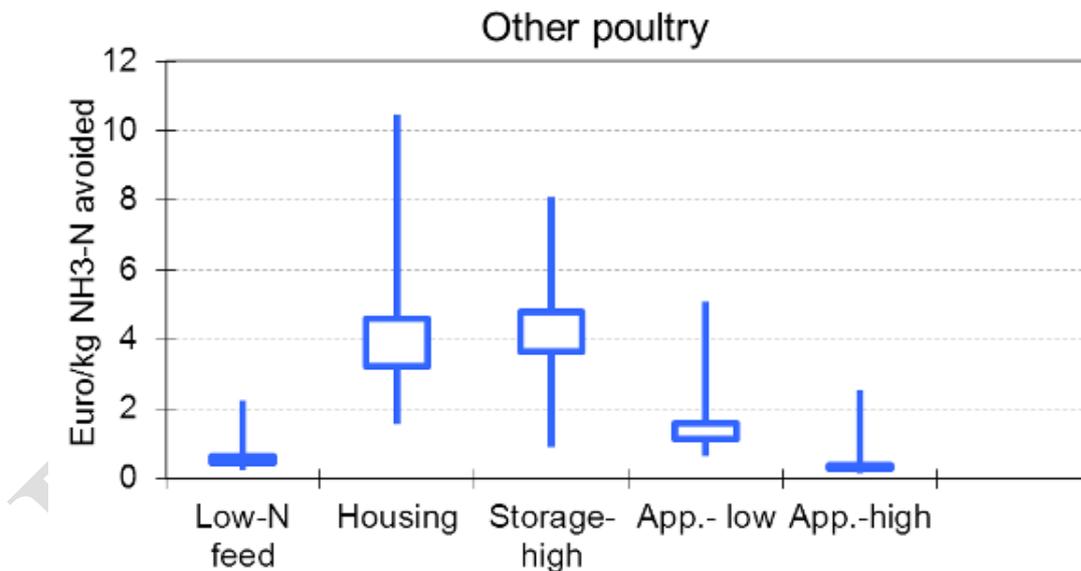
manure. Ammonia abatement costs are relatively low for broiler systems across feed, housing, manure storage and spreading measures (Figure 2.12).



Source: Based on data in Leinonen et al. (2012a)

Figure 2.11. Main sources of environmental burdens in broiler production

In fact, the feed and water contributions to GWP and EP referred to above, based on attributional LCA, could be under-estimates owing to large possible deforestation effects associated with soy-based feed produced in South America. This was highlighted as a risk factor for poultry production by DEFRA (2008), and also has large environmental implications for biodiversity loss.



NB: Bars display 25th to 75th percentile ranges, whilst lines display absolute range in GAINS values calculated across European countries. Excludes potential fertiliser replacement effects.

Source: Winiwarter et al. (2011) based on GAINS data

Figure 2.12. Range of European abatement costs for ammonia emissions from broiler systems

Based on the environmental burden sources for chicken meat production referred to above, the most important BEMP techniques to reduce the overall burden of broiler systems are summarised in

Table 2.13.

Table 2.13. Key BEMP measures to reduce the environmental burden of European broiler production

Source	Key BEMP measures	Section
*Feed production	Breeding for improved productivity	Section 8.1
	Maintaining animal health	Section 8.6
	Green procurement of feed	Section 8.5
Manure storage	Manure management in housing	Section 9.1
	Manure storage	Section 9.3, 9.4, 9.5
	Anaerobic digestion	Section 9.2
Soil emissions (air and water burdens)	Field and farm nutrient budgeting	Section 5.1, 8.2
	Dietary optimisation of N intake (excretion)	Section 8.3
	Precision fertiliser/manure application	Section 5.3
	Injection/banded slurry application	Section 9.6, 9.7
Resource consumption	Resource management	Section 3.2, 3.5, 9.2
* Primary control point to drive improvement		

2.5.2 Egg production

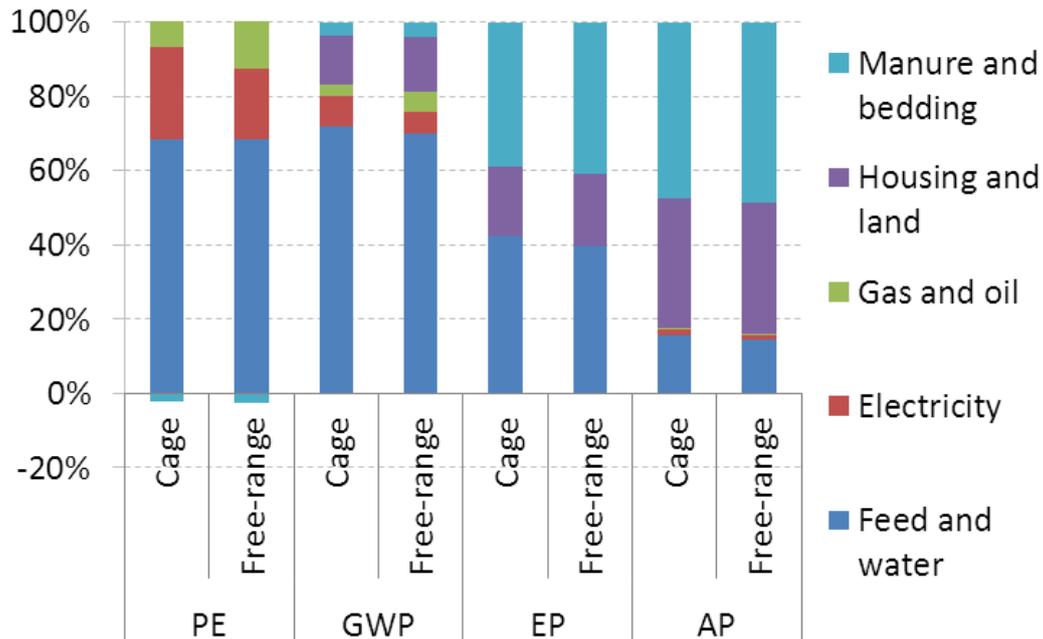
Table 2.11 displays the lifecycle environmental burdens arising from the production of one tonne of chicken meat from different types of poultry production system, from DEFRA (2008).

Table 2.14 Environmental burdens attributable to the production of one tonne of eggs (20,000 eggs) in alternative systems

Impacts & resources used	Non-organic	Organic	100% cage, non-organic	Free-range, non-organic
Primary energy used, MJ	14,100	16,100	13,600	15,400
Global warming potential, CO ₂ e	5,530	7,000	5,250	6,180
Eutrophication potential, kg PO ₄ e	77	102	75	80
Acidification potential, kg SO ₂ e	306	344	300	312
Pesticides used, dose ha	7.8	0.1	7.2	8.7
Abiotic resource depletion, kg Sb e	38	43	39	35
Land use, ha	0.66	1.48	0.63	0.78
N losses				
NO ₃ -N, kg	36	78	35	39
NH ₃ -N, kg	79	88	77	81
N ₂ O-N, kg	7.0	9.0	6.6	7.9
<i>Source: DEFRA (2008).</i>				

A subsequent study undertook further modelling based on these data, and reported the relative contributions of five main processes for cage and free-range systems (Figure 2.13). As for broiler production, feed and water clearly dominate the GWP, PE and EP impact categories, reflecting the upstream burdens of soy and wheat production, whilst “manure and bedding” and “housing and land” dominate the AP category, reflecting the high NH₃ emissions arising from chicken manure. Ammonia

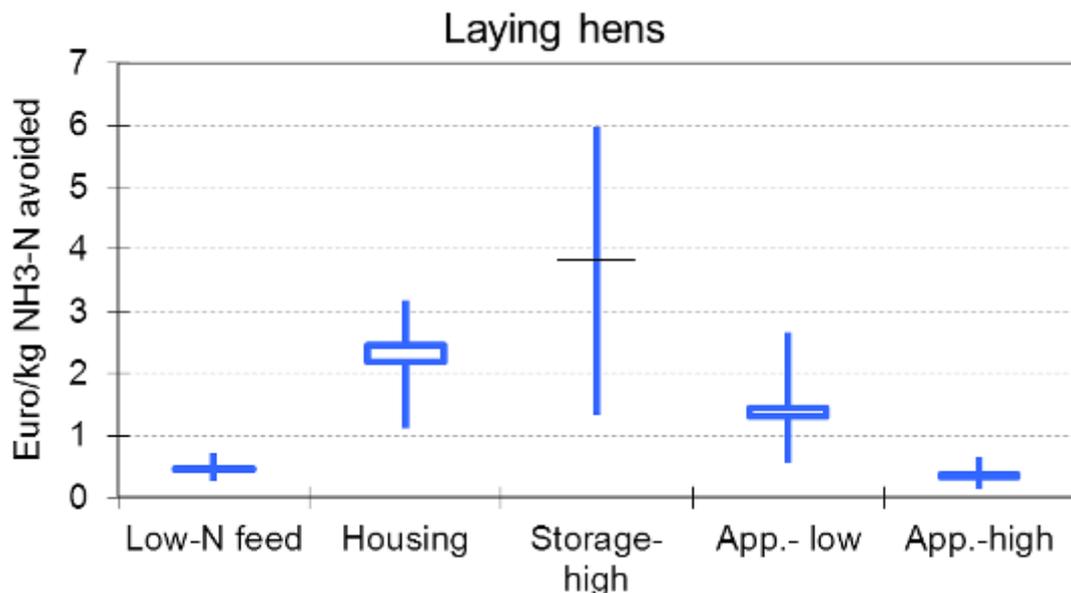
abatement costs are relatively low for egg-laying hen systems across feed, housing, manure storage and spreading measures (Figure 2.14).



Source: Based on data in Leinonen et al. (2012b)

Figure 2.13. Main sources of environmental burdens in egg production

As for the broiler systems, processing, transport and packaging make minor contributions to the lifecycle environmental burdens, but the feed contribution to GWP and EP, and the biodiversity impact of egg production, could be considerably higher if land use change associated with soy production in South America is taken into account (DEFRA, 2008).



NB: Bars display 25th to 75th percentile ranges, whilst lines display absolute range in GAINS values calculated across European countries. Excludes potential fertiliser replacement effects.

Source: Winiwarter et al. (2011), based on GAINS data

Figure 2.14. Range of European abatement costs for ammonia emissions from egg-laying hen systems

Based on the environmental burden sources for egg production referred to above, the most important BEMP techniques to reduce the overall burden of broiler systems are summarised in Table 2.15, below.

Table 2.15. Key BEMP measures to reduce the environmental burden of European egg production

Source	Key BEMP measures	Section
*Feed production	Breeding for improved productivity	Section 8.1
	Maintaining animal health	Section 8.6
	Green procurement of feed	Section 8.5
Manure storage	Manure management in housing	Section 9.1
	Manure storage	Section 9.3, 9.4, 9.5
	Anaerobic digestion	Section 9.2
Soil emissions (air and water burdens)	Field and farm nutrient budgeting	Section 5.1, 8.2
	Dietary optimisation of N intake (excretion)	Section 8.3
	Precision fertiliser/manure application	Section 5.3
	Injection/banded slurry application	Section 9.6, 9.7
Resource consumption	Resource management	Section 3.2, 3.5, 9.2
*Primary control point to drive improvement		

2.6 Grain production

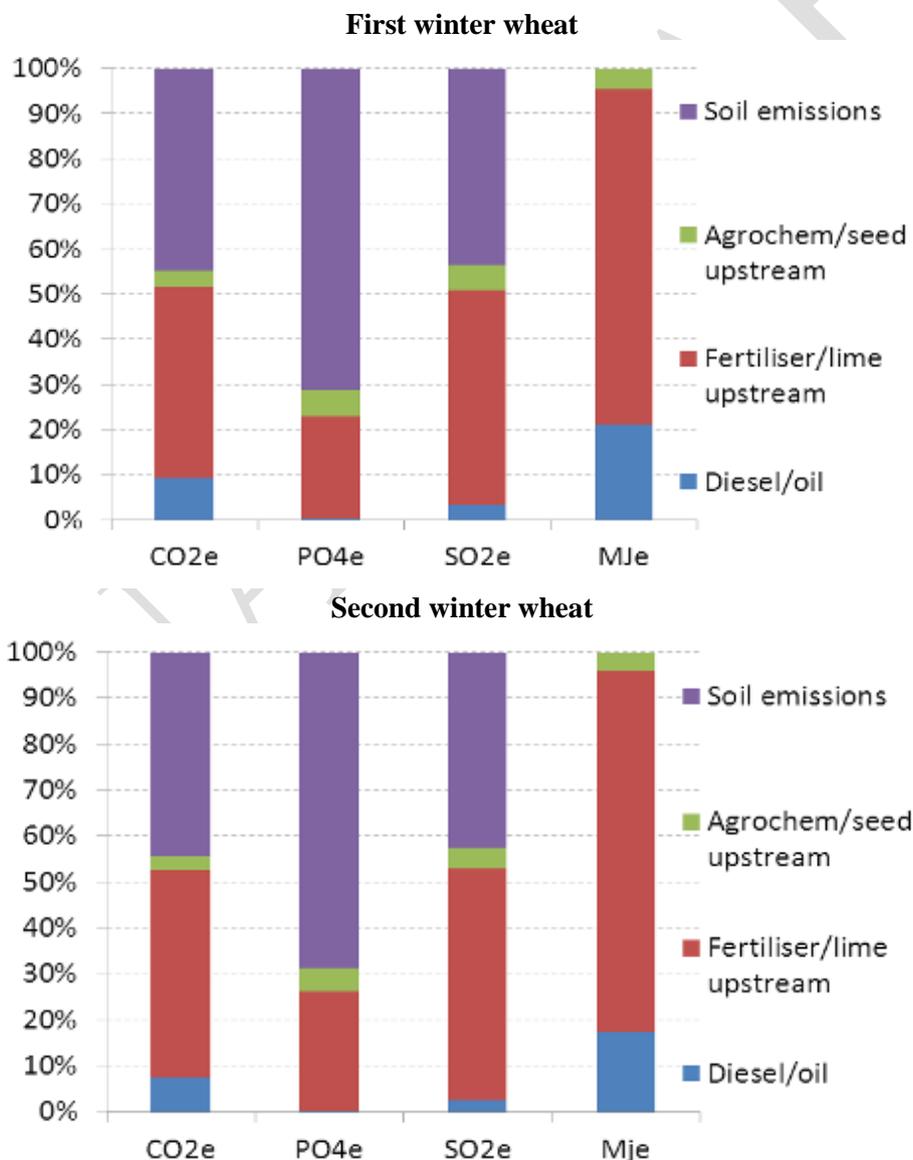
Table 2.16 summarises the environmental burdens for winter wheat and spring barley grain production, up to the farm gate, based on the Bangor University agricultural LCA tool, and representing efficient farm management with no organic fertiliser inputs. Owing to high demand, winter wheat is often grown twice in sequence within crop rotations, with lower yields and higher fertiliser requirements for the second crop (DEFRA, 2010). Therefore, the environmental burden of winter wheat can vary significantly depending on its position within a rotation (Table 2.16). Data presented are for UK yields. The UK and France have particularly high yields of winter wheat compared with other countries in the world (Fischer et al., 2009), so it is possible that the burdens reported below, expressed per tonne grain (at 85% dry matter), are lower than for other European member states.

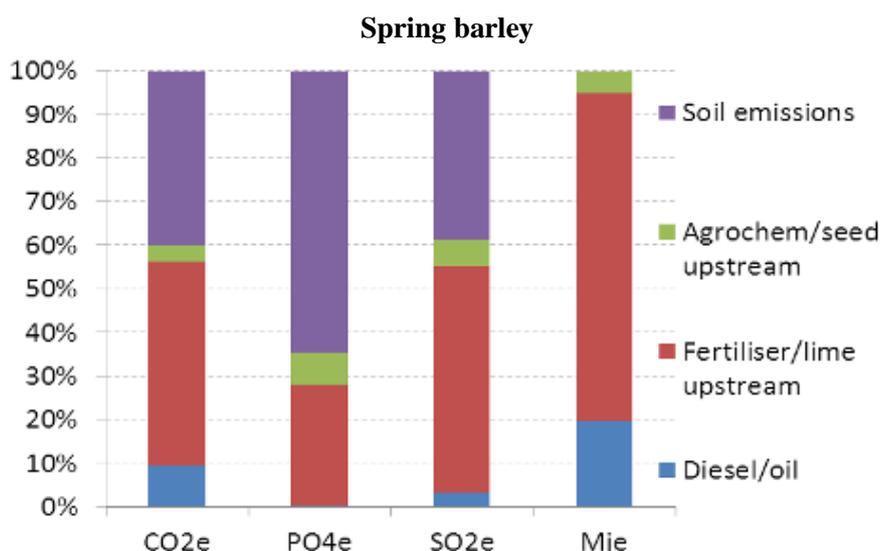
Table 2.16. Life cycle environmental burdens arising from the cultivation of one tonne of grains, up to the farm gate

	GWP	EP	AP	ARDP	
	Kg CO ₂ e	Kg PO ₄ e	Kg SO ₂ e	MJe	Kg Sb e
1st winter wheat	284	1.6	1.3	1662	0.80
2nd winter wheat	345	2.1	1.7	2059	0.99
Spring barley	301	2.1	1.6	1989	0.96
NB: 85% dry matter grains, total cultivation burdens allocated according to exported energy in grains and straw assuming two thirds harvestable straw exported.					
<i>Source: Bangor University (2013)</i>					

The relative contributions of different sources to overall environmental burdens are shown in Figure 2.15. The manufacture and application of mineral N fertiliser dominates GWP, EP and AP for the three types of grain-rotation. Diesel consumption contributes about 10% to GWP burdens and 20% to

resource depletion. Where organic fertilisers, such as animal manures, are used, burdens attributable to upstream fertiliser manufacture will be lower whilst soil emissions (especially NH₃) will be higher. Wheat may require irrigation in some circumstances, especially in southern European member states, but overall wheat production is not responsible for a major share of blue water consumption in the EU28 (Vanham and Bidoglio, 2013). However, a major environmental hotspots for tillage agriculture not reflected in the above data is soil erosion and degradation. Where wheat is cultivated on land recently cleared of grass or woodland, or on peat soils, large soil emissions of CO₂ and N₂O will be incurred, and environmental burdens will be considerably greater than listed in Table 2.16. Compared with livestock production, the relative contributions of transport and processing are likely to be higher for final food products derived from grains, reflecting the lower burdens of farm production (up to the farm gate) for grains and the wide range of processing operations undertaken throughout production chains for products including pasta and bread, including drying, storage, milling, mixing, baking, etc. Williams et al. (2010) calculated lifecycle PE of 2.4 GJ, GWP of 7 t CO₂e, EP of 3.1 t PO₄e and AP of 3.3 kg SO₂e per tonne processed (dried, stored and transported) bread wheat. Environmental burdens associated with food and drink processing are addressed in a background report being prepared for the JRC on that topic (EC, 2013).





Source: Bangor University (2013)

Figure 2.15. Contributions of four major source categories to environmental burdens of grain cultivation, based on LCA up to the farm gate

Based on the environmental burden sources for grain production referred to above, the most important BEMP techniques to reduce the overall burden of grain cultivation are summarised in Table 2.17, below.

Table 2.17. Key BEMP measures to reduce the environmental burden of European grain production

Source	Key BEMP measures	Section
Agro-chemicals and upstream impacts	Select reduced impact synthetic fertilisers	Section 5.4
	Crop rotation and IPM techniques	Section 11.1
	Crop protection product selection	Section 11.2
Soil emissions (air and water burdens)	Restrict tillage to appropriate areas	Section 6.1
	Soil Nutrient Management Planning	Section 4.1, 5.1
	Optimised crop rotation	Section 5.2, 5.4
	Sustainable organic matter amendments	Section 4.2
	Soil drainage management	Section 4.3, 4.4
	Cover crops	Section 6.5
	Low-impact tillage operations	Section 6.3
Biodiversity burdens	Precision fertiliser/manure application	Section 5.3, 9.6, 9.7
	Appropriate land use	Section 3.1, 3.3
Resource consumption	Habitat management	Section 3.4
	Nutrient use efficiency	Section 3.2, 5.1
	Soil management	Section 3.3, 4.1, 4.4
	Energy management	Section 3.2, 3.5
	Irrigation management	Section 10.1, 10.2

2.7 Potato production

Table 2.18 summarises the environmental burden attributable to the cultivation and storage of one tonne (wet weight) of maincrop potatoes. In terms of GWP, approximately 27% of pre farm-gate burden is attributable to fertiliser manufacture, 33% to N₂O emissions following fertiliser-N application, and 20% to diesel consumed for field operations (DEFRA, 2008).

Table 2.18. Environmental burdens attributable to the production, storage and transport of 1 tonne of potatoes

PE (GJ)	GWP (kg CO ₂ e)	EP (kg PO ₄ e)	AP (kg SO ₂ e)	ARDP (kg Sb e)	Pesticides (does/ha)	Land area (ha)	Irrigation (m ³)
1.4	200	1.0	0.8	0.4	0.4	0.03	21

Source: Williams et al. (2010)

Maincrop potatoes have significantly lower burdens per tonne than early varieties. DEFRA (2008) refer to the considerably greater water, energy and GWP burdens of early potatoes imported to the UK from Israel, owing to lower yields and high irrigation requirements. The storage and cooling of maincrop potatoes to ensure a year-around supply requires as much energy as the initial cultivation, accounting for between 26 and 43% of total primary energy demand in the DEFRA (2008) study. Over the entire value chain of potatoes, cooking (by final consumers, food processors or other intermediaries) makes a large contribution to PE and GWP burdens, but is not readily influenced by the crop and animal production sector. Based on the environmental burden sources for grain production referred to above, the most important BEMP techniques to reduce the overall burden of potato cultivation are summarised in Table 2.19, below.

Table 2.19. Key BEMP measures to reduce the environmental burden of European potato production

Source	Key BEMP measures	Section
Agro-chemicals and upstream impacts	Select reduced impact synthetic fertilisers	Section 5.4
	Optimising and reducing the use of crop protection products	Section 11.1
	Crop protection product selection	Section 11.2
Soil emissions (air and water burdens)	Restrict tillage to appropriate areas	Section 6.1
	Soil Nutrient Management Planning	Section 4.1, 5.1
	Optimised crop rotation	Section 5.2, 5.4
	Sustainable organic matter amendments	Section 4.2
	Soil drainage management	Section 4.3, 4.4
	Cover crops	Section 6.5
	Low-impact tillage operations	Section 6.3
Biodiversity burdens	Precision fertiliser/manure application	Section 5.3, 9.6, 9.7
	Appropriate land use	Section 3.1, 3.3
Resource consumption	Habitat management	Section 3.4
	Nutrient use efficiency	Section 3.2, 5.1
	Soil management	Section 3.3, 4.1, 4.4
	Energy management	Section 3.2, 3.5
	Irrigation management	Section 10.1, 10.2

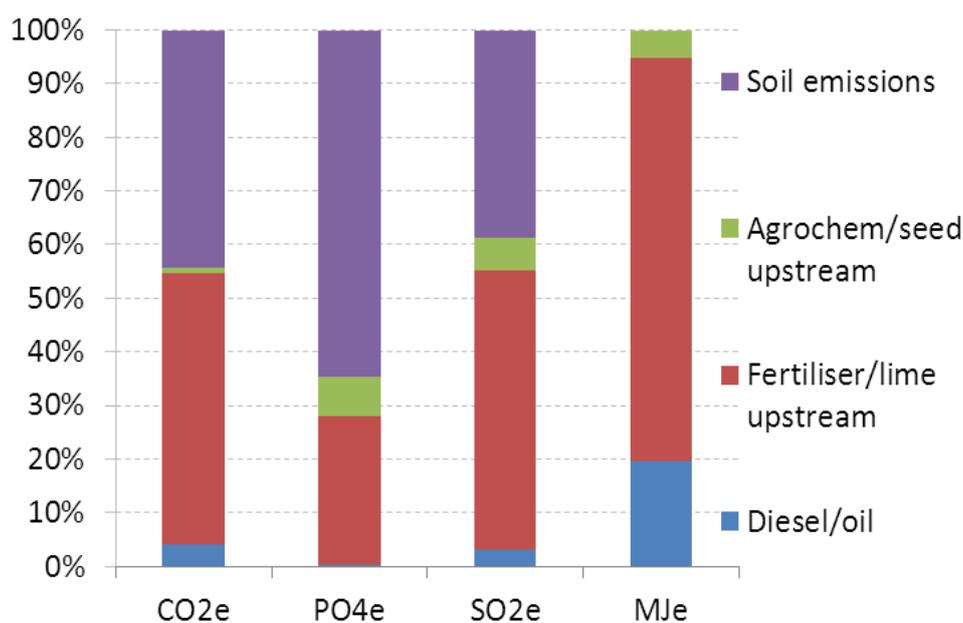
2.8 Oil seed rape production

Table 2.20 summarises the life cycle environmental burdens arising from the cultivation of one tonne of oil seed rape seeds, to the farm gate.

Table 2.20. Life cycle environmental burdens arising from the cultivation of one tonne of grains, up to the farm gate

	GWP	EP	AP	ARDP	
	Kg CO₂e	Kg PO₄e	Kg SO₂e	MJe	Kg Sb e
Oil seed rape	870	2.1	1.6	1989	0.96
NB: 85% dry matter grains, total cultivation burden allocated to seeds (assumes no straw exported)					
Source: Bangor University (2013)					

The contributions of major sources to each of the four impact categories considered are summarised in Figure 2.16. Similarly to grain production, the manufacture and application of fertiliser-N are the main drivers of environmental burdens. Upstream fertiliser manufacture emissions will be lower, and soil emissions higher, where organic fertilisers (e.g. animal manures) are used.



Source: Bangor University (2013).

Figure 2.16. Contributions of four major source categories to environmental burdens of oil seed rape cultivation, based on LCA up to the farm gate

The processing of rape seed can make significant contributions to the different impact categories, especially PE and GWP. Based on Biograce (2013), the ARDP and GWP burdens of seed processing are approximately 3,200 MJ e and 193 kg CO₂e, respectively.

Based on the environmental burden sources for oil seed rape production referred to above, the most important BEMP techniques to reduce the overall burden of oil seed rape cultivation are summarised in Table 2.21, below.

Table 2.21. Key BEMP measures to reduce the environmental burden of European oil seed rape production

Source	Key BEMP measures	Section
Agro-chemicals and upstream impacts	Select reduced impact synthetic fertilisers	Section 5.4
	Optimising and reducing the use of crop protection products	Section 11.1
	Crop protection product selection	Section 11.2
Soil emissions (air and water burdens)	Restrict tillage to appropriate areas	Section 6.1
	Soil Nutrient Management Planning	Section 4.1, 5.1
	Optimised crop rotation	Section 5.2, 5.4
	Sustainable organic matter amendments	Section 4.2
	Soil drainage management	Section 4.3, 4.4
	Cover crops	Section 6.5
	Low-impact tillage operations	Section 6.3
Biodiversity burdens	Precision fertiliser/manure application	Section 5.3, 9.6, 9.7
	Appropriate land use	Section 3.1, 3.3
Resource consumption	Habitat management	Section 3.4
	Nutrient use efficiency	Section 3.2, 5.1
	Soil management	Section 3.3, 4.1, 4.4
	Energy management	Section 3.2, 3.5
	Irrigation management	Section 10.1, 10.2

2.9 Horticultural production

2.9.1 Imported versus local

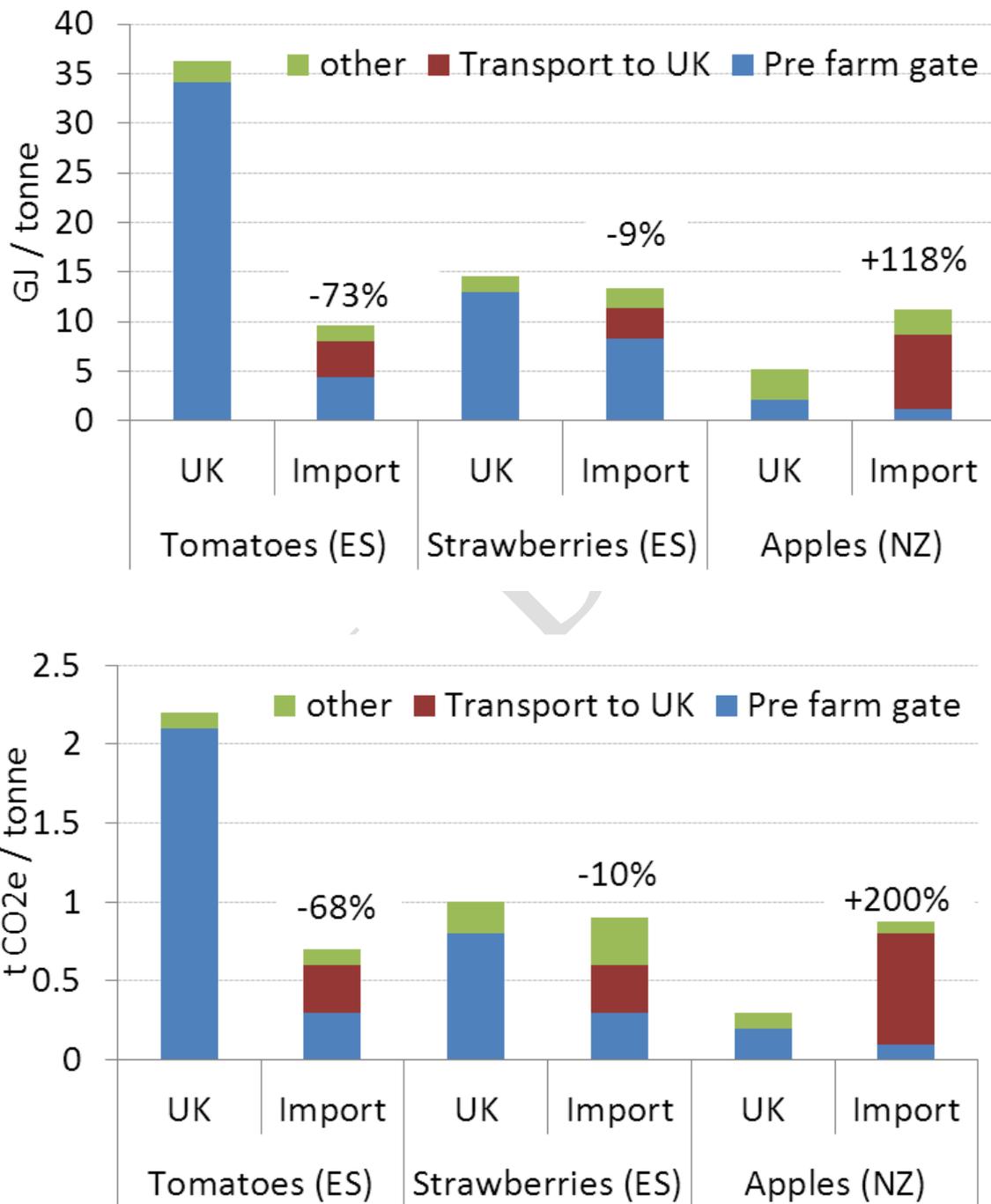
This section addresses environmental burdens arising along the supply chains of three major horticultural crops:

- Tomatoes
- Strawberries
- Apples

From a life cycle perspective in Northern European member states, it is pertinent to consider whether these products are more efficiently produced locally in winter with heated glasshouses or imported from warmer climates. DEFRA (2008) compared the environmental burdens of these products grown year-round in the UK or imported from major source countries, up to the point of UK retail distribution centres. The results are summarised in Figure 2.17.

Energy demand, resource depletion and GHG burdens for tomatoes and strawberries are typically dominated by fossil-fuel-heating of glasshouses in northern Europe and transport from southern Europe. Meanwhile, for apples, these burdens are typically dominated by chilled storage and transport. Figure 2.17. shows that Spanish tomatoes (standard variety, sold loose) and strawberries imported to the UK require 73% and 9% less primary energy consumption, and result in 68% and 10% less GHG emissions, than tomatoes and strawberries cultivated in heated glasshouses. However, for apples, the fuel oil consumed for long-distance sea transport considerably outweighs more efficient pre farm gate cultivation of apples in New Zealand, to result in a 118% higher primary energy demand, and 200%

greater carbon footprint, per tonne New Zealand apples than per tonne UK apples (up to the point of the UK retail distribution centre). DEFRA (2008) reported that the carbon footprint of UK heat-glasshouse tomatoes (2.24 t CO₂ per t) is similar to estimates reported by Biel et al. (2006) for glasshouse production in Sweden (2.72 t CO₂ per t), Denmark (3.65 t CO₂ per t) and the Netherlands (2.91 t CO₂ per t). Abiotic resource depletion is 70 % greater for UK production owing to the resources needed to build permanent glass houses (DEFRA, 2008).

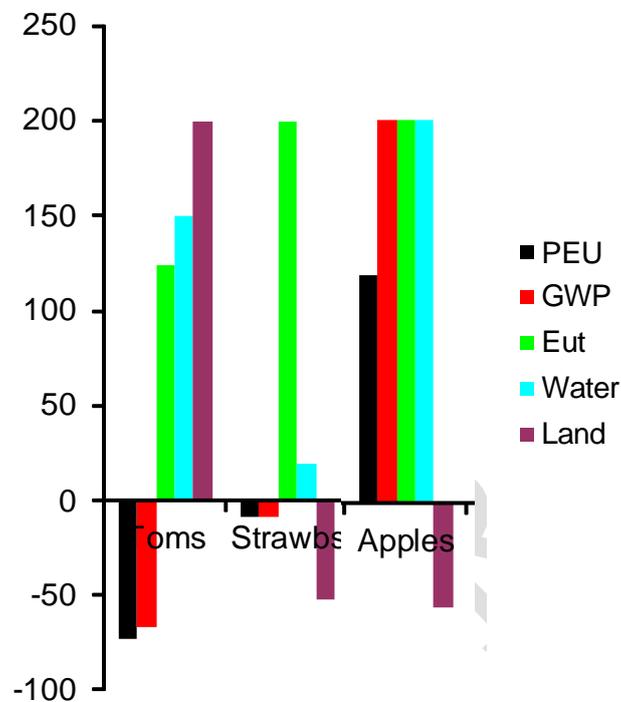


NB: Burdens calculated up to the retail distribution centre (distribution and consumer stages the same for UK and imported products).

Source: Based on data in DEFRA (2008).

Figure 2.17. Primary energy demand and GHG emissions per tonne tomatoes, strawberries and apples produced in the UK or in Spain (New Zealand for apples)

Figure 2.18 shows that the comparative environmental burden for UK versus imported products differs considerably across impact categories considered. Notably, whilst primary energy demand and GHG emissions are lower for tomatoes and strawberries imported from Spain, eutrophication and consumption of water and demand for land are all higher for imported Spanish products.



NB: Environmental burdens = primary energy use, global warming potential, Eutrophication potential, water consumption and land demand. Values capped at 200%.
 Source: DEFRA (2008).

Figure 2.18. Percentage difference in environmental burdens arising up to the UK retail distribution centre, for tomatoes, strawberries and apples produced in the UK or in Spain (New Zealand for apples)

The human- and eco- toxicity burdens of Spanish tomato and strawberry production is likely to be considerably higher than for UK production owing to the much greater use of pesticides in Spanish production: up to 7 times higher (DEFRA, 2008).

2.9.2 Tomatoes

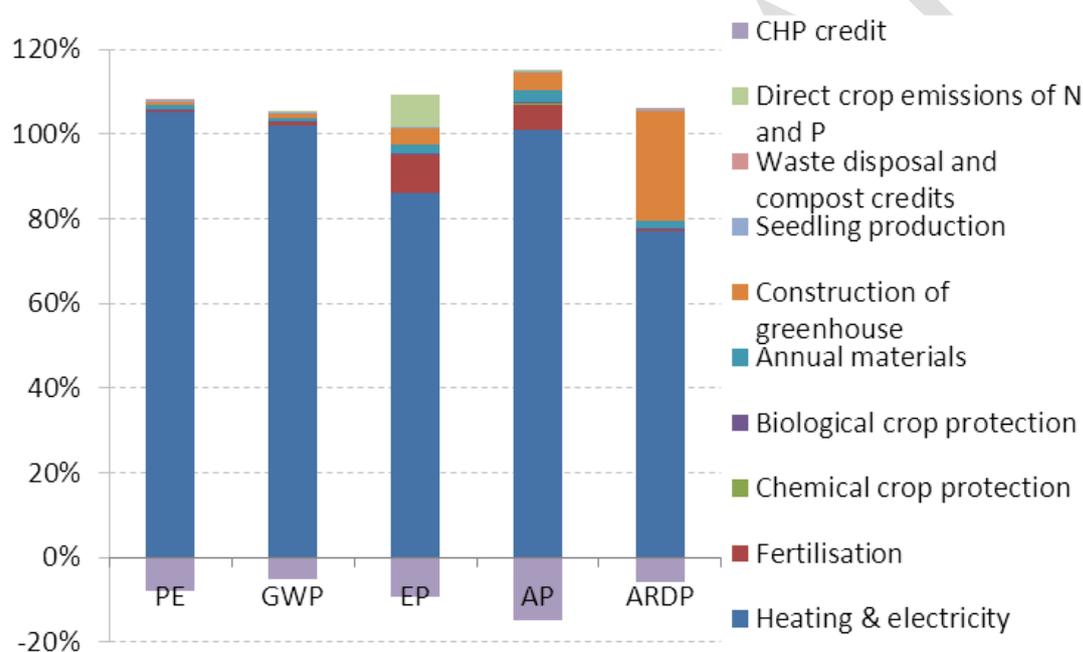
The environmental burdens associated with producing, storing and transporting one kg of tomatoes up to the point of UK retail distribution centres are summarised for UK- and Spanish- grown tomatoes in Table 2.22. Cold storage of tomatoes gives rise to ozone depletion via refrigerant leakage emissions, in addition to PE and GWP burdens.

Figure 2.19 shows the relative contributions of different processes to five major environmental impact category burdens for tomato production in glasshouses heated with combined heat and power (CHP) units. The dominance of CHP heating as a source of environmental burdens for tomato production in northern Europe is clear.

Table 2.22. Environmental burdens attributable to the production, storage and transport (to UK retail distribution centres) of 1 kg of UK and Spanish tomatoes

Burden	UK tomatoes	Imported Spanish tomatoes
Primary energy used (MJ)	36.2	9.6
Global warming potential, kg CO ₂ e	2.24	0.74
Eutrophication potential, kg PO ₄ e	0.0002	0.00005
Acidification potential, kg SO ₂	0.0024	0.0041
Ozone potential depletion, g CFC-11 e	0.0005	0.0008
Pesticides used, kg active ingredient	0.0003	0.0022
Abiotic resource depletion, kg Sb e	0.0182	0.0135
Land (m ²)	0.0185	0.089
Irrigation Water (L)	24	36
Proportion of renewable primary energy, %	1	5

Source: DEFRA (2008).



Source: Based on data from DEFRA (2008).

Figure 2.19. Contributions of various source categories to environmental burdens of tomato production in glass houses heated with CHP units

Horticultural production in semi-arid southern Europe, especially southern Spain, is highly dependent on irrigation, leading to environmental impacts such as soil salination, deterioration of aquifer water quality and water stress. The authors of the DEFRA (2008) report refer to the following environmental hotspots for tomato production in southern Spain:

eutrophication and salinisation of groundwater

- water stress, in relation to high regional demand from other sectors such as tourism and leisure activities
- energy and resource depletion associated with increasing reliance on seawater desalination to meet water requirements.

Some additional “hotspot” impacts for Spanish strawberry production are referred to in the next section, and are also relevant for tomato production.

Based on the above information, the most important BEMP techniques in this report that can reduce the environmental burdens of horticultural tomato production are listed in Table 2.23, below.

Table 2.23. Key BEMP measures to reduce the environmental burden of European tomato production

Source	Key BEMP measures	Section
Agro-chemicals and upstream impacts	Nutrient management planning	Section 5.1
	Select reduced impact synthetic fertilisers	Section 5.4
	Optimising and reducing the use of crop protection products	Section 11.1
	Crop protection product selection	Section 11.2
Energy	Energy management	Section 3.2, 3.5, 12.2
	Energy efficiency in horticulture	Section 12.2
Irrigation	Water management	Section 10.1, 10.2, 12.3
Waste management	Waste management in horticulture	Section 3.2, 3.6

2.9.3 Strawberries

The environmental burdens of strawberry production in polytunnels are summarised in Table 2.24, and are generally lower than for tomato production on a weight-basis because strawberries are seasonally produced using only natural solar heating (in most cases). The differences are not as great between UK and Spanish production and transport, compared with tomatoes. Spanish production and transport to the UK results in lower PE, GWP, AP, ozone-depletion potential and ARDP burdens, amongst others, but considerably higher EP (sandy soils) and PM₁₀ burdens.

Table 2.24. Environmental burdens attributable to the production, storage and transport (to UK retail distribution centres) of 1 kg of UK and Spanish strawberries

Burden	UK			Spain		
	Farm	Storage-transport	Total	Farm	Storage-transport	Total
Primary energy used, GJ	12.9	1.6	14.6	8.3	5.1	13.3
GWP, t CO ₂ e	0.85	0.14	0.99	0.35	0.56	0.90
Eutrophication potential, kg PO ₄ e	2.5	0.1	2.6	14.9	0.4	15.3
Acidification potential, kg SO ₂ e	6.5	1.3	7.7	3.9	3.2	7.1
Ozone potential depletion, g CFC-11e	3.0	-	3.0	1.5	-	1.5
Pesticides used, kg a.i.	1.1	NA	1.1	0.4	-	0.4
Abiotic resource use, kg Sb e	12.9	2.0	14.9	3.7	3.0	6.7
Land, ha	0.054	-	0.054	0.026	-	0.026
Irrigation water, m ³	108	-	108	128	-	128
PM ₁₀ , kg	NA	0.08	0.08	NA	0.22	0.22
Photo-chemical oxidation potential, kg ethylene e	0.59	0.02	0.61	0.16	0.08	0.24
Non-methane Volatile Organic Carbon, kg C e	1.75	0.16	1.91	0.66	0.50	1.16
Proportion of renewable primary energy, %	6	1	6	7	2	5

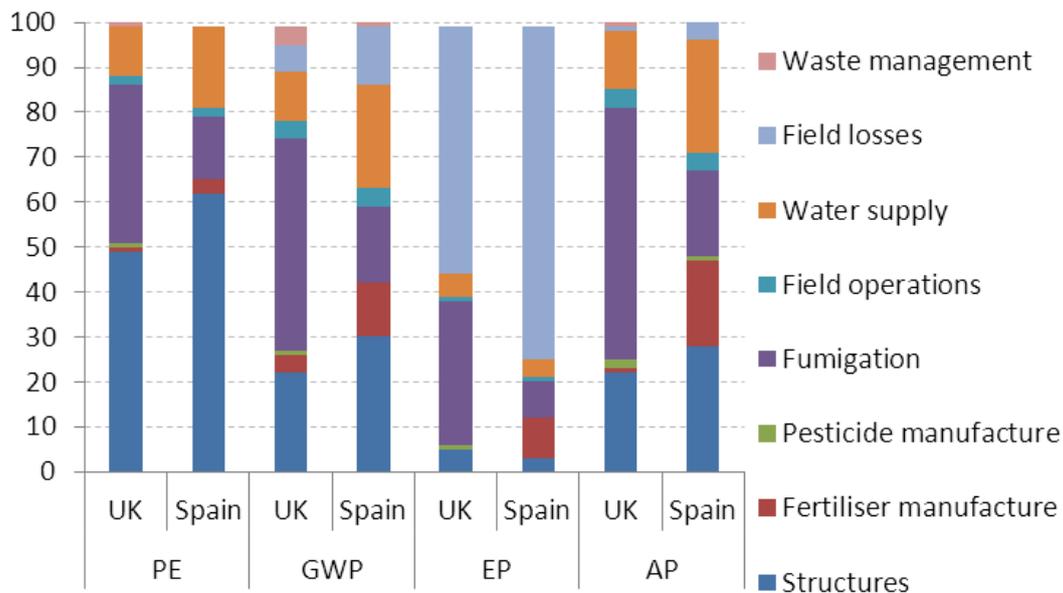
Source: DEFRA (2008).

The relative contributions of major processes to environmental burdens for UK and Spanish grown strawberries are shown in Figure 2.20, below. Hotspot processes include:

- construction of polytunnels in the UK (PE)
- fumigation (high PE and GWP from manufacture of chemicals)
- field losses of N (EP)
- water supply (GWP and AP in Spain).

Life cycle impact assessment results often fail to highlight local environmental stresses that may arise from practices in particular locations. Some geographical hotspot impacts of strawberry production in the Huelva region of SW Spain were documented in DEFRA (2008), based on past bad practice:

- Past N application rates up to 1000 kg N/ha/yr (now 250 kg N/ha/yr)
- Past irrigation rates of 7000 m³/ha/yr (now 4600 m³/ha/yr)
- Groundwater nitrate-N concentrations were measured up to 70-110 mg/l.



Source: Based on data in DEFRA (2008).

Figure 2.20. Contributions of various source categories to environmental burdens of strawberry production in polytunnels

Intensive use of water for horticulture is contributing to a lowering of the water table, making water more energy intensive to extract. DEFRA (2008) refer to a WWF report that highlights concerns over horticulture in the Guadalquivir area (Almonte, Rociana, Lucena, Bonares) where all irrigation water comes from underground aquifers, often via boreholes. In some areas desalination by reverse osmosis is cheaper than pumping from a great depth.

In the UK, water sourcing for horticulture is more sustainable but drier areas of the south and east face water stress. Although gutter systems have been developed, rainwater harvesting from polytunnels is not widely practiced, so that these protected crops require more irrigation water than outdoor production (DEFRA, 2008).

Based on the above information, the most important BEMP techniques in this report that can reduce the environmental burdens of horticultural strawberry production are listed in Table 2.25, below.

Table 2.25. Key BEMP measures to reduce the environmental burden of European strawberry production

Source	Key BEMP measures	Section
Agro-chemicals and upstream impacts	Nutrient management planning	Section 5.1
	Select reduced impact synthetic fertilisers	Section 5.4
	Optimising and reducing the use of crop protection products	Section 11.1
	Crop protection product selection	Section 11.2
Energy	Energy management	Section 3.2, 3.5, 12.2
	Energy efficiency in horticulture	Section 12.2
Irrigation	Water management	Section 10.1, 10.2, 12.3
Waste management	Waste management in horticulture	Section 3.2, 3.6

2.9.4 Apples

The environmental burdens arising from the production, storage and transport of one tonne of apples, up to UK retail distribution centres, for apples produced and transported immediately from New Zealand, and apples grown and stored for five months in the UK, are summarised in Table 2.26. Even accounting for storage energy and GWP burdens, producing and storing apples in the UK is more efficient than transporting apples from New Zealand despite higher yields per ha in New Zealand and a lower ozone depletion potential burden for New Zealand apples.

Apple orchard yields vary considerably depending on the management system and local conditions. The study that generated the results below used an average New Zealand yield of 63 t/ha and an average UK yield of 30.5 t/ha (DEFRA, 2008). The study notes that annual variations can be owing to factors such as frost damage.

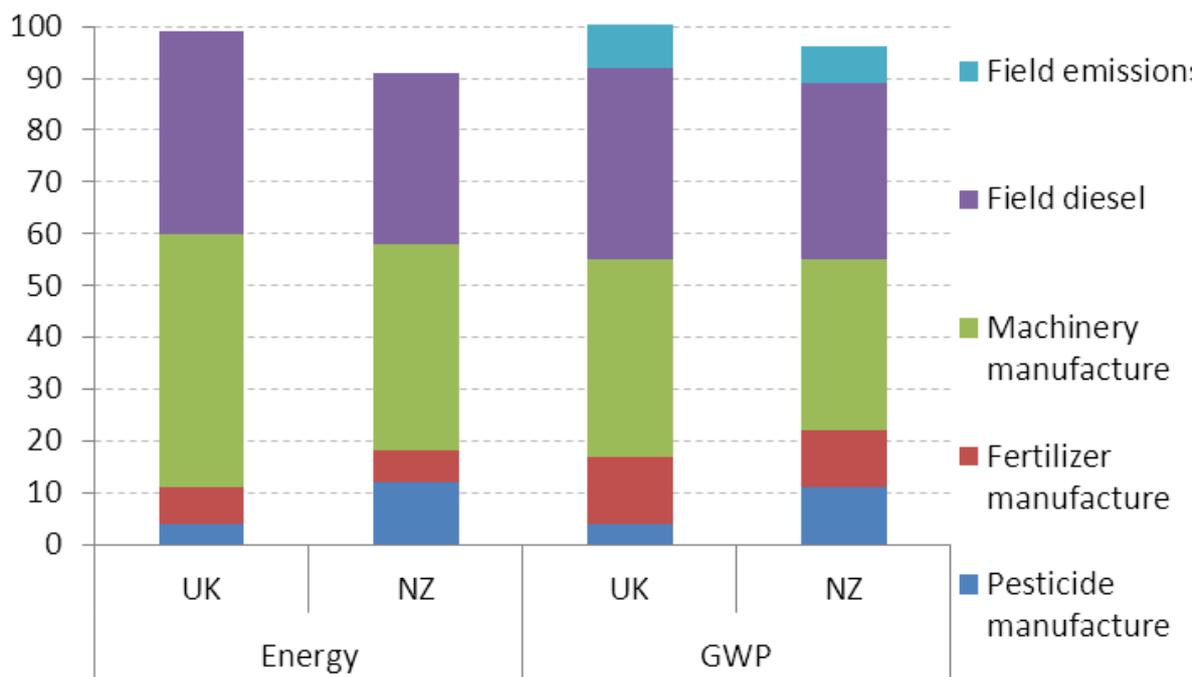
Table 2.26. Environmental burdens attributable to the production, storage and transport (to UK retail distribution centres) of 1 tonne of UK and New Zealand apples (includes 5 months storage for UK apples)

Burden	UK			New Zealand		
	Farm	Storage, transport	Total	Farm	Storage, transport	Total
Primary energy used, GJ	2.1	3.0	5.1	1.2	10.0	11.2
Global warming potential, t CO ₂ e	0.16	0.19	0.35	0.08	0.78	0.87
Eutrophication potential, kg PO ₄ e	0.3	0.1	0.4	0.1	3.6	3.7
Acidification potential, kg SO ₂ e	0.6	1.1	1.8	0.3	23.7	24.1
Ozone potential depletion, g CFC-11e	0.4	-	0.4	0.2	-	0.2
Pesticides used, kg a.i.	0.6	-	0.6	0.3	-	0.3
Abiotic resource depletion, kg Sb e	0.8	1.0	1.8	0.5	5.1	5.5
Land ha/t	0.038	-	0.038	0.017	-	0.017
Water, m ³	-	<0.01	<0.01	NA	<0.01	<0.01
Irrigation water, m ³	10	-	10	88	-	88
PM ₁₀ kg	0.01	0.17	0.18	0.01	0.59	0.60

Burden	UK			New Zealand		
	Farm	Storage, transport	Total	Farm	Storage, transport	Total
Photochemical oxidation potential, kg ethylene e	-0.08	1.14	1.33	-0.04	0.77	0.73
Non-methane Volatile Organic Carbon, kg C e	0.04	0.15	0.19	0.03	1.22	1.25
Proportion of renewable primary energy, %	2	5	4	8	21	19

Figure 2.21 shows the contributions of different source categories to PE and GWP burdens, for apple cultivation up to the farm gate. Low nutrient inputs were assumed to match off-takes in apples, so that fertiliser manufacture and field emissions are low compared with other crop types. Machinery manufacture, and field diesel (includes irrigation pumping) therefore make relatively large contributions to energy use and GHG emissions up to the farm gate.

However, as shown in Table 2.26 above, the majority of the overall environmental burden arising through apple supply chains occurs post farm-gate, during storage and transport. Transport burdens from New Zealand are particularly high in terms of AP and EP owing to high SO_x and NO_x emissions from shipping (use of heavy fuel oil, poorly regulated compared with road transport).



Source: Based on data in DEFRA (2008)

Figure 2.21. Contributions of various source categories to environmental burdens of apple cultivation (up to the farm gate)

Based on the above information, the most important BEMP techniques in this report that can reduce the environmental burdens of apples production are listed in Table 2.27, below.

Table 2.27. Key BEMP measures to reduce the environmental burden of European apple production

Source	Key BEMP measures	Section
Agro-chemicals and upstream	Nutrient management planning	Section 5.1
	Select reduced impact synthetic fertilisers	Section 5.4

Source	Key BEMP measures	Section
impacts	Optimising and reducing the use of crop protection products	Section 11.1
	Crop protection product selection	Section 11.2
Energy	Energy management	Section 3.2, 3.5, 12.2
	Energy efficiency in horticulture	Section 12.2
Irrigation	Water management	Section 10.1, 10.2, 12.3
Waste management	Waste management in horticulture	Section 3.2, 3.6
Transport and storage	Best practice detailed in the Best practice report ⁸ for retail trade sector (EC, 2013)	

2.9.5 Wine

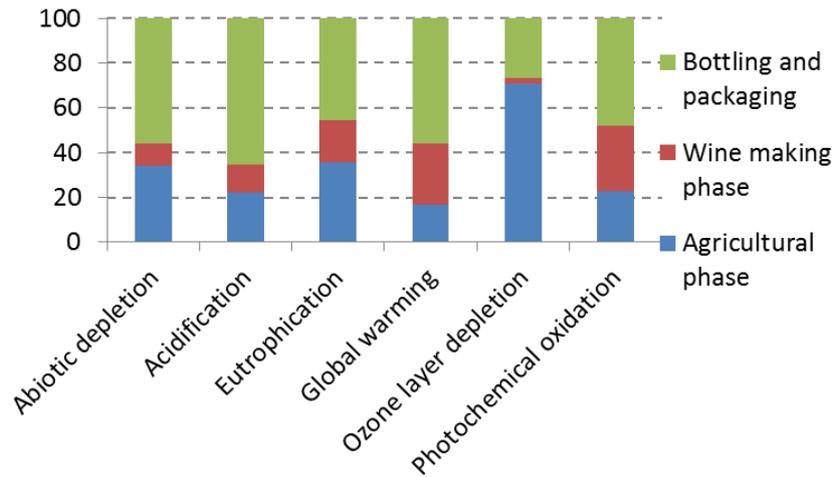
Wine can be transported long distances following bottling, so that the “bottling and packaging” stage reported by Fusi et al. (2014), which includes transport, makes a large contribution to lifecycle environmental burdens arising from the production and supply of a 750 ml bottle of Sardinian white wine (Table 2.28; Figure 2.22). These authors included the fate (disposal/recycling) of glass bottles within their LCA boundaries. The value chain of one bottle of wines gives rise to GHG emissions of 1.01 kg CO₂e, and contributes 0.00688 kg SO₂e emissions towards acidification, among other effects. The use of lighter, recycled glass bottles, and transporting wine in bulk, are major areas for improvement in the resource efficiency metrics summarised in Table 2.28 (addressed in the EMAS SRD on Food and Beverage Manufacturing currently under development), alongside consumption of locally or regionally sourced wines (section 3.7).

Table 2.28. Environmental burdens per 750 ml bottle of Sardinian white wine

Environmental burden	Unit	Agricultural phase	Wine making phase	Bottling and packaging	Total
Abiotic depletion	kg Sb e	2.57E-03	7.61E-04	4.19E-03	7.53E-03
Acidification	kg SO ₂ e	1.52E-03	8.46E-04	4.51E-03	6.88E-03
Eutrophication	kg PO ₄ e	3.22E-04	1.67E-04	4.12E-04	9.02E-04
Global warming	kg CO ₂ e	1.69E-01	2.74E-01	5.62E-01	1.01E+00
Ozone layer depletion	kg CFC-11 eq.	1.58E-07	5.51E-09	5.89E-08	2.23E-07
Photochemical oxidation	kg C ₂ H ₄ eq.	7.54E-05	9.74E-05	1.60E-04	3.33E-04

Source: Fusi et al. (2014)

⁸ The summarised best practices are also described in the Commission Decision EU/2015/801, 20th May 2015, on reference document on best environmental management practice, sector environmental performance indicators and benchmarks of excellence for the retail trade sector under Regulation (EC) No 1221/2009 of the European Parliament and of the Council on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS)



Source: Derived from data in Fusi et al. (2014)

Figure 2.22. Contribution of different stages to total environmental burdens from Sardinian white wine production

In terms of agricultural practice, the main hotspots of environmental concern that are addressed in various BEMP within this report are:

- Eco-toxicity
- Soil degradation.

Whilst Villanueva-Rey et al. (2014) reported that the use of synthetic pesticides, including folpet and or terbuthylazine, represented over 99% of the total eco-toxicity burden of Spanish wine production according to a LCA study, Komárek et al. (2010) report on the problem of fungicide, especially, copper contamination of vineyard soils. Copper is used as a fungicide in both conventional and organic wine production, and can accumulate in soils over time to a toxic level, especially in more acidic soils where it is more bioavailable (Komárek et al., 2010). Coll et al. (2011) note that most vineyard soils are highly degraded in terms of: (i) loss of organic carbon from erosion and diminution of nutrient contents; (ii) accumulation of metals and organic pollutants; (iii) compaction due to tractor traffic. Based on the above pressures, relevant BEMPs for wine value chains are summarised in Table 2.29.

Table 2.29. Key BEMP measures to reduce the environmental burden of European wine production

Source	Key BEMP measures	Section
Eco-toxicity	Optimising and reducing the use of crop protection products	Section 11.1
	Crop protection product selection	Section 11.2
Soil quality	Assessing and improving soil structure and drainage	Section 4.1, 4.2, 4.3, 4.4
Waste management	Waste management	Section 3.6
Agro-chemicals and upstream impacts	Nutrient management planning	Section 5.1
	Select reduced impact synthetic fertilisers	Section 5.4
Processing	Best practice detailed in the Best practice report for the Food and Beverage manufacturing sector ⁹	
Transport and storage	Best practice detailed in the Best practice report ¹⁰ for retail trade sector (EC, 2013)	

⁹ More information about the Best practice report for the Food and Beverage manufacturing sector can be found here: <http://susproc.jrc.ec.europa.eu/activities/emas/fooddrink.html>

¹⁰ The summarised best practices are also described in the Commission Decision EU/2015/801, 20th May 2015, on reference document on best environmental management practice, sector environmental performance indicators and benchmarks of excellence for the retail trade sector under Regulation (EC) No 1221/2009 of the European Parliament and of the Council on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS)

2.10 Reference literature

- Bangor University, 2013. Farm LCA tool (Styles, D., Gibbons, J., 2013).
- BioGrace, 2012. BioGrace Excel tool version 4b, downloaded from the BioGrace website July 2012: www.biograce.net
- CML, 2002. *Abiotic Resource Depletion in LCA*. CML, Leiden.
- CML, 2010, in JRC-IES (2010). *ILCD Handbook: Analysing of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment* (First edition). Ispra, 2010. Available to download at: <http://lct.jrc.ec.europa.eu/assessment/assessment/publications#indicators>
- Coll, P., Le Cadre, E., Blanchart, E., Hinsinger, P., Villenave, C., 2011. Organic viticulture and soil quality: A long-term study in Southern France. *Applied Soil Ecology* 50, 37–44.
- DEFRA, 2008. *Comparative Life Cycle Assessment of Food Commodities Procured for UK Consumption through a Diversity of Supply Chains*. Final report for DEFRA-funded project FO0103, prepared by AEA, Cranfield University, Ed Moorhouse, Paul Watkiss Associates, AHDBMS and Marintek. DEFRA, London.
- DEFRA, 2012. *Green Food Project Dairy Subgroup Report*. DEFRA, London.
- EBLEX, 2009. *Testing the water: The English Beef and Sheep Production Environmental Roadmap - Phase 2*. EBLEX, UK. Available to download at: http://www.eblex.org.uk/wp/wp-content/uploads/2013/05/p_cp_testingthewater061210.pdf
- EC DG ENV, 2011. *Preparatory study on food waste across the EU27*. Technical report prepared by Bio Intelligence Service. EC DG ENV, Brussels. ISBN : 978-92-79-22138-5
- FAOstat, 2013. Agri-statistics homepage. Last accessed December 2013: <http://faostat3.fao.org/faostat-gateway/go/to/home/E>
- Fischer, J., Brosi, B., Daily, G.C., Ehrlich, P.R., Goldman, R., Goldstein, J., Lindenmayer, D.B., Manning, A.D., Mooney, H.A., Pejchar, L., Ranganathan, J., Tallis, H. 2008, *Should agricultural policies encourage land sparing or wildlife friendly farming?* *Frontiers in Ecology and the Environment*, Vol. 6, pp. 380–385.
- Footprints4Food (2013). *Anonymous Welsh pig farm footprints*. Footprints4Food, Bangor.
- Fusi, A., Guidetti, R., Benedetto, G., 2014. Delving into the environmental aspect of a Sardinian white wine: From partial to total life cycle assessment. *Science of the Total Environment* 472, 989–1000.
- Gibbons, J. M., Ramsden, S. J., & Blake, A., 2006. Modelling uncertainty in greenhouse gas emissions from UK agriculture at the farm level. *Agriculture, Ecosystems & Environment* 112, 347-355.
- Hörtenhuber, S.J., Lindenthal, T., Zollitsch, W. (2011). Reduction of greenhouse gas emissions from feed supply chains by utilising regionally produced protein sources: the case of Austrian dairy production. *Journal of the Science of Food and Agriculture*, 91, 1118-1127.
- IEEP, 2012. *Delivering environmental benefits through ecological focus areas*. Available at: http://www.ieep.eu/assets/949/IEEP_2012_Delivering_environmental_benefits_through_ecological_focus_areas.pdf.
- Jones, A.K., Jones, D.L., Edwards-Jones, G., Cross, P., 2013. Informing decision making in agricultural greenhouse gas mitigation policy: A Best–Worst Scaling survey of expert and farmer opinion in the sheep industry. *Environmental Science and Policy* 29: 46-56.
- EC, (European Commission). 2008, *Environmental Improvement Potentials of Meat and Dairy Products*. IPTS, Seville. Technical Report EUR 23491 EN.

- Komárek, M., Čadková, M., Chrastný, V., Bordas, F., Bollinger, J.C., 2010. Contamination of vineyard soils with fungicides: A review of environmental and toxicological aspects. *Environment International* 36, 138–151.
- Leinonen, I., Williams, A.G., Wiseman, J., Guy, J., Kyriazakis, I., 2012a. Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: Broiler production systems. *Poultry Science* 91: 8–25.
- Leinonen, I., Williams, A.G., Wiseman, J., Guy, J., Kyriazakis, I., 2012b. Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: Egg production systems. *Poultry Science* 91: 26-40.
- MA. 2005. *Ecosystems and Human Well-being - overall Synthesis*. In *Millennium Ecosystem Assessment*. Washington, DC: World Resource Institute.
- Ripoll-Bosch, R., de Boer, I.J.M., Bernués, A., Vellinga, T.V., 2013. Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: A comparison of three contrasting Mediterranean systems. *Agricultural Systems* 116: 60–68.
- Schoenberger, H., Galvez-Martos, J.L., Styles, D., 2013. *Best Environmental Management Practice in the Retail Trade Sector: Learning from frontrunners*. JRC Scientific Report. IPTS, Seville. ISBN 978-92-79-30495-8. Available at: <http://susproc.jrc.ec.europa.eu/activities/emas/documents/RetailTradeSector.pdf>
- Teagasc, 2011. *Sectoral Roadmap: Suckler Beef*. Accessed July 2013: www.teagasc.ie/publications/2011/767/Roadmap_SucklerBeef.pdf
- Teagasc, 2012. *A Marginal Abatement Cost Curve for Irish Agriculture*. Teagasc submission to the National Climate Policy Development Consultation. Teagasc, Carlow.
- Taylor, R., Edwards-Jones, G., 2010. *Carbon footprint for an anonymous Welsh sheep farm*. Bangor University, Wales.
- TFRN, 2011. *Draft guidance document for preventing and abating ammonia emissions from agricultural sources*. WGSR informal document No. 21. TFRN.
- Vanham, D., Bidoglio, G., 2013. A review on the indicator water footprint for the EU28. *Ecological Indicators* 26: 61–75.
- Villanueva-Rey, P., Vázquez-Rowe, I., Moreira, T.M., Feijoo, G., 2014. Comparative life cycle assessment in the wine sector: biodynamic vs. conventional viticulture activities in NW Spain. *Journal of Cleaner Production* 65, 330-341.
- Wall, 2013. *Marginal GHG abatement cost curves for agriculture*. Presentation at CEUKF conference, Birmingham, January 2014.
- Williams, A.G., Audsley, E. and Sandars, D.L., 2006. *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities*. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk
- Williams, A.G., Audsley, E., Sandars, D.L., 2010. Environmental burdens of producing bread wheat, oilseed rape and potatoes in England and Wales using simulation and system modelling. *Int J Life Cycle Assess* 15:855–868.
- Winiwarter, W., Klimont, Z., Sutton, M., 2011. *Summary of ammonia abatement costings in GAINS*. Spreadsheet 2b. TFRN.

3 SUSTAINABLE FARM AND LAND MANAGEMENT

Introduction

Environmental management is ultimately a cross-cutting objective. Good environmental management spans across all processes with significant environmental impact over which managers (i.e. farmers) have direct control or significant influence. There are cross-cutting themes within all chapters of this report. This chapter addresses overarching issues related to environmental and landscape management on farms, and provides a framework for prioritising measures to achieve resource efficient and environmentally responsible farming.

Environmental management systems may be informal organisation systems, or internationally recognised systems certified by a third-party, such as ISO 14001 and EMAS. This report for EMAS provides guidance on sector-specific best practice measures and indicators, and proposes “benchmarks of excellence”, as specified under article 46 of EC 1221/2009. Basic compliance criteria for EMAS are documented in EC 1221/2009 and guidance documents provided by competent bodies in member states. In this chapter, and the remainder of the BEMP chapters in this report, emphasis is placed on key measures, indicators and benchmarks of best practice, with a focus on measurable resource and environmental efficiency.

The main target audience for this chapter is farmers and farm advisors, but elements are relevant to all stakeholders in the agriculture sector, including policy makers. This is especially true for landscape management which may require higher level facilitation and/or coordination.

The systems approach (Figure 3.1) to quantify resource flows and environmental burdens (usually associated with points of resource loss, in the form of emissions) can be particularly useful for farmers, given that less than 20% of fertiliser N imported to livestock farm systems is exported as food (PBL, 2011).

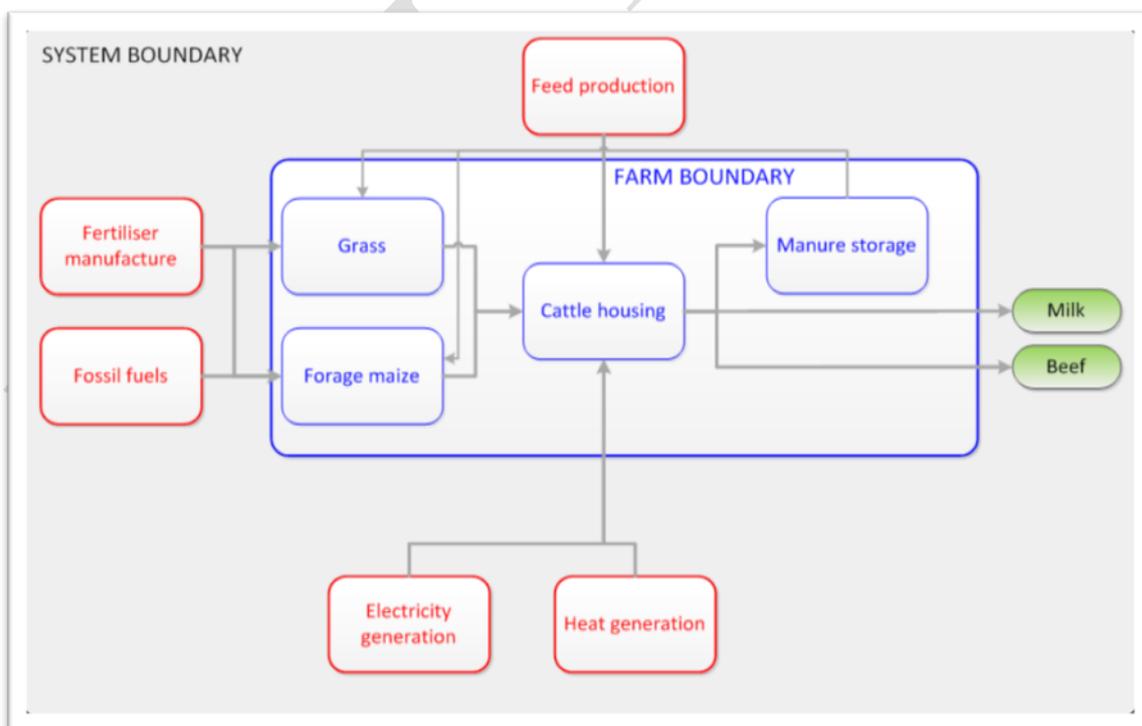


Figure 3.1. Basic schematic of a dairy farm system (PBL, 2001)

Invisible losses of N in the form of NH₃, NO₃ and N₂O cause the majority of farm environmental burdens and also represent a large financial loss for farmers given that fertiliser-N costs approximately one euro per kg. farmers must consider how these losses affect compliance with various European and national regulations (Figure 3.2). The systems approach can facilitate this.

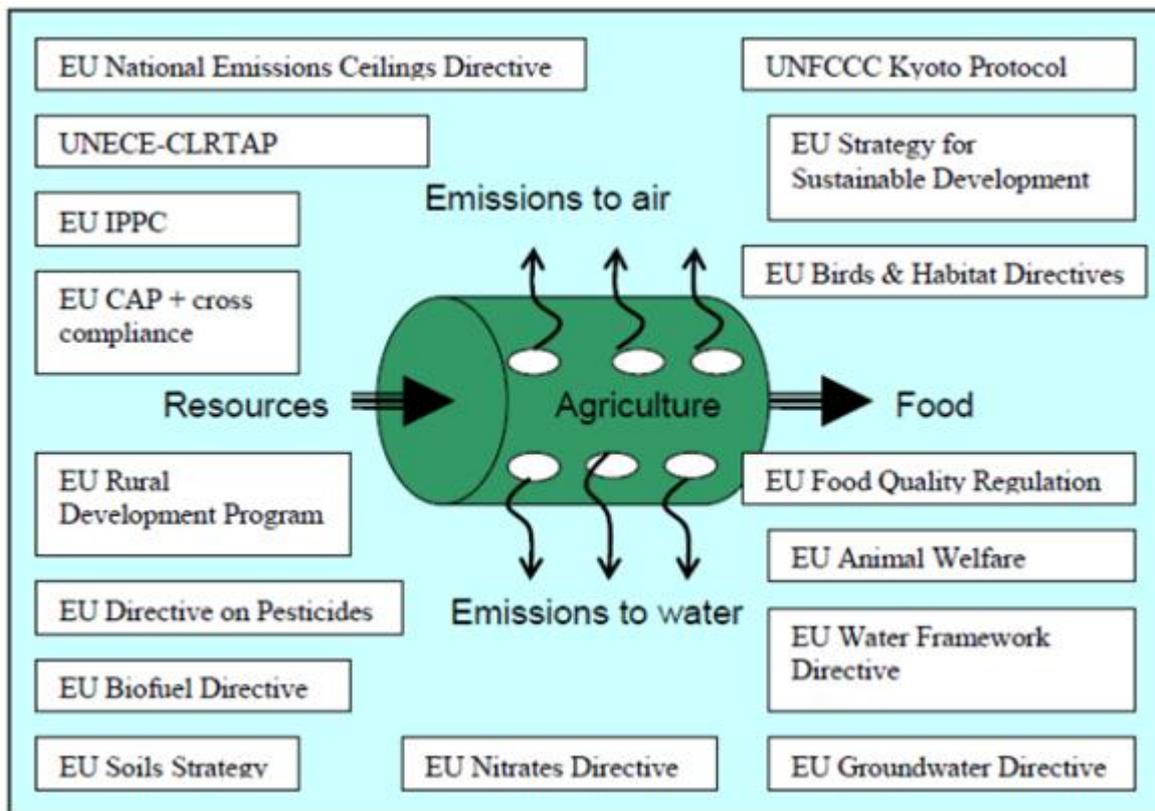
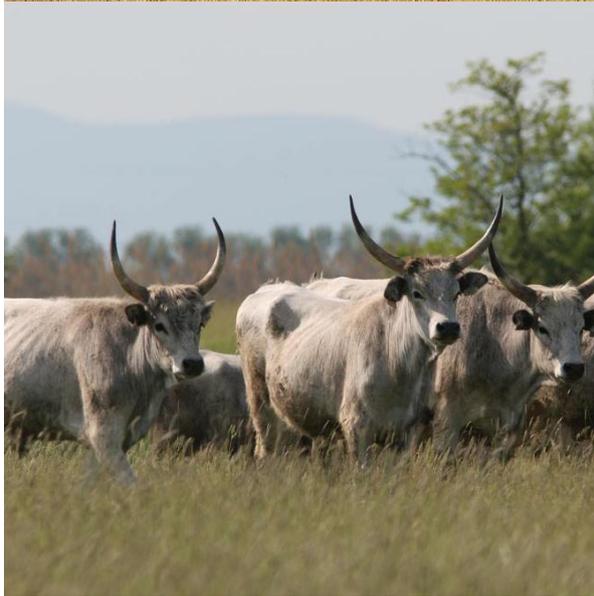


Figure 3.2. Agriculture as a leaky pipe, giving rise to emissions addressed by many European regulations

Landscape management

Agriculture occupies 160 million hectares in the EU-27, representing 42% of EU territorial area (FSS 2010), shaping landscapes on a vast scale. Adaptation of agricultural practices to local conditions has led to a wide variety of agricultural landscapes in Europe, ranging from almost entirely man-made and intensively managed polders in the Netherlands to semi-natural extensive grazing areas in the high Alps (EC, 2012).



Source: ELN-FAB (no date).

EC (2012) described agricultural landscapes as a multi-scale public good that is difficult to describe due to its multidimensional character that encompasses agronomic, environmental, social, cultural and economic dimensions. They propose three scales of landscape planning action to maximise the public good: (i) the management of landscape features at farm level; (ii) farms' coordination towards landscape structure management at landscape level; (iii) the conservation of the diversity of agricultural landscapes in the EU as a global public good.

The ecosystems services framework provides a useful approach for assessing landscape management. In fact, Everard and McInnes (2013) argued that such an approach enables the identification of “systemic solutions” that involve multiple stakeholders (including farmers) and environmental benefits. Importantly, the ecosystems services approach can help to optimise the mix of different

services provided by land, and agricultural management of it, rather than maximising any one services (e.g. food production).

Environmental performance benchmarking

Management and performance benchmarks are specified throughout this report in relation to major farm processes giving rise to environmental impacts. In this chapter, BEMPs are described to systemise environmental improvement through identification and prioritisation of relevant BEMPs described in the remainder of the report – essentially BEMP mapping for individual farms. Emphasis is placed on a quantitative systems approach, and selection of appropriate metrics to measure environmental performance and resource efficiency. One example of high-level benchmarking of farm and product resource efficiency is the development of full LCA metrics (Figure 3.3) – where data are available. However, most of the BEMPs in this report will be associated with process-specific indicators and benchmarks, such as feed digestibility, feed conversion efficiency, NH₃-N losses per kg manure N stored or spread, etc. these benchmarks will relate to overall farm- and product- level performance via effects on individual source categories displayed in Figure 3.3.

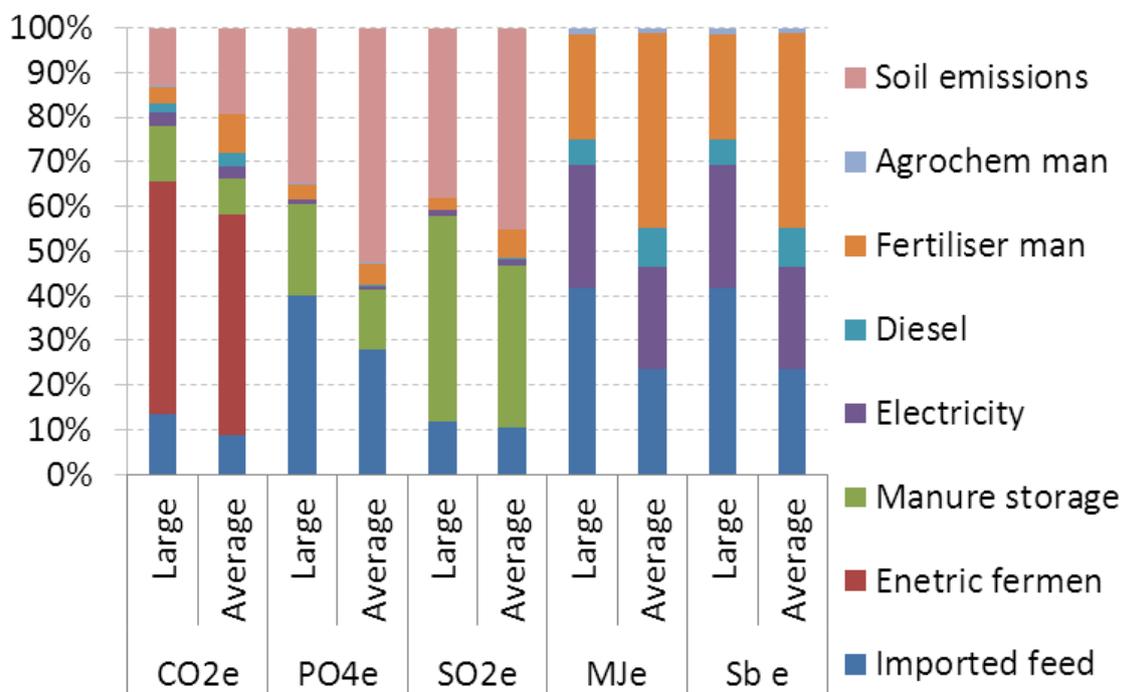


Figure 3.3. Environmental burdens arising from milk production on an optimised large- and average-sized dairy farm (Bangor University farm LCA tool)

This chapter also contains BEMPs related to cross-cutting themes of resource management, waste management and responsible consumption. The latter topic is of critical importance for sustainable food supply chains. It is addressed from the narrow perspective of what the farmer can do to influence consumers in this chapter, avoiding potentially contentious issues around consumer diet choices, etc.

Best practice resources

Simple calculator tools and information resources for farmers and farm advisors are being made available online at an astounding rate. In terms of best practice guides, a wide range of extensive resources are available, at:

- Pan European level – e.g. <http://www.cost869.alterra.nl/dbase/default.aspx>
- Regional level – e.g. http://www.balticdeal.eu/measures/selection_measures/
- National level – e.g. <http://www.adas.co.uk/LinkClick.aspx?fileticket=vUJ2vIDHBjc%3D&tabid=345>

This report cannot be exhaustive in referring to all existing best practice literature and available tools, but can point users in the direction of relevant literature and tools. Examples will be provided in relevant BEMP sections, to demonstrate the types of tools and information available. A key aspect of best practice is for farmers and farm advisors to periodically check for new online tools and other resources to facilitate efficient farm management.

Reference literature

- Alterra, 2014. *Cost 869 factsheet finder homepage*. Last accessed February 2014: <http://www.cost869.alterra.nl/dbase/default.aspx>
- Baltic Deal, 2014. *Homepage: Putting best agricultural practices into work*. Last accessed February 2014: http://www.balticdeal.eu/measures/selection_measures/
- EC 2012. The influence of the Common Agricultural Policy on agricultural landscapes. JRC Scientific and Policy reports, edited by: Lefebvre M., Espinosa M., Gomez y Paloma S., ISSN: 1831-9424, doi: 10.2791/94269.
- ENL-FAB (no date). *Functional AgroBiodiversity for a more sustainable agriculture and countryside in Europe*. The European Learning Network on Functional AgroBiodiversity, Tilberg.
- Everard, M., Innes, R., 2013. Systemic solutions for multi-benefit water and environmental management. *Science of the Total Environment*, 461–462, 170–179.

3.1 Strategic farm management plan

Description

Farmers needed to compile a strategic farm management plan, which eventually must be used in order to assess their performance. For the compilation of this plan, support from farm advisers may be needed. Moreover, the farmers should join a group of (similar) farmers in order to perform an assessment of their performance and thus to establish the appropriate strategic management plan. The main elements of a strategic farm management are presented below.

Biodiversity conservation

There are three main levels of biodiversity; i. ecosystem, ii. species and iii. genetic diversity. Each of the abovementioned levels is further discussed below. This particular BEMP requires farmers to develop a medium-term strategic management plan for their farm that can optimise the mix of biodiversity measures e.g. ecosystem services delivered within the current and forecast natural, socio-economic and regulatory context¹¹.

With the 'Ecosystem services' term, the variety of the ecosystems in a given territory is mentioned including the different and various ways they function. Figure 3.4 shows how land appropriation for human activities results in a progressive reduction in ecosystem services such as cultural value and ecosystem regulation, but can increase ecosystem services related to human provisioning (especially food production) – to a point. The 'Ecosystem Approach' is a strategy for the integrated management of land, water and living resources that promotes conservation and the sustainable and equitable use of natural resources (MEA, 2005). It involves application of appropriate scientific methods focused on levels of biological organization, which encompass the essential processes, functions and interactions among organisms and their environment. However, the development of indicators capable of representing ecosystem service functions at a practical level is challenging, and there are currently no widely accepted indicators of ecosystem service provision (GRI, 2011). Where possible, this report refers to practical indicators that assist farmers in maximising the ecosystem services provided by their farm.

Relation of Ecosystem Services, land use types and biodiversity (MSA indicator)

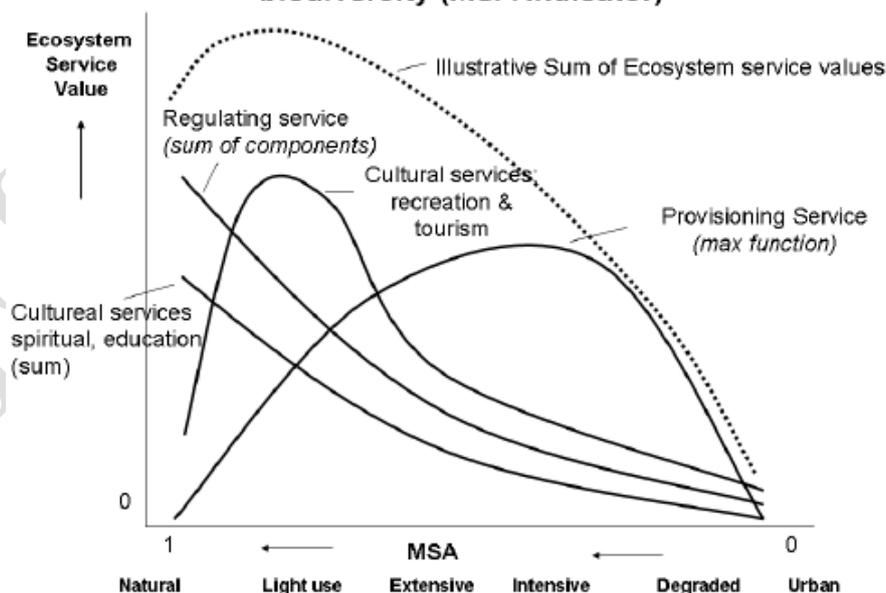


Figure 3.4. General relationship between different ecosystem services, mean species abundance (MSA) and land use intensity (Braat and ten Brink, 2008)

¹¹ More information regarding ecosystems and biodiversity in general is found at BEMP 3.4 (chapter 3)

Furthermore, another important element for the compilation of farm management plan is the preparation of a list of the observed species on a farm including their conservational or functional characteristics. Compiling such a list, farmers (or the related advisers) obtain the knowledge whether where and why species diversity aspects are well established on their farm (Luscher et al., 2014). Likewise, regarding genetic diversity, the impact of agricultural practices and the choices of the farmers (e.g. practices like mowing, fertilisation etc.) can be compared at plot and farm scale (Figure 3.5). Additionally, within a strategic farm management plan the impacts on different indicator species groups can be compared (Jeanneret et al., 2008).

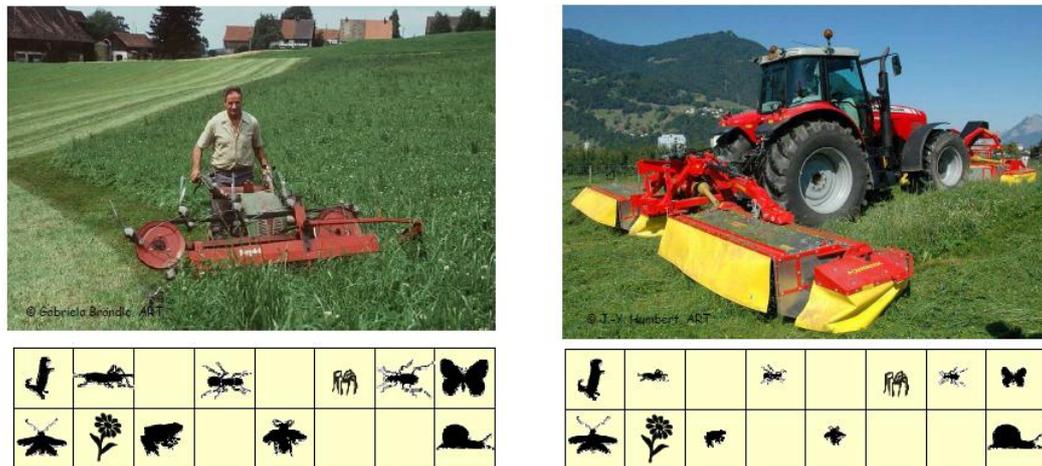


Figure 3.5. Impacts on species diversity from the farmers choices (Jeanneret et al., 2008)

Locally appropriate farming

Farming in Europe has evolved over millennia, and local methods have adapted to local conditions, implying some degree of spatial optimisation. Market pressures and other factors such as national and European policy, especially the Common Agricultural Policy (CAP), has strongly influenced farming practices over the past fifty years or so (Lefebvre et al., 2013). In some cases, current farming systems are not well adapted to the local environment, and rely on unsustainable practices such as:

- groundwater abstraction for irrigation in excess of recharge rates (e.g. strawberry production in Huelva, Spain) (Williams and Gianessi, 2011)
- intensive tillage of erosion-prone soils (e.g. cultivation of peat soils in Fenlands of East Anglia, eastern England)
- excessive stocking rates on wet soils, or drainage of wet soils leading to flooding risk downstream (e.g. upland areas throughout Europe) .

In some such cases, the type or intensity of agriculture practiced may be incompatible with the local conditions over the long term. In other cases, agricultural management of land is being abandoned owing to insufficient financial returns. This can lead to positive or negative environmental effects. Extensive agricultural management, such as low intensity grazing, is practised on large areas of land, and can maintain unique and high nature value habitats that would be lost under both intensive agriculture and abandonment (Haddaway et al., 2014).

Best practice is to decide on the most appropriate land use in any given area to maximise the public good through ecosystem service provisioning, including food production, water purification, flood regulation, climate regulation and biodiversity conservation.

Farmer roles at different scales

Lefebvre et al. (2013) highlighted the different scales of action required to optimise ecosystem service provisioning, providing an initial reference point for farmers who may contribute actions targeted at each of these scales:

- management of landscape features at the farm level
- farms' coordination towards landscape structure management at landscape level

- conservation of diversity within EU agricultural landscapes as a global public good.

Typically, as demonstrated throughout this report, better management practices focus on the field and process level, but often result in effects at the landscape level. And landscape factors have a significant influence on field and farm scale sustainability measured according to some indicators such as the abundance of particular species – often dependent on surrounding habitats (Benton, 2013). Benton (2013) refers to three main scales of sustainability, similar to Lefebvre et al. (2013):

- Farm
- Landscapes
- Long distance

One method of relating some long distance effects to local management practices is LCA, especially consequential LCA that considers marginal effects of management changes throughout markets. Life cycle assessment accounts for the production of agricultural inputs such as feed (including potential indirect land use change) and downstream effects such as compensatory production (consequential LCA). Benton relates the concept of sustainable intensification to higher food yields achieved through higher chemical, capital, labour or knowledge inputs, without leading to negative landscape or long distance effects. Conceptually, the description of BEMPs in this report addresses capital (technology) and knowledge deficits.

Best practice

EC, (2013) decided that the current BEMP could be summarised as the integration of market, regulatory, environmental and ethical considerations/restrictions into a ten year strategic plan for the farm business. Those plans should be future proofed against volatile commodity prices, likely regulations and climate change effects. Establishing and updating such a plan provides a framework for making long term investment decisions, e.g. in achieving a particular type of certification, or construction of efficient animal housing (section 9.1), covered manure storage (section 9.4) or anaerobic digestion (section 9.2). Strategic investments may overcome output constraints associated with e.g. total N application restrictions in NVZs or ammonia emission rates in or adjacent to Natura 2000 sites. Alternatively, if it is clear that farm output will be severely constrained through compliance with e.g. Natura 2000 regulations, adaption of the farm to a certified low input system may be identified as the most profitable and environmentally responsible strategy.

Depending on the intensity of farm management with respect to food production, it may be appropriate to focus on either production efficiency metrics (LCA) or land management metrics (ecosystem service provisioning). Application of these metrics to all relevant processes should capture important “long distance” effects, such as animal feed production. Regional landscape effects can also be managed through collaboration with neighbouring farms and engagement with government initiatives (Lüscher et al., 2014).

Best practice can thus be summarised as:

- Implementation of a strategic business plan for the farm that addresses market, regulatory, environmental and ethical considerations over a time period of ten years
- Identification of, and progress to attaining accreditation by, relevant sustainable farming or food certification schemes that add value to farm produce and demonstrate commitment to sustainable management
- Use of appropriate LCA or ecosystem services metrics to inform continuous improvement of farm management (see also section 3.2)
- Collaboration with neighbouring farmers and public agencies to coordinate the delivery of priority ecosystem services at the landscape scale (see also catchment sensitive farming in section 3.3)

An important element of ecosystem functioning and agricultural sustainability that should be mentioned within a LCA context is the soil quality. The inclusion of soil quality impacts caused by

upstream processes e.g. geographic location is essential but not always difficult due to the site-dependency of soil and local climate conditions. Therefore the inventory items that have to be quantified should be relevant for the calculations of impacts on soil quality according to one or more functional units with as less as possible uncertainty based on available and published data at a global scale. In general, processes that degrade the soil are the most suitable inventory items to assess impacts within a LCA perspective. Therefore processes like soil organic matter change, erosion, compaction and salinization can contribute to the formulation of the methodological framework (Garrigues et al., 2012).

Achieved environmental benefits

Environmental benefits achieved will be highly dependent on farm specific circumstances and the relative influence of strategic management decisions. Environmental benefits quantified for specific management practices throughout the rest of this report provide guidance on the type and magnitude of benefits achievable. For instance, some indicative environmental benefits are listed below (EFP, 2010):

- Reduction of pest populations, which contribute to reduce crop losses
- Soil formation and retention processes, which maintain soil productivity and prevent soil loss due to wind and water erosion
- Nutrient storage where nutrients are available to domestic and native plants improving also the water quality

Appropriate environmental performance indicators

Ecosystem services

In the first instance, it is important that farmers and land managers are aware of the range of mostly non-priced ecosystem services delivered by the land they manage. The 24 ecosystem services defined by MEA (2005) provide a useful framework for ecosystem service assessment and land management (Table 3.1).

Table 3.1. Ecosystem services defined by the Millenium Ecosystem Assessment report (MEA, 2005)

Provisioning services	Regulating services	Supporting services	Cultural services
<ul style="list-style-type: none"> – Food, fibre, fuel – Genetic resources – Biochemicals – Fresh water 	<ul style="list-style-type: none"> – Invasion resistance – Herbivory – Pollination – Seed dispersal – Climate regulation – Pest regulation – Disease regulation – Natural hazard protection – Erosion regulation – Water purification 	<ul style="list-style-type: none"> – Primary production – Provision of habitat – Nutrient cycling – Soil formation and retention – Production of atmospheric oxygen – Water cycling 	<ul style="list-style-type: none"> – Spiritual and religious values – Knowledge system – Education/inspiration – Recreation and aesthetic value

Relevant indicators may be identified for some of these ecosystem services, such as:

- biomass production
- biodiversity conservation (e.g. species and genetic species diversity etc.)
- water quality (or nutrient and sediment losses via runoff)
- soil infiltration capacity and evidence of surface runoff
- soil and biomass carbon sequestration.

More detailed quantitative indicators related to these ecosystem services are referred to throughout this report, and some are summarised in the next section. A walk around the farm could be used to identify where and how these different ecosystem services are delivered, to produce a basic map of ecosystem service delivery. Another important aspect of best practice for landscape scale ecosystem service delivery is to work collaboratively with neighbouring farmers, as described in the Pontbren case study (section 3.3.1).

One example of a land management change for which quantifiable benefits are estimable is the rewetting of organic soils, which, in addition to providing a valuable wetland habitat, could lead to large GHG emission avoidance. According to IPCC (2006) emission factors, this emission avoidance could amount to 22 t CO₂e/ha/yr.

Garrigues et al., (2012) claimed that it is difficult to establish one single indicator on soil quality due to the difficulty in aggregating several processes such as erosion, organic matter change and compaction into a single measure (Figure 3.6). Nevertheless, there are some ways to measure the impacts by taking into account the following parameters (Garrigues et al., 2012):

1. soil rehabilitation cost or prevention of the soil degradation
2. regeneration time
3. reduction in net primary production

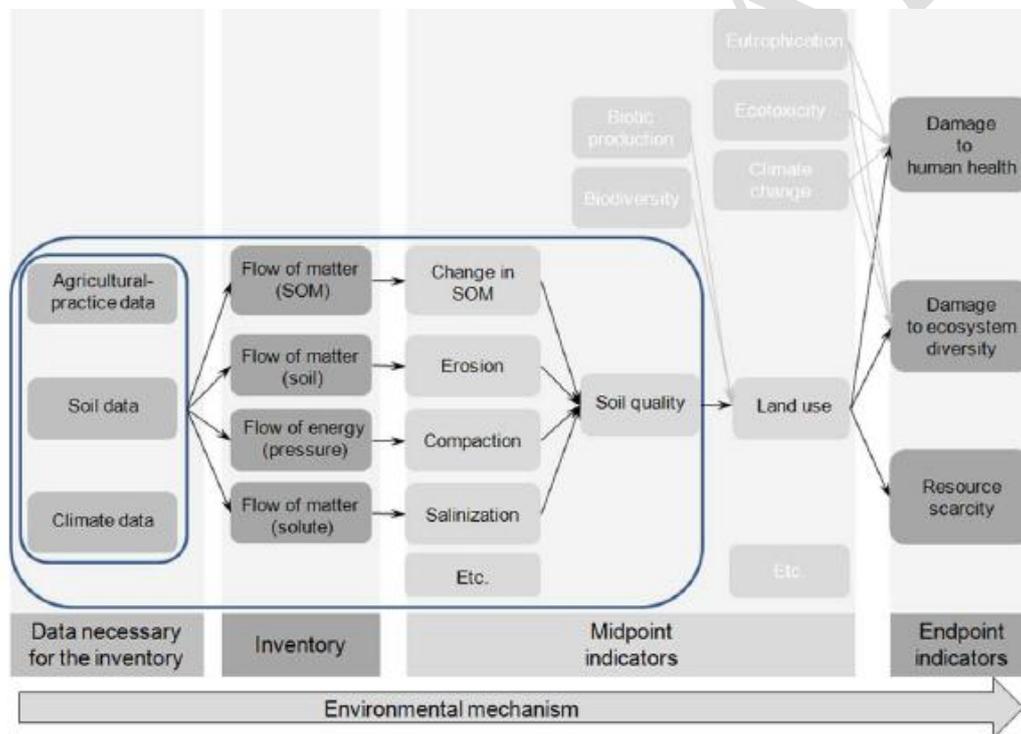


Figure 3.6. Steps for assessing environmental impacts on soil quality within the concept of Life Cycle Assessment indicators (Garrigues et al., 2012)

Accreditation

One best practice indicator is:

- accreditation with a relevant scheme that includes environmental management requirements.

A selection of accreditation schemes are briefly summarised in Table 3.2. Many others exist, as listed in the report on best environmental management practice in the retail trade sector (EC, 2013). The Swedish Climate Label for Food contains a number of frontrunner benchmarks highly relevant to this report, and cited in later BEMP sections.

Table 3.2. Selection of accreditation schemes

Label	Summary
	<p>Global G.A.P. certificates are awarded to producers following independent third-party inspection and certification by auditing companies (certification bodies) who are also responsible for updating the global online G.A.P. database. GLOBALG.A.P. standards are available for a range of producer types. Over 142 independent and accredited certification bodies (CBs) carry out GLOBALG.A.P. certification worldwide via announced and unannounced onsite farm inspections.</p> <p>Link: http://www.globalgap.org/uk_en/</p>
	<p>LEAF (Linking Environment And Farming) is an organisation promoting sustainable food and farming. The LEAF Marque logo on food assures that farmers have produced that food according to high environmental standards. LEAF also builds public understanding of food and farming through e.g. year round farm visits to a national network of Demonstration Farms.</p> <p>Link: http://www.leafuk.org/leaf/home.eb</p>
 <p data-bbox="207 1146 558 1176">Swedish Climate Label for Food</p>	<p>The Swedish Climate Label for Food is an initiative started in 2007 by KRAV and the Swedish Seal (Svenskt Sigill) to develop climate certification for the food chain. The project is managed in cooperation with several major Swedish food companies: Milko, Lantmännen, the Federation of Swedish Farmers, Scan and Skånemejerier. The purpose is to create a certification system that reduces negative climate effects from food production and identifies more climate responsible products to consumers. Frontrunner products are identified within major product categories, accounting for the entire production chain. The climate certification can only be used in combination with another certification scheme (criteria are specified in the standard) that certifies components of sustainable food production. Labelling is taken care of by existing certification organisations rather than introducing a new label.</p> <p>Link: http://www.klimatmarkningen.se/in-english</p>

Cross-media effects

The purpose of this BEMP is to achieve the optimum balance of financial, environmental and ethical performance through strategic, long-term management, and thus minimise cross-media effects. Significant trade-offs may exist, including between animal welfare and resource efficiency maximisation, or between profit maximisation and environmental protection.

Operational data

Cross-compliance

Cross-compliance criteria for the EU CAP represent the baseline minimum agri-environment measures to be implemented on farms. For all requirements falling under cross-compliance, the compliance costs have to be borne by farmers¹².

Best practice goes considerably beyond cross-compliance standards. Strategic implementation of cross-compliance criteria, and attaining higher-level agri-environmental subsidies such as the Higher Level Stewardship scheme in the UK, can leverage multiple environmental benefits. For example, using any areas of organic soils for set-aside and semi-natural habitat provisioning could enable that soil to be rewetted (draining blocked), leading to large GHG emission avoidance.

¹² A useful index page from cross-compliance criteria is accessible here: http://ec.europa.eu/agriculture/envir/cross-compliance/index_en.htm

Ecosystem services provisioning

IPIECA (2011) describe the following steps for applying ecosystem services checklists as a way to integrate ES into operations:

- **Step 1: Select relevant ES checklist(s):** This involves identifying the habitat types on the farm and then selecting the relevant checklist.
- **Step 2: Assess ES dependencies and impacts:** This involves working through the checklist to identify the potentially significant ecosystem service dependencies and impacts associated with relevant farming activities and issues.
- **Step 3: Identify ES risks and opportunities:** For each of the potentially significant ES dependencies and impacts, two *Risk and Opportunity* tables are used to identify relevant associated risks and opportunities.
- **Step 4: Consider mitigation and enhancement measures:** For each relevant risk and opportunity, *Risk and Opportunity* tables are used to identify potential mitigation and enhancement measures to implement.

Whilst the above steps were defined in relation to oil and gas industry projects, they apply equally well to farming contexts.

Integrated Farm Management

Integrated Farm Management (IFM) can be a major component of strategic farm management, comprising a whole farm perspective, scientific basis and multiple objectives. According to EFMA, (2010), “IFM is based on an understanding of the scientific processes in the farming environment, e.g. nutrient flows, factors influencing soil quality, and the application of this knowledge to identify aspects of the farming practice that need attention”. EISA have produced a document on integrated farming providing guideline for sustainable agriculture that can be used for indicators and benchmarks (EISA, 2010). The LEAF marque is based on IFM principles.

The following criteria are required for LEAF marque certification, and provide a useful indication of good practice in integrated farm management:

Integrated Farm Management (IFM) is a whole farm policy. You must therefore have appropriate assurance for each enterprise on your holding. For example, if you have potatoes and cereals, you must be a member of the appropriate schemes for both enterprises, such as GLOBALGAP (Cereals) or GLOBALGAP (FV) or other schemes that are benchmarked as equivalent to GLOBALGAP e.g. Red Tractor Farm Assurance - Produce Scheme.

You must have a farm environmental policy that is communicated to all staff. It must be documented and form the basis for the farm’s objectives and targets. The policy must:

- contain reference to IFM,
- meet all regulatory and legislative requirements,
- include references to:
 1. Effective resource management through reducing and reusing waste; reducing raw material consumption;
 2. Eliminating or minimising appropriate polluting releases to the environment i.e. air, water, soil, including ‘greenhouse gases’ (GHG) mitigation (e.g. ruminant diets);
 3. Optimising energy and water efficiency;
 4. Minimising adverse environmental effects.

You must develop from your Environmental Policy a documented plan that sets out your short-term and long-term (1 to 5 years) environmental objectives.

The plan must include aspects such as energy, water, pollution, 'greenhouse gas' (GHG) mitigation practices and other aspects of the business that impact on the environment. It must also include non-food enterprises that impact on the business. The LEAF Audit ‘targets for action’ and ‘performance profile’ can form the basis for this plan. It must also be integrated with the Whole Farm Conservation Plan.

You must set targets, with a timescale, to improve and enhance the environment. This must include a link to your Whole Farm Conservation Plan, but must also include targets on water, soil, air,

'greenhouse gases' (GHG) and energy use. The targets must be measurable and linked to monitoring when appropriate.
You must review your environmental policy and plan to ensure that it is relevant and being implemented. This must be every year and a record must be kept of this review. Following the review any amendments must be made and highlighted.
You must ensure that staff have received and understood the Environmental Policy and plan and asked them to sign / mark to this effect. The policy must be displayed for everyone to read and where staff induction training takes place, be part of it.
You must communicate the environmental policy to key suppliers and contractors who are directly involved in the farming business, especially where they have an impact on the business's environmental performance. They must be made aware of its content and their responsibility to help achieve its aims and objectives.
When purchasing new equipment or establishing new buildings you should look for the best available and appropriate technology. This should include water and energy efficient products/designs; you should justify your decision based on economic and environmental criteria, without forgetting animal welfare issues. A written policy to show your commitment to reduction of energy through proper purchase decisions should be present and can be part of your environmental policy.
Farm staff that has a critical impact on your business (including contractors) must be made aware of your commitment to IFM. There are many comprehensive benefits that result from staff training e.g. increased job satisfaction and motivation. This must be done on a regular basis and at least annually. Regular team meetings can be useful to discuss with relevant members of staff IFM principles and practices employed on farm and identify with them opportunities for improvement and an increased awareness of IFM.
<i>Source: LEAF (2012).</i>

Applicability

This BEMP applies to all types and sizes of farms.

Economics

Economic considerations are embedded within strategic farm management decisions. There are increasing examples of farmers receiving payment for the delivery of ecosystem services, both from public subsidies through e.g. cross-compliance criteria in CAP, and also from private companies – e.g. for water quality and carbon sequestration.

As mentioned, a whole farm perspective is required to fully account for costs and benefits associated with various management decisions. With respect to certification costs, these may be paid back quickly via premium produce prices and, as with environmental management more widely, cost savings. For example, LEAF membership varies from €80/year for a farm < 121 ha to €320/year for a farm over 700 ha. However, based on results of an extensive survey, LEAF (2012) claimed that the average saving for adopting LEAF's IFM was €50/ha.

Additionally, an estimate of the cost of erosion and change in soil organic matter in the form of prevention or damage to infrastructures in Europe has high uncertainty (e.g. uncertainty range 0.7-14.0 billion € for erosion). These costs do not include damage to the ecological functions of soil, which were impossible to quantify (EC, 2006; Garrigues et al. 2012). According to Guarriges et al. (2012) the establishment/proposal of reference values for acceptable economic costs of soil degradation or the initial quality of land before it was transformed requires future research. As far as the cost of soil degradation is concerned, a practical and pragmatic estimation may incorporate the related decrease in the revenues because of the decreasing crop yield taking into account that the combined influence of erosion soil organic matter change, compaction or salinization on yield has high variability and uncertainty (Garrigues et al., 2012).

Driving forces for implementation

Driving forces for strategic farm planning include:

- Financial pressures
- Environmental regulations
- Animal welfare regulations
- Buyer demands (e.g. for various types of certification)
- Volatile commodity and produce prices (risk management)
- Environmental and ethical responsibility

Reference organisations

GLOBAL G.A.P.
KRAV
Morley Farms, UK
LEAF Marque

Reference literature

- CCRI, 2010. *The Benefits of LEAF Membership: a qualitative study to understand the added value that LEAF brings to its farmer members*. Countryside and Community Research Institute, UK. Available at: [http://www.sustainable-agriculture.org/stuff/The%20Benefits%20of%20LEAF%20Membership%20Final%20Report%20\(3\).pdf](http://www.sustainable-agriculture.org/stuff/The%20Benefits%20of%20LEAF%20Membership%20Final%20Report%20(3).pdf)
- DEFRA, 2012. *Green Food Project Dairy Subgroup Report*. DEFRA, London.
- EC, 2006. Commission staff working document—document accompanying to the communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions—Thematic strategy for soil protection.
- EC, 2013. Best Environmental Management Practice in the Retail Trade Sector. Learning from frontrunners. ISSN: 1831-9424 (online) doi:10.2791/1775
- EC, 2013. Minutes of the meeting. Kick-off meeting of the technical working group for the EMAS sectoral reference document on best environmental management practices for the agriculture - crop and animal production sector. Editors: Canfora P., Dri M., Antonopoulos I.S., Styles D. Williamson J., ISSN 1831-9424 (online), doi:10.2791/46615.
- EFMA, c.2012. FARMING FOR THE FUTURE: How mineral fertilizers can feed the world and maintain its resources in an Integrated Farming System. EFMA. Accessed at: <http://www.sustainable-agriculture.org/stuff/EFMA%20Farming%20for%20the%20Future.pdf>
- EFP 2010. Planning for biodiversity: A guide for BC farmers and ranchers, Canada-BC, Environmental Farm Plan, available online: <http://www.bcac.bc.ca/sites/bcac.localhost/files/Biodiversity%20Guide%20Chapter%201%20-%20Overview.pdf>, accessed February 2015.
- EISA, 2010. *European Integrated Farming Framework. A European Definition and Characterisation of Integrated Farming (IF) as Guideline for Sustainable Development of Agriculture*. Revised version, August 2010. Accessed at: <http://www.sustainable-agriculture.org/stuff/EISA-Framework-english-040810.pdf>
- FSS. (2010). Farm Structure Survey. Website accessed December 2010: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Farm_structure_survey_%28FSS%29.
- Garrigues E., Corson M.S., Angers D.A., van der Werf H.M.G., Walter C. 2012. Soil quality in Life Cycle Assessment: Towards development of an indicator, *Ecological indicators*, 18, 434-442.
- GRI, 2011. *Approach for reporting on ecosystem services: Incorporating ecosystem services into an organisations performance disclosure*, GRI, Amsterdam. ISBN: 978-90-8866-0528.

- Haddaway, N.R., Styles, D., Pullin, A.S., 2013. What are the environmental impacts of farm land abandonment in high altitude/mountain regions: a systematic map of the evidence. *Environmental Evidence*, 2, 18: doi:10.1186/2047-2382-2-18
- IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>
- IPIECA, 2011. *Ecosystem services guidance: Biodiversity and ecosystem services guide and checklists*. IPIECA (The global oil and gas industry association for environmental and social issues), London.
- LEAF, 2012. *LEAF Marque Global Standard version 10.0 – issued 01/10/12*. LEAF, UK.
- Luscher G., Schneider M.K., Turnbull L.A., Arndorfer M., Bailey D., Herzog F., Pointereau P., Richner N., Jeanneret P. 2014. Appropriate metrics to inform farmers about species diversity, *Environmental science & policy*, 41, 52–62.
- MEA, 2005. *Ecosystems and Human Well-being: Synthesis*. MEA, Washington DC. ISBN 1-59726-040-1
- Pointereau, P., Coulon, F., Girard, P., Lambotte, M., Stuczynski, T., Sanchez Ortega, V., Del Rio, A., Anguiano, E., Bamps, C., Terres, J, 2008. *Analysis of farmland abandonment and the extent and location of agricultural areas that are actually abandoned or are in risk to be abandoned*. Ispra: JRC.
- Rieger Farm, 2013. *Umwelterklärung 2013 Landwirtschaftsbetrieb*. Ernst and Birgit Rieger, Blaufelden, Raboldshausen.
- Jeanneret P., Baumgartner D., Knuchel R.F., Gaillard G. 2008. Integration of biodiversity as impact category for LCA in agriculture (SALCA-Biodiversity). ©Agroscope Reckenholz-Tänikon Research Station ART, 12 November.
- Lefebvre M., Espinosa M., Gomez y Paloma S. 2012. The influence of the Common Agricultural policy on agricultural landscapes, JRC Scientific and policy Reports. ISSN 1831-9424, doi: 10.2791/94269
- Williams A. and Gianessi L. 2011. Fumigation Makes Spain the #1 Exporter of Strawberries in the World. International Pesticide Benefits Case Study No. 17, September.

3.1.1 Examples of strategic farm management priorities in different regions

UK farmer collaboration for water management

See the pontbren case study in section 3.3.1.

UK dairy farm recommendations

Burns et al. (2012) in DEFRA (2012) propose that the environmental impact of dairy farms in the UK can be most effectively reduced by increasing cropping diversity and/or within sward diversity to increase the heterogeneity of grassland and other forage species. In particular, they note that mixed grass and cereal production for animal feed could improve biodiversity (especially for bird species), and highlight the superiority of cereals over maize in terms of biodiversity. They also recommend better integration of dairy, beef and arable production. These measures could improve biodiversity, nutrient use efficiency, soil structure and result in other environmental benefits.

Netherlands dairy farm recommendations

In the Netherlands, the most valuable ecosystem service provided by intensive dairy farms is considered to be milk. Therefore, the priority for Dutch dairy farms is to maintain or expand output within regulatory nutrient balance constraints. Geert (deMarke, October 2013) suggests that the challenge for Dutch farmers after milk quotas are lifted in 2015 will be to shift the mindset from “how to minimise resources for fixed output” to “how to maximise output from fixed resources”.

UK arable farm case study

Morley Farms is a 700 ha farm located within an NVZ in southeast England, growing winter wheat, oil seed rape, barley and sugar beet on light sandy loam or loamy sand soils that are low in organic matter following decades of depletion (typical of UK arable soils). The farm is managed by a farm manager on behalf of a charity trust, which is cited as a reason for longer-term investment and sustainability decisions. The farm manager (Morley Farms. 2013) emphasises the importance of experience and patience to inform management decisions on a daily and yearly basis. An important issue related to optimised timing is to have the correct equipment well maintained (not necessarily new), and well-motivated staff, so that operations can be carried out rapidly when required during ideal drilling or harvesting windows.

Morley Farms invested €400,000 in a new grain store that provides greater flexibility in the timing of harvest operations and selling produce to maximise revenue. For example, by selling oil seed rape in September rather than August immediately after harvest, Morley Farms received €11 more per tonne, netting an additional €7,000. An additional benefit was that more resources could be directed towards harvesting other crops during the harvest season, rather than securing sales. Furthermore, the farm manager foresees stricter regulations on food storage facilities, and the new sheds are seen as future-proofed against such regulations. A final point is that the sheds have an asset value in themselves, making simple payback calculations irrelevant. A whole-farm (strategic) perspective is required to make economically and environmentally sound decisions.

Rieger arable farm, Germany

Rieger Farm is an arable farm located in Blaufelden, Germany, that cultivates wild flowers for seed and medicinal plants (Figure 3.7), and holds EMAS accreditation. This is an example of where a farmer has identified an opportunity to manage their farm in an environmentally friendly manner and represents a strategic approach to environmental management of a farm.

- Biodiversität: Anbauflächen von Wildkräutern, -gräsern und -gehölzen in Blaufeldern:



Kräuterparzellen zur Saatgutproduktion



Anbau Zittergras



Anbau Wegwarte



Pflanzung heimischer Sträucher zur Saatgutgewinnung



Agroforst-Anpflanzungen zur Saatgutgewinnung heimischer Gehölze

Figure 3.7. Extract from the environmental statement of Rieger Farm (Rieger Farm, 2013)

3.2 Embed benchmarking in environmental management

Description

This BEMP is mapping out a framework for systematic monitoring as well as reporting the farm performance at the process level. The main objective is to set quantitative benchmarks against best achievable performance wherever possible. The focus of this particular BEMP is the establishment of a framework and procedures for performance benchmarking across the farm: specific indicators and benchmarks are detailed throughout the remainder of this report.

An Environmental Management System (EMS) provides an organisation with a framework for managing its environmental responsibilities efficiently, with respect to reporting and performance improvement. Implementation of an effective EMS should lead to continuous improvement in management actions, informed by monitoring key performance indicators related to those actions (Figure 3.8).

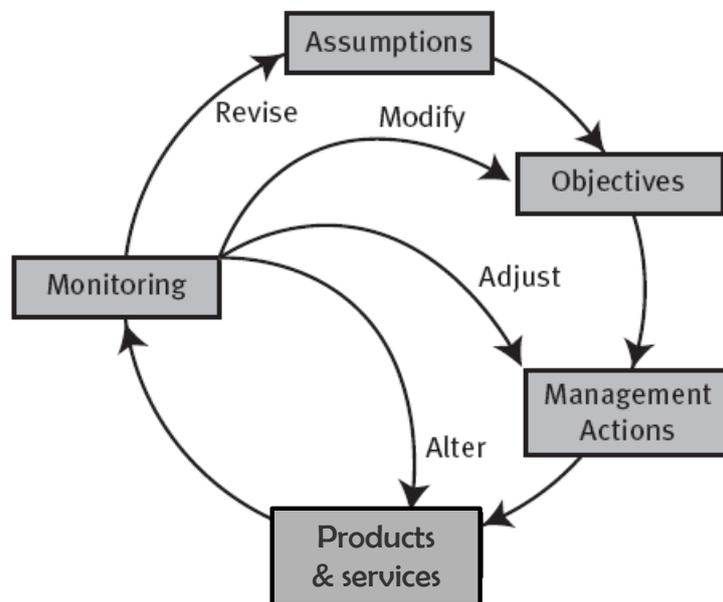


Figure 3.8. The continuous planning and improvement cycle (modified from SCBD 2007).

In the first instance, a strategic business plan should be established for the farm to address long term strategy in relation to anticipated pressures and challenges. A more detailed environmental management plan may be drawn up and implemented to achieve strategic goals. Table 3.3 summarises EMS implementation in relation to the Plan-Do-Check-Act approach, and highlights the relevant aspects of this report for each stage. Key points are the establishment of an organisation level environmental policy, followed by the development of action plans with specific targets. These should be informed by an awareness of what is commercially achievable, as described in BEMP techniques and quantified by associated benchmarks of excellence in subsequent sections of this report.

The identification of significant environmental aspects is the first stage of environmental management, and as part of accredited EMS requirements enterprises must perform an environmental review. Following the environmental review, the monitoring of relevant environmental performance indicators forms a reference point for implementation of best practice in cross cutting issues (this chapter), soil and nutrient management (chapters 4 and 5), grass management (chapter 6), soil preparation and arable practices (chapter 7), animal husbandry (chapter 8), manure management (chapter 9), irrigation (chapter 10), crop protection from weeds, pests and disease (chapter 11) and protected horticulture (chapter 12).

Table 3.3. Stages of the Plan-Do-Check-Act cycle, with reference to relevant use of this report

Cycle stage	Management activities/steps	Relevant environmental management tool (use of this report)
Plan	<ul style="list-style-type: none"> – Identify priority issues (significant environmental aspects) – Establish a policy to address these issues – Identify performance standards and improvement opportunities (best practice) – Allocate specific responsibilities – Set objectives and targets – Prepare action plans, programmes and procedures for achieving (performance) objectives 	Environmental review (refer to relevant best practice techniques and benchmarks of excellence for particular processes)
Do	<ul style="list-style-type: none"> – Responsible persons implement plans, programmes and procedures 	Standards and procedures (implement best practice techniques)
Check	<ul style="list-style-type: none"> – Monitor results – Evaluate performance against objectives and targets – Determine reasons for deviations and non-conformances 	Environmental monitoring and management audit (use appropriate indicators, compare with benchmarks of excellence)
Act	<ul style="list-style-type: none"> – Take corrective action for non-conformances – Consider performance and adequacy of system elements in relation to targets – Identify changing circumstances – Modify system elements, including policy, objectives, targets, responsibilities, plans, programmes, procedures 	Management review (re-assess relevance of particular best practice techniques and benchmarks of excellence for particular processes)

Guidelines for generic EMS implementation and resource efficient management on farms have been produced by various sources. A selection of these is listed under ‘Appropriate environmental indicators’, below. A wide range of free online tools are also available to facilitate management decision making by farmers and farm advisors. Examples of relevant tools are provided in subsequent BEMP sections of this report, and some of these are also listed under ‘Operational data’ section below.

In summary, best practice is to devise a farm management plan based on selective quantitative indicators for resource efficient management, life cycle assessment indicators for food production and relevant indicators of ecosystem service provisioning. Full use should be made of relevant freely available tools to assist farm management. This is in addition to full regulatory compliance. An important aspect to ensure EMS implementation is the development of a clear protocol for major operations and the training of staff to follow them, especially regarding Nutrient Management Planning (NMP) and pesticide management.

Achieved environmental benefits

Effective implementation of some form of EMS (at a minimum monitoring) is a prerequisite for, and often directly leads to, the realisation of continuous improvement across key environmental pressures. It is the starting point from which to realise environmental benefits associated with BEMP techniques described throughout this report. Front-runners in EMS implementation are also front-runners in environmental performance.

Appropriate environmental performance indicators

Quantitative indicators

Appropriate environmental indicators are measured at the process level and associated with best practice techniques described subsequently. Best practice is for farmers to systematically identify the indicators and best practice techniques relevant to their farm. Note that in many cases indicators critical to environmental or resource efficiency are also important for farm productivity and financial performance. The quantitative systems approach encouraged by an EMS creates additional impetus to

use indicators that should already be used for farm profit maximisation. Table 3.4 relates some of the key quantitative performance indicators identified for BEMP techniques throughout this report to major types of farm system.

Table 3.4. A selection of relevant environmental performance indicators for different farm systems (shaded cells identify farm systems for which indicators most important where indicators apply to multiple farm systems)

	Dairy	Beef	Sheep	Pig and poultry	Crops	Protected horticulture
Energy						
Field energy, L diesel/ha/yr	✓	✓	✓	✓	✓	✓
Animal housing energy, kWh/m ² /yr	✓			✓		
Greenhouse heating, kWh/m ² /yr						✓
Transport to retail, MJ/kg product						✓
Renewable energy generation, kWh/yr	✓	✓	✓	✓	✓	✓
Soils						
Erosion, tonnes/ha/yr	✓	✓	✓	✓	✓	✓
Infiltration capacity, mm/hour	✓	✓	✓	✓	✓	✓
Soil organic matter content, % mass	✓	✓	✓	✓	✓	✓
Soil nutrient status, mg/kg soil	✓	✓	✓	✓	✓	✓
GHG emissions						
Product footprint, kg CO ₂ e/kg product exported	✓	✓	✓	✓	✓	✓
Farm carbon footprint, kg CO ₂ e/yr	✓	✓	✓	✓	✓	✓
Animal feed						
Feed digestibility, D%	✓	✓	✓	✓		
Feed conversion ratio, %	✓	✓	✓	✓		
kg concentrate per kg output	✓	✓	✓	✓		
Silage dry matter loss, %	✓	✓	✓			
Green procurement, % certified	✓	✓	✓	✓		
Green procurement, % soy-based feed	✓	✓	✓	✓		
Manure management						
Housing loss NH ₃ -N, % TAN	✓	✓	✓	✓		
Anaerobic digestion, % slurry	✓	✓	✓	✓		
Storage loss of NH ₃ -N, % TAN	✓	✓	✓	✓		
Storage loss of CH ₄ , % MCF	✓	✓	✓	✓		
Application loss NH ₃ -N, % TAN	✓	✓	✓	✓		
Water						
Irrigation, m ³ /ha/yr					✓	✓
Drinking water, L/LU/yr	✓	✓	✓	✓		
Water footprint ¹³ , L/kg output	✓	✓	✓	✓	✓	✓
Waste						

¹³ The water source should always be defined by the farmer e.g. grey, blue or green water

kg/ha/yr waste generated	✓	✓	✓	✓	✓	✓
Kg/ha/yr to landfill	✓	✓	✓	✓	✓	✓
% “waste” reused or recycled	✓	✓	✓	✓	✓	✓
Biodiversity						
Non-farmed “natural” habitat, % area	✓	✓	✓	✓	✓	✓
Native species, number	✓	✓	✓	✓	✓	✓

Accreditation

One important indicator of EMS implementation is accreditation according to one of the many schemes that address important aspects of environmental management, some of which are listed under ‘Operational data’, below, and which include ISO 14001, LEAF, GlobalGAP, Organic certification, etc – in addition to EMAS. However, the purpose of this report, and the revised EMAS regulation, is to support performance-oriented environmental management by providing guidance on pertinent quantitative indicators and benchmarks of excellence at the process level, related to BEMPs.

Cross-media effects

Cross-media effects associated with implementation of specific techniques are described in subsequent sections. Successful implementation of an EMS involves assessment of all major environmental aspects and processes, so that actions are targeted to minimise negative environmental (and social and economic) consequences. Often, efficiency measures have multiple benefits. For example, optimised feed dosing minimises the upstream GHG emissions, eutrophication, acidification and resource depletion burdens associated with feed production, and also enteric fermentation GHG emissions. Closed slurry storage avoids CH₄ and NH₃ emissions, and also leads to higher Nutrient Use Efficiency (NUE) and therefore lower fertiliser N manufacture.

Operational data

Systematic implementation of best practice measures

Farm managers and consultants may refer to the index of this report for the crop and animal production sector to identify BEMP techniques relevant to their farm. The performance of their farm may then be compared against the proposed benchmarks of excellence to identify the environmental improvement potential and associated economic implications. Where there appears to be significant improvement potential, the possibility to apply proposed best practice measures can be assessed. Best practice is to perform this systematically across relevant departments and processes.

Good practice advice

Farm advisory services play an important role in disseminating best practice to farmers. This advice should be delivered via independent and trusted advisors trained in agronomic and environmental issues. A UK Parliamentary report (UK Parliament, 2011) noted that the provision of agricultural advice in the UK has become fragmented and disjointed since being outsourced to private consultants and farm suppliers. More effective examples of farm advisory services include Denmark’s farmer-owned service (UK Parliament, 2011) and Ireland’s Teagasc – a national organisation responsible for both agricultural research and advisory services (Hamell, 2013). National governments have an important role to play in sustainable farming by ensuring effective farm advisory services are in place.

A range of online sources of good practice guidance also exist and may be accessed by any farmer or farm advisor. These include:

- EISA (European Initiative for Sustainable development in Agriculture). EISA promote and provide guidance on integrated farming through an ‘all-farm approach’ that encourages farmers to act according to their site and situation to achieve continuous improvement via detailed planning and evaluation. An extensive guidance document (EISA, 2012) is available on the website: <http://sustainable-agriculture.org/>

- FAO Good Ag Practices <http://www.fao.org/prods/gap/>
- Netherlands farmer advice website: <http://www.bureaumestafzet.nl/home>
- New Zealand dairy farmer advice booklet: <http://www.es.govt.nz/media/5868/fde-dairy-booklet.pdf>
- Index to agricultural sustainability indicators and data from across Europe: <http://www.agribenchmark.org/>
- Spanish sustainable agri-environmental indicators can be found at the following link: www.agriculturasostenible.org
- Sustainable Agricultural Initiative provides an extensive library of best practice case studies and advice: <http://www.saipatform.org/>

Decision support tools

There has been a proliferation of decision support tools in recent years. Some of these tools are very useful, and provide valuable information to measure and improve resource efficiency on farms. A selection of a few such tools is listed below in Table 3.5, and throughout this report.

Table 3.5. A selection of tools available to assist farm management

Aspect	Tool	Applicability	Source
Greenhouse gas emissions	Cool Farm Tool	All farm types, Europe and US	http://www.coolfarmtool.org/CoolFarmTool
	EBLEX “What If” E-CO ₂	UK sheep, beef and dairy farms	http://www.eco2project.com/WhatIfTool.aspx#
Manure management	MANNER -NPK	All farm types in UK	http://www.planet4farmers.co.uk/Manner
Nutrient management	PLANET		http://www.planet4farmers.co.uk/Content.aspx?name=PLANET
Nutrient management	European tools linked to Dairyman project	European dairy farms	http://www.interregdairyman.eu/tools/fertilisation/
Grassland management			http://www.interregdairyman.eu/nl/tools/grassland-management/
Herd management			http://www.interregdairyman.eu/tools/herd-management/
Farm systems			http://www.interregdairyman.eu/tools/farm-systems/
Sustainability			http://www.interregdairyman.eu/tools/sustainability/
Environment			http://www.interregdairyman.eu/nl/tools/environment/

Staff training

It is recommended that sustainability issues are included in basic training for all levels of staff. This includes induction training where environmental objectives and the rationale behind them can be explained alongside practical actions. It is particularly important to establish a link between individual actions and aggregate environmental benefits. A sequence of key principles for effective staff training is listed below:

- Clarify definitions to ensure that objectives and actions are understood by everyone.
- Include practical experience at all levels of training, and include study visits to demonstrate best practice in action where possible.
- Motivate staff with competitive objectives, including those for the organisation, to become environmental front-runners.
- Ensure that responsibilities are clearly defined.
- Encourage staff feedback and suggestions for environmental management.
- Analyse and evaluate reasons why best practices are not applied and improve training through review-loops to improve performance (including staff feedback).

Applicability

All types of farms can implement an EMS. It is likely to be easier for large intensive farms with digitised record keeping and continuous monitoring systems to implement a formal EMS. Nonetheless, EMS is equally applicable to smaller farms, and may eventually lead to greater environmental improvement on such farms by encouraging systematic performance monitoring and optimisation.

Economics

Implementation of an EMS leads to the identification of efficiency savings detailed for BEMP techniques in subsequent sections. The main objective of most BEMPs in this report is to minimise resource consumption per unit of output. In particular, many BEMPs lead to higher NUE, reducing fertiliser costs per unit of output.

A survey of over 100 LEAF members (LEAF, 2012) found that the average saving for adopting LEAF's Integrated Farm Management was £14,000 (€16,500) or £40 per hectare per year (€ 47/ha/yr). Sixty four percent of LEAF members agreed that they had found savings by adopting LEAF's Integrated Farm Management. The survey also found that 84% of LEAF members had improved their environmental performance. The cost of LEAF membership varies from £72 per a farm < 121 ha to £288 for a farm over 700 ha, so it appears that there is a good return on investment.

Driving forces for implementation

As demonstrated above, the systems approach of EMS can be particularly beneficial for farms, to stimulate critical appraisal of practices and elucidate options for resource efficiency that are not obvious from day-to-day observations (e.g. by quantifying “invisible” N losses from manure management). A range of factors encourage farms to implement an EMS. Objectives of EMS implementation either certified or not include:

- identify and implement opportunities to improve operational efficiency
- manage environment-related risks and liabilities, for example related to regulation
- gain access to supply chains where buyers are demanding environmental accountability.

Reference organisations

- Dutch milieukeur lable
- EISA
- LEAF
- GQSBW

Reference literature

- Baden Württemberg, 2014. Whole farm quality assurance for agricultural enterprises in Baden-Württemberg. Available online: <http://www.lel-bw.de/pb/Lde/Startseite/Markt+und+Ernaehrung+mit+Landesstelle/Qualitaetssicherung>, accessed February 2014.
- CCRI, 2010. The Benefits of LEAF Membership: a qualitative study to understand the added value that LEAF brings to its farmer members. Countryside and Community Research Institute, UK. Available online: [http://www.sustainable-agriculture.org/stuff/The%20Benefits%20of%20LEAF%20Membership%20Final%20Report%20\(3\).pdf](http://www.sustainable-agriculture.org/stuff/The%20Benefits%20of%20LEAF%20Membership%20Final%20Report%20(3).pdf), accessed February 2014.
- deHaan, 2013. Personal communication December 2013. 2012 data from farms participating in the Cows and Opportunities project. Wageningen University, Netherlands.

- EISA, 2012. *European Integrated Farming Framework. A European Definition and Characterisation of Integrated Farming (IF) as Guideline for Sustainable Development of Agriculture*. Revised version, February 2012.
- EFMA, c.2012. FARMING FOR THE FUTURE: How mineral fertilizers can feed the world and maintain its resources in an Integrated Farming System. EFMA. Available online: <http://www.sustainable-agriculture.org/stuff/EFMA%20Farming%20for%20the%20Future.pdf>, accessed February 2014.
- Hamell, personal communication 15.03.2013, Brussels.
- Kringloop Wijzer, 2013. Project 'Annual Nutrient Cycling Assessment (ANCA)'
- LEAF, 2012. *LEAF Marque Global Standard version 10.0 – issued 01/10/12*. LEAF, UK.
- UK Parliament, 2011. European Union Committee - Nineteenth Report. Chapter 5: Knowledge transfer and innovation systems. Downloaded February 2014 from: <http://www.publications.parliament.uk/pa/ld201012/ldselect/ldecom/171/17108.htm>

FINAL DRAFT

3.2.1 Quantitative environmental management case studies

Dutch dairy farms

A group of Dutch dairy farms involved in the ANCA project provide an excellent example of best practice in quantitative (environmental) performance measurement (deHaan, 2013). The objective of the ANCA project is to develop a tool which can calculate the N, P and C cycles of individual dairy farms based on readily available and verifiable data. This tool is intended to produce a set of indicators that can be used to demonstrate farm resource efficiency towards governments and milk processors, in addition to informing optimised management. Stakeholders from the Dutch dairy industry have agreed that, from the beginning of 2015, the use of ANCA should be mandatory for all dairy farms that produce more excrement than they are permitted to apply on their own fields (about 250 kg N/ha and 90 kg P₂O₅/ha/y). For the less intensive farms the use of ANCA will strongly be encouraged.

Estimating the cycles on the dairy farm follows a step-by step procedure and ultimately leads to the following indicators, quantified on an annual basis (illustrated in Figure 3.9).

1. Manure production: nitrogen (N) and phosphate (P₂O₅) excretion of cattle (kg/ha);
2. Efficiency of feeding: conversion of N and P₂O₅ from feed into milk and meat (%);
3. Ammonia (NH₃) emission, divided over housing, manure storage, grazing, manure spreading and mineral fertiliser application (kg/ha);
4. Yield grassland and maize land: dry matter, N, and P₂O₅ (kg/ha) and energy (kVEM/ha),
5. Efficiency of fertilisation: conversion of N and P₂O₅ from chemical fertilisers and organic manures into crop yield (%);
6. Soil surplus N, P₂O₅ and C (including the longer term development of soil stores; kg/ha);
7. Nitrate (NO₃) in groundwater (mg/l);
8. Emission of the greenhouse gases methane (CH₄), nitrous oxide (N₂O) and carbon dioxide (CO₂) (kg/ha);
9. Farm surplus N, P₂O₅ and C (kg/ha);
10. Efficiency of farming: conversion N and P₂O₅ from bought product (mainly feeds and fertilisers) into sold milk and animals (%).

Reference and normative values are added to the farm performance. Reference values may be the average values achieved by farms under similar conditions or, e.g. the values of the 25% best performing farms. Normative values can be values for 'good agricultural practice' or values on which legislation is based. As an example, the European Nitrate Directive stipulates that the nitrate concentration of groundwater should not exceed 50 mg/l. This is the normative value. Reference and normative values allow the farmer to compare the performances of his farm with those of his colleagues as well as with the target values laid down by the government.

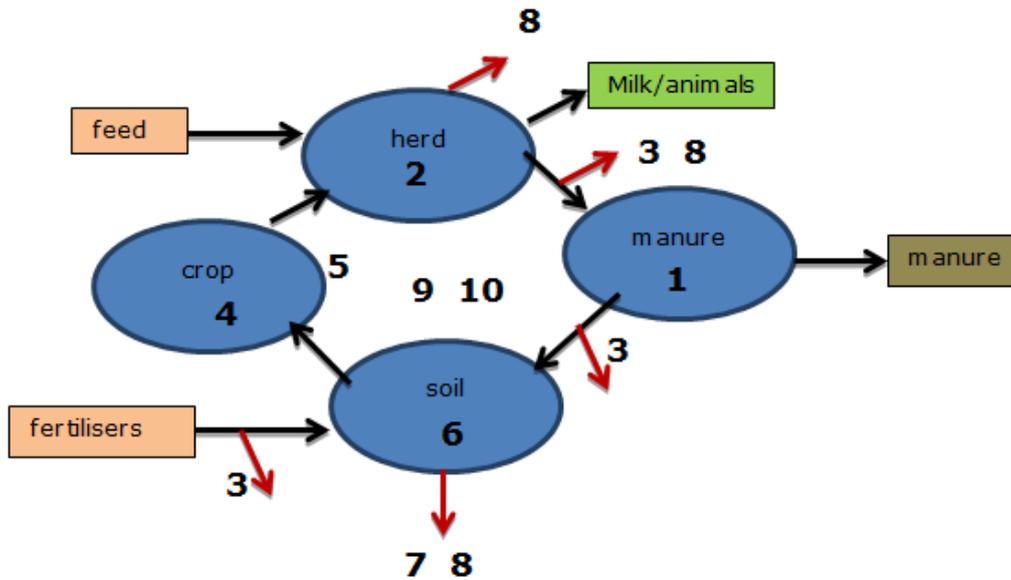


Figure 3.9. An example of the phosphorus cycle on a dairy farm (Kringloop Wijzer, 2013)

ANCA does not account for off-farm emissions from e.g. imported feed production, but it is noted that such emissions can be expressed as a coefficient per unit purchased product. A farmer should be aware that off farm emissions can be reduced by buying products with lower coefficients. The ANCA tool is a modular extension of BEX, a calculation tool developed by the Cows & Opportunities project that quantifies the herd part of the N and P farm cycles. It calculates the farm specific excretion of the herd as feed intake minus the production of milk, calves and additional bodyweight. Most Dutch dairy farmers are already using BEX. ANCA and similar tools, work well for specialised systems. Benchmarking is more difficult for mixed farms. Data from ANCA farms are presented in Chapter, in relation to animal husbandry best practice benchmarking.

Dutch Milieukeur label

The Dutch Milieukeur label provides an example of rigorous, performance oriented environmental management, based on clearly defined criteria that address environmental hotspots for intensive livestock systems. A score board approach is used to rate farms, based on, amongst others, the following criteria (Harm Smit, 2013):

- Ammonia emissions: Stables must be an ammonia reducing system that reduces ammonia emissions more than legally required.
- Animal welfare: Stable measures should be taken to improve the well-being of the animal.
- Animal health: In this theme the measures are based on three principles: prevention of diseases entering the farm, preventing a disease from spreading within the farm, and improving the resistance of the animal in the stable.
- Energy and CO₂ emissions: The measures will contribute to reduce greenhouse gas emissions through energy conservation and generation of renewable energy for use on the farm.
- Particulate matter: Measures are aimed at reducing emissions of particulate matter to the environment and the reduction of particulate matter in the animal quarters within the stable.
- Company & environment: This theme is divided into four subjects. Landscape is the most significant. The others are environmental orientation, disturbance (odour, noise, light) and water.

The system works with a score board. All measures that could be taken by farmers are rated with sustainability points. There are basic standards for each of the sustainability issues. On top of that, farmers earn additional points for specific issues to get a final minimum score. The farmer is allowed to choose on which specific issue or issues these additional points are earned. For farms with large numbers of animals there is a higher level of ambition for the critical issues of animal welfare and health: the minimum number of points for these issues is related to the number animals on the farm. As an independent body certifies the stable, the determination of farm size (number of animal places)

is determined independently, rather than being based on self-reported dimensions. The minimum number of points on the metrics mentioned is related to firm size counted in nge (Dutch size unit) and defined at three levels:

- Company size ≤ 350 nge
- Company size > 350 and ≤ 700 nge
- Company size > 700 nge

The scoring board for sustainable animal husbandry is developed for the animal categories ducks, turkeys, rabbits, hens, goats, dairy cattle, pigs, calves, chickens (meat and eggs) and beef cattle.

There are also scoring board for sustainable greenhouses (green label) and sustainable aquaculture.

Further information on the Milieukeur label can be found (in Dutch) at:

- <http://www.milieukeur.nl/232/english/the-dutch-environmental-quality-label-milieukeur.html>
- <http://www.maatlaturzameveehouderij.nl/31/home.html>

Whole farm quality assurance for agricultural enterprises in Baden-Württemberg

GQS_{BW} is a whole farm quality assurance scheme for agricultural enterprises in Baden-Württemberg, Germany. GQS_{BW} is a comprehensive tool for self-monitoring and documentation for agricultural enterprises. GQS_{BW} consists of three folders. Those contain checklists, filing plans, printed forms, leaflets and a wall calendar. In terms of content, GQS_{BW} covers both the legal regulations of good agricultural practice (e.g. regulation for the use of fertilizer, animal welfare, drug use and of Cross Compliance as well as the requirements of the most important private quality assurance programs (e.g., QS, QM-milk, GLOBALPGAP, QZBW). GQS_{BW} is not an additional quality assurance program but an effective working tool that supports the farmer in carrying out their requirements of self-control and record keeping. GQS_{BW} is updated annually. The use is voluntary. GQS_{BW} can be ordered as a full print version or as editable eGQS_{BW} PC program (see the online order form). With the internet application GQS_{BW} online you can also create and print your company-specific version. GQS_{BW} is an approved FAS (Farm Advisory System).

Reference literature

- deHaan, 2013. Personal communication December 2013. 2012 data from farms participating in the Cows and Opportunities project. Wageningen University, Netherlands.
- Kringloop Wijzer, 2013. Project ‘Annual Nutrient Cycling Assessment (ANCA)’, edited by: Aarts F. and de Haan M.

3.3 Landscape water quality management

Description

Catchment sensitive farming refers to land management at a catchment scale to minimise water pollution via nutrient, agrochemical, sediment and pathogen runoff. At the highest level, it involves management of hydrologically defined river basins, to identify land for priority measures such as the establishment of integrated constructed wetlands. This represents good implementation of River Basin Management Plans (RBMP) required under the Water Framework Directive. A major challenge for effective catchment sensitive farming at this level is achieving coordination and “buy-in” across land owners.

At the farm level, catchment sensitive farming comprises an assortment of individual, often small, measures that can collectively achieve a significant improvement in water quality and flow regulation if implemented across farms. Key measures include:

- Establishment of buffer strips
- Establishment of integrated constructed wetlands at strategic catchment locations
- Maintaining good soil quality
- Establishment of cover crops to reduce winter nutrient runoff
- Ensuring appropriate timing and method of manure application

Ultimately, catchment sensitive farming is a cross-cutting issue that comprises many separate actions related to a wide range of processes on farms. Some of the most important aspects of management described elsewhere in this report are listed in Table 3.6.

Table 3.6. Important aspects of catchment sensitive farming addressed elsewhere in this report

Aspect	BEMP	Relevant report section
Maintaining good soil structure	Assessing soil condition	Section 4.1
	Maximising organic matter amendments	Section 4.2
	Maintaining soil structure	Section 4.3
	Managing soil drainage	Section 4.4
	Appropriate timing of soil preparation	Section 6.1
	Low impact soil preparation	Section 6.2
	Crop rotations for soil quality	Section 6.4
	Establish cover crops	Section 6.5
Nutrient management planning	Field nutrient budgeting	Section 5.1
	Crop rotations for nutrient cycling	Section 5.2
	Precision application of fertilisers and manures	Sections 5.3, 9.3, 9.4, 9.5 and 9.6
	Nutrient budgeting on livestock farms	Section 8.2
	Dietary reduction of nutrient excretion	Section 8.3
Grazing management	Managing extensive grazing	Section 7.2
	Pasture renewal and legume inclusion	Section 7.3
Irrigation management	Minimise irrigation	Section 10.1 and 10.2
Crop protection	Implement integrated pest management	Section 11.1
	Select less toxic active ingredients	Section 11.2

Best practice is to implement all relevant BEMPs listed in Table 3.6. The main measures that will be described in this section, specifically addressing water quality management, are:

- Establishment of buffer strips
- Establishment of integrated constructed wetlands at strategic catchment locations

- Site-appropriate drainage systems (e.g. maintain or block existing systems as appropriate to the soil type and hydrological connectivity with water bodies)
- Catchment level management planning, including coordination of land management across farms
- Identify signs of soil erosion

Integrated constructed wetlands

One example of catchment sensitive farming is the establishment of integrated constructed wetlands – shallow wetlands containing emergent macrophytes that essentially filter runoff water. According to McInnes (2014), integrated constructed wetlands are defined by the integration of the following objectives:

- Regulation of water quality and quantity
- Landscape fit
- Enhanced biodiversity
- Social, environmental and economic coherence

This implies strategic planning with respect to their location within a farm and the wider catchment.

Buffer strips

Maintain areas adjacent to water courses without fertiliser and agrochemical applications, as per regulations – 6 m to water courses for precision application, 10 m for general application methods, but in addition avoid intensive animal grazing (see also BEMP 5.1) and plant trees such as willows to: (i) provide natural animal and wind barrier; (ii) intercept runoff and sediment; (iii) mop up nutrients and (iv) provide source of energy is harvested. The latter options mean that the land area is still “productive” and therefore eligible for agri-payments. Planting buffer strips with trees or wild grasses provides maximum biodiversity benefit, in addition to runoff-water interception benefits.

Appropriate drainage

Drainage is discussed further in section 4.3 with respect to soil structure and section 4.4 with respect to artificial drainage. Good guidance on sustainable rural drainage systems is provided in Environment Agency (2012).

Achieved environmental benefits

Cumulative benefits

The main cumulative benefits of effective and widespread catchment sensitive farming measures are:

- Reduced erosion and stream sediment concentrations
- Reduced nutrient losses and stream eutrophication
- Reduced rates of surface runoff (reduced flood risk downstream)
- Potentially enhanced biodiversity within catchments and water courses

Extensive grassland management

Restoring semi-natural grasslands in strategic locations within catchments can lead to significant improvement in water quality. Ross (2014) presented the following benefits attributed to the restoration of Culm grassland in southwest England:

- Sediment and particulate phosphorus (P) down by 78-90%
- Soluble P and faecal indicator organisms down by 60-68%
- Nitrate and nitrite down by 53-60%
- Ammonium down by 53%.

Integrated constructed wetlands

Integrated constructed wetlands have been linked with large improvements in river water quality, especially in terms of sediment and nutrient concentrations. Some of the main advantages and disadvantages of integrated constructed wetlands are summarised in Table 3.7.

Buffer strips

EC (2013) reported the following primary and secondary benefits of buffer strips (Table 3.8).

Table 3.7. Main benefits and disadvantages of integrated constructed wetlands

Benefits	Disadvantages
<ul style="list-style-type: none">– High NO₃ removal rate– High P removal rate– High SS removal rate– Carbon sequestration in vegetation	<ul style="list-style-type: none">– Large land area– CH₄ emissions

Table 3.8. Primary and secondary benefits of buffer strips reported in EC (2013)

Primary benefits	Secondary benefits
<ul style="list-style-type: none">– Reduce pollutants and nutrients from entering water through retardation of flow, deposition of sediment and sediment-bound contaminants, interception by vegetation, plant uptake, and infiltration– Protect against overland flow from agricultural area and prevent run-off– Reduce pesticide loading– Vegetative buffers are effective at trapping sediment from runoff and at reducing channel erosion– The water vegetation and the area around the base of the river bank offer shelter for many species of macro-zoobenthos	<ul style="list-style-type: none">– Considerable improvement for the whole agricultural ecosystem– Positive effects also on biodiversity by creating “ecological corridors”– Potential to sequester C in the soil and via tree planting– Harvesting biomass from the buffer zone, if carried out without destroying it, could offset the costs of using land for buffers rather than food crops– Improvement of soil quality and prevention of soil erosion, soil conservation– For riparian woodland, benefits of shade, shelter and C sequestration

EC (2013) report the following quantified benefits for 5 m wide buffer strips:

- 15-20% reduction in total runoff (10% in meadows)
- 42-96% reduction in P loading to water (hilly areas)
- 27-81% reduction in N loading to water (hilly areas)
- 55-97% reduction in particulate loading to waters (hilly areas)
- 83-90% reduction in organic matter loading to waters (hilly areas)

Appropriate environmental performance indicators

The indicators for this BEMP are distinguished into two categories, the water quality and the farm indicators.

Water quality indicators

The following key water quality indicators are routinely measured and can be used to monitor the efficacy of catchment sensitive farming measures at the catchment scale:

- Stream total phosphorus or phosphate concentrations (ug/L)
- Stream total N or nitrate concentrations (mg/L)
- Stream suspended solid concentration (mg/L)
- Stream dissolved organic carbon concentration (mg/L)
- Faecal indicator organisms (colony forming units/mL)

Farm indicators

- Soil nutrient status (see section 5.1)
- Implementation of a soil management plan, including erosion risk mapping (section 4.1)

- Visible indicators of soil erosion (rills, gulleys, deposited sediment banks – see pictures under ‘Operational data’ section)
- Buffer zones of at least 10 m in width are established adjacent to all water courses, where tillage and grazing excluded
- Farmers work collaboratively with neighbouring farmers and river basin managers from relevant authorities

Cross-media effects

The establishment of integrated constructed wetlands and buffer strips involves removing agricultural land from food production, potentially displacing food production to other (high nature value) areas. However, the land used for such measures is usually wet and of low productivity. Good management of wetland and buffer areas can improve drainage and productivity in neighbouring and downstream fields. In addition, use of buffer zones for e.g. willow biomass production can provide useful fuel or animal bedding material.

Operational data

Soil erosion risk mapping

Although difficult to precisely measure, erosion is highly visible and can be readily identified through field inspection (Figure 3.10). Best practice is to map fields in terms of soil types and slope to identify fields with higher erosion risk, and to avoid high erosion risk crops such as potatoes on those fields.



Raindrop impact on bare land over winter causes dislodgement of soil particles and can initiate erosion.



Deposition of sediment at the bottom of slopes is a clear indication of erosion.



An example of rill erosion, which is likely to occur on slopes that have been cultivated parallel to the slope, rather than to contours (see contour ploughing, chapter 8).



An example of gully erosion, where rills converge and expand into wider gulleys.



An extreme example of gully erosion.

Figure 3.10. Visible examples of erosion (Environment Agency, 2007 and EC, 2013).

In the UK, detailed advice is provided by DEFRA (2005). This includes recommended crops for soils of different erosion risk as identified using the erosion risk matrix in Table 3.9 and crop lists in Table 3.10.

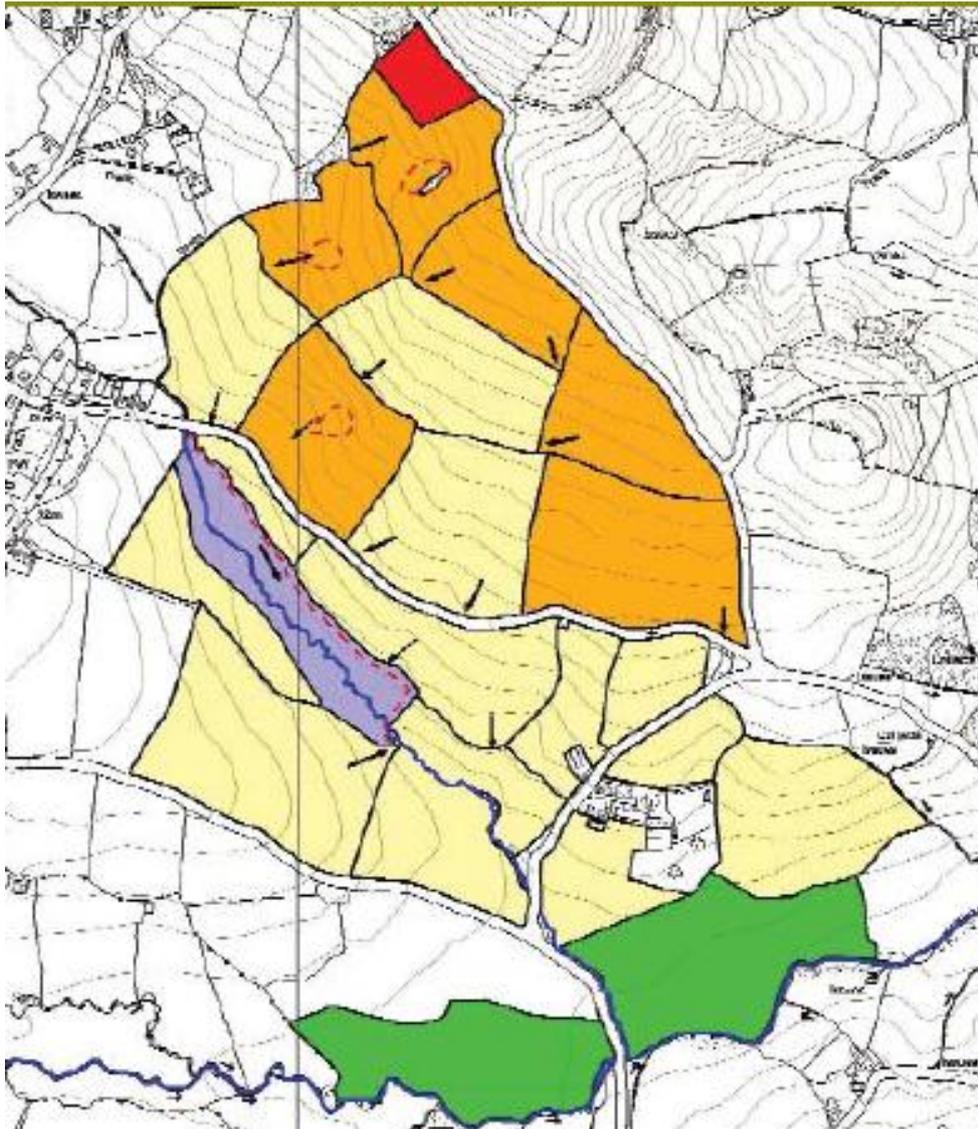


Figure 3.11 provides an example of a farm erosion risk map, and Table 3.11 provides a risk matrix for different processes on various soil types. The approach was tested, and largely validated, by Boardman et al. (2009).

Table 3.9. Erosion risk matrix (DEFRA 2005)

Soils	Steep slopes > 7°	Moderate slopes 3-7°	Gentle slopes 2-3°	Level ground < 2°
Sandy and light silty soils	Very high	High	Moderate	Lower
Medium and calcareous clay soils	High	Moderate	Lower	Lower
Heavy soils	Lower	Lower	Lower	Lower

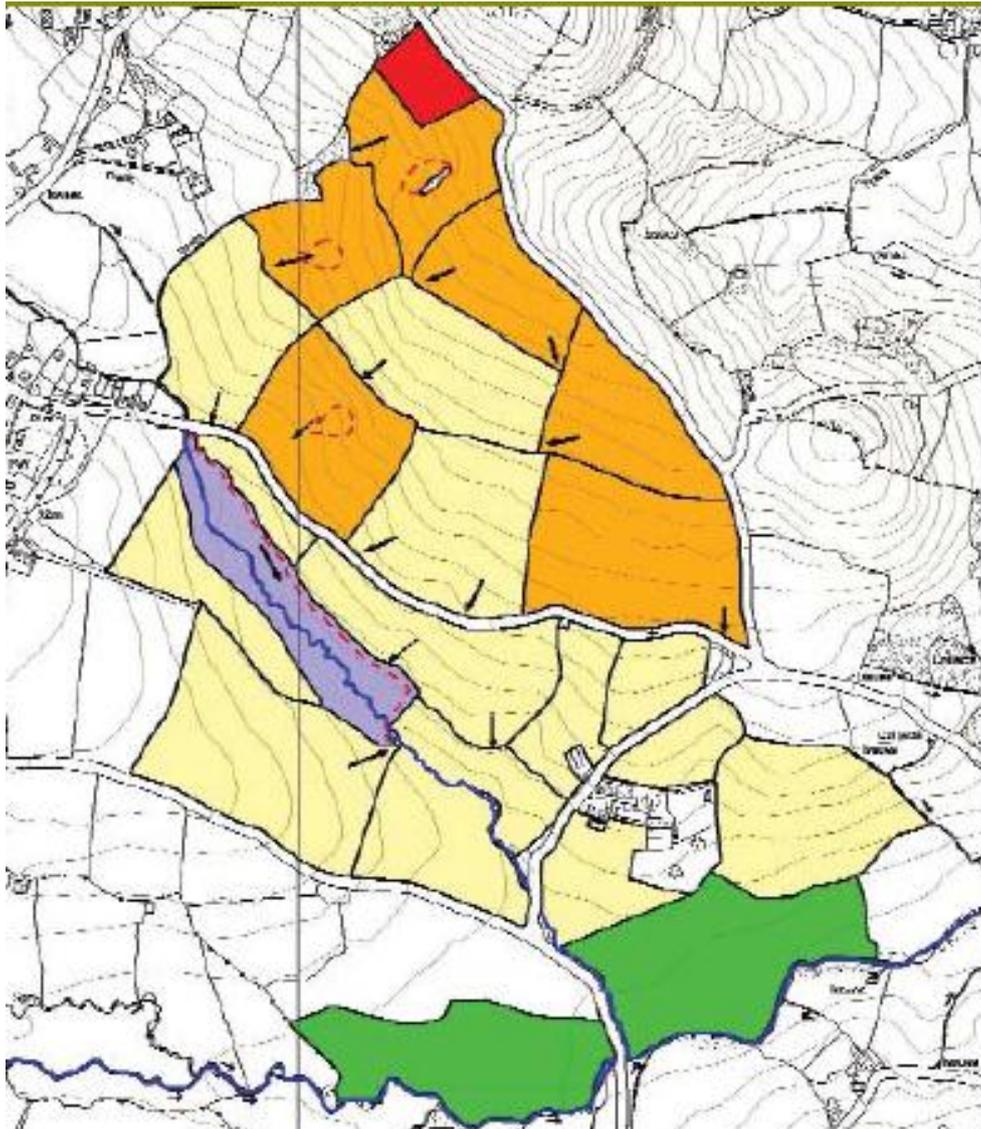


Figure 3.11. Example of an erosion risk map for a farm (DEFRA, 2005)

Table 3.10. Crop selection guidance for fields with high erosion risk (DEFRA 2005).

Avoid	Cultivate with care	Prioritise
<ul style="list-style-type: none"> x Late sown winter cereals x Potatoes x Sugar beet x Field vegetables x Outdoor pigs x Grass re-seeds x Forage maize x Out-wintering stock x Autumn/winter grazing of forage crops 	<ul style="list-style-type: none"> ! Early sown winter cereals ! Oil seed rape ! Spring sown cereals ! Spring sown linseed ! Coppiced willow/miscanthus 	<ul style="list-style-type: none"> ✓ Woodland ✓ Permanent grass ✓ Long grass leys

Soil Concerns/Soil Type:	Sandy and light silty	Medium	Heavy	Chalk & limestone	Peaty
Compaction due to cultivations and mechanical damage	HIGH	MODERATE	HIGH	LOW	HIGH
Runoff or water erosion from arable land	HIGH	MODERATE	MODERATE	MODERATE	HIGH
Runoff or water erosion from grassland	LOW	LOW	MODERATE	LOW	MODERATE
Poaching of soil by livestock	LOW	MODERATE	HIGH	LOW	HIGH
Low soil organic matter – as indicated by soils that cap and slump easily or are difficult to cultivate	HIGH	MODERATE	LOW	LOW	LOW
Waterlogging	LOW	MODERATE	HIGH	LOW	HIGH
Wind erosion	HIGH	LOW	LOW	MODERATE	HIGH
BASELINE RISK RATING	HIGH	MODERATE	HIGH	LOW	HIGH

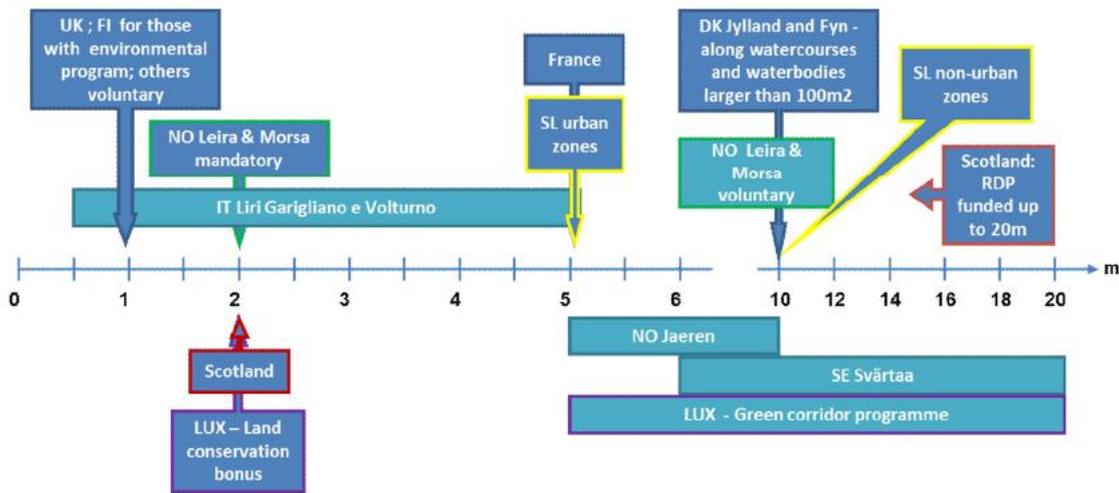
Table 3.11. Risk matrix for different processes across different soil types in the UK (DEFRA 2009)

Newell-Price et al. (2011) provided the following best practice advice related to erosion reduction:

- Move gateways located in high-risk surface runoff areas, such as at the bottom of a slope and near to a watercourse, to lower-risk areas on upper slopes.
- Create well-drained tracks with appropriate surfaces; avoid routes with steep slopes; Improve track surfaces and repair any damage promptly; provide good drainage and divert runoff to adjacent grassed areas, soakaways or swales; avoid directing runoff towards bare soil, roads or watercourses.
- Plant new hedges along fence lines and use them to break-up the hydrological connectivity of the landscape.

Buffer zones

EC (2013) note that requirements regarding the width of buffer strips range by country, generally falling between 0.6 m and 20 m (Figure 3.12). Most countries prohibit the use of fertilizer, pesticide, plant protection products, tillage, ploughing and spraying in buffer zones, and some countries also prohibit grazing and any agricultural use. Denmark’s Green Growth Strategy recommends 10 m buffer strips that may be used for cultivation of perennial pasture or bioenergy crops provided no fert, pest, or cultivation.



Legend: dark blue box refers to a specific point. Light blue refers to a range. Coloured borders are used for several limits referring to the same country, i.e. SL – yellow, Scotland – red, NO – green, LUX – violet.

Figure 3.12. Minimum buffer strip widths required by different schemes across EU Member States (EC 2013)

It is noted that narrow (1m wide) strips are unlikely to provide filtering for medium/heavy soils, whereas 6m riparian grass buffer removes sand and silt size particles and can reduce pesticide loading.

Figure 3.13 shows a simple cattle nose water feeder that can be used to avoid significant erosion and water pollution arising from cattle drinking directly from rivers. Such feeders may be placed behind fences used to create buffer zones along river banks.



Source: Woodland trust (2013)

Above: Cattle drinking from a river, causing significant damage to the banks, leading to erosion and water pollution.



Left: A cattle water feeder, activated by cattle nose motion, to avoid river bank damage.

Source: Environment Agency (2008)

Figure 3.13. Cattle water feeder as a solution to river bank damage

The following best practice relating to buffer strips and river bank management is recommended by Newell-Price et al. (2011).

Erect stock-proof fences in grazing fields and on trackways adjoining rivers and streams.
Construct bridges to allow livestock and vehicles to cross rivers and streams without damaging the banks, and to prevent animals urinating and defecating directly into the water.
Do not apply manufactured fertiliser at any time to field areas where there are direct flow paths to watercourses. For example, areas with a dense network of open drains, wet depressions (flushes) draining to a nearby watercourse, or areas close to road culverts/ditches.

Farm yard runoff management

Dirty water from farmyards contaminated with slurry, etc, should be sent to the slurry stores for field application at appropriate times. This increases the required slurry storage capacity and volumes of slurry applied, and at the same time reduces the effective duration of slurry storage, potentially causing problems for compliance with NVZ regulations, and leading to higher nutrient losses from fields and reduced nutrient use efficiency. Minimising the water that comes into contact with the farmyards can effectively reduce some of these negative effects. One simple way to do this is to intercept roof runoff (Figure 3.14). Ideally, this water could be used to as a supply of livestock drinking water.



Figure 3.14. Simple approach to rain water collection reduces capacity required for dirty water storage

Best practice for manure management described throughout Chapter 9 is critical for water quality. A few additional best measures related to manure management are referred to here, from Blair et al., (2006) and Newell-Price et al. (2011).

Avoid spreading (straw-based) farmyard manure (FYM) to fields at times when there is a high-risk of surface runoff or drainflow, for example, where rain falls shortly after applying FYM to ‘wet’ soils.

For farms in NVZs where livestock manure N loadings exceed 170 kg total N/ha each year organic manure N in excess of this limit needs to be transported to farms that do not have surplus N (or a grassland derogation applied for, stocking rates reduced etc). This situation is most likely on dairy and pig farms (usually as slurry), and poultry farms (i.e. layer manure and poultry litter).

Transport poultry litter to an incinerator where it is burnt for energy recovery.

Integrated constructed wetlands

Newell-Price et al. (2011) provide the following best practice advice in their mitigation manual: “Construct (or establish) wetlands with fences and channels that will be sufficient to capture runoff and sediment from a field group of fields or farm hardstandings.”

A useful guide on the creation of integrated constructed wetlands was published by the Irish Department of Environment, Heritage and local Government¹⁴ in 2010 (DEHLG, 2010).

Figure 3.15 shows an example of an integrated constructed wetland in Wales, constructed as part of an Interreg research project to ascertain its value in mopping up nutrients and pesticide residues from runoff – located in Pwllpeiran upland farm (near Aberystwyth).

Applicability

Catchment sensitive farming is applicable to all farms. It is easier to implement within smaller catchments involving fewer land owners.

¹⁴ This guide is available to download at:
<http://www.environ.ie/en/Publications/Environment/Water/FileDownload,24931.en.pdf>



Figure 3.15. Constructed wetland system consisting of four treatment cells and a final ‘polishing’ cell at Pwllpeiran Farm, Wales

Economics

Water treatment costs

ICW represent a low cost water treatment option compared with mechanical treatment, and may generate new revenue sources for farmers via recreational value of wetlands and enhanced quality of water courses. In the UK, Wessex Water is working with farmers to reduce nitrate and pesticide loading at source, in order to avoid expensive treatment of drinking water following abstraction downstream. They have a target to reduce N loading by 45 tonnes per year from the catchment by 2020. A nitrogen removal plant costs c. € 14 million (Bardon, 2014).

Recreational value

Constructed wetlands often have a significant recreational value. In the Anne Valley of County Waterford in Ireland, high value Brown Trout and Salmon species have returned to the Anne River following the introduction of an ICW, drawing in revenue from anglers (McInnes, 2014).

Improving surface water quality from “bad” to “good” ecological status according to WFD definitions can lead to societal benefits of up to € 170,000 per km of river channel (Baxter, 2014).

Public financing

There may be public money available to support capital investment in projects aiming to improve water quality¹⁵.

Payment for ecosystem services

There are some fledgling examples of payments for ecosystem services (PES) in practice, and this approach could generate significant revenue for farmers in the future. However, at present, considerable challenges remain to determine the value of particular services related to specific management practices (e.g. rewetting upland organic soils), their verification, and transfer of payment from beneficiaries to providers (e.g. farmers).

Driving forces for implementation

- Water Framework Directive, especially RBMPs
- Drinking water quality standards
- Water companies financing upstream catchment management programmes
- Government subsidies or low interest loans (Rivers Trust work)

Reference literature

- Bardon, R., 2014. *A Water Industry Experience of ‘Non-traditional’ Solutions*. Presentation at: *Environmental Sustainability Knowledge Transfer Network Systemic solutions at the landscape-water interface*. On 10.02.2014 at the Bristol Aquarium, Bristol, UK.
- Baxter, D., 2014. *Water for Life and Livelihoods: Water Framework Directive as an enabler of systemic thinking*. Presentation at: *Environmental Sustainability Knowledge Transfer Network Systemic solutions at the landscape-water interface*. On 10.02.2014 at the Bristol Aquarium, Bristol, UK.
- Blair N., Faulkner R.D., Tilla A.R., Poulton <http://www.sciencedirect.com/science/article/pii/S0167198705002758> - aff2 P.R. (2006), Long-term management impacts on soil C, N and physical fertility: Part I: Broadbalk experiment, *Soil and Tillage Research*, 91(1-2), 30–38.
- Boardman, J., Shepherd, M.L., Walker, E., Foster, I.D.L. (2009). Soil erosion and risk assessment for on- and off-farm impacts: A test case using the Midhurst area, West Sussex, UK. *Journal of Environmental Management*, 90, 2578-2588.
- DEFRA, 2005. *Controlling soil erosion: a manual for the assessment and management of agricultural land at risk of water erosion in lowland England*. London, DEFRA. Downloaded October 2013 from: <http://archive.defra.gov.uk/environment/quality/land/soil/documents/soilerosion-lowlandmanual.pdf>
- DEFRA, 2009. *Single Payment Scheme Cross Compliance Guidance for Soil Management*. London, DEFRA. PB13315. Downloaded October 2013 from:

¹⁵ For example, in the UK, the Catchment Sensitive Farming Capital Grant Scheme (CGS) provides financial support for specific capital investment in designated priority catchment areas:
<http://www.naturalengland.org.uk/ourwork/farming/csf/cgs/default.aspx#update>

- [http://rpa.defra.gov.uk/rpa/index.nsf/0/2ba694d4a8a991478025768e005e67c0/\\$FILE/Cross%20Compliance%20Guide%20to%20Soil%20Management%202010%20edition.pdf](http://rpa.defra.gov.uk/rpa/index.nsf/0/2ba694d4a8a991478025768e005e67c0/$FILE/Cross%20Compliance%20Guide%20to%20Soil%20Management%202010%20edition.pdf)
- DEHLG, 2010. *Integrated Constructed Wetlands: Guidance Document for Farmyard Soiled Water and Domestic Wastewater Applications*. DEHLG, Dublin.
 - Environment Agency, 2007. *Think Soils*. Bristol, EA. Downloaded October 2013 from: <http://www.ahdb.org.uk/projects/documents/ThinkSoils.pdf>
 - Environment Agency, 2012. *Rural Sustainable Drainage Systems (RSuDS)*. EA, Bristol. ISBN: 978-1-84911-277-2
 - JRC, 2012. *The state of soil in Europe*. Ispra, JRC. ISBN 978-92-79-22806-3. Downloaded October 2013 from: http://ec.europa.eu/dgs/jrc/downloads/jrc_reference_report_2012_02_soil.pdf
 - LEAF, 2012. *LEAF Marque Global Standard version 10.0 – issued 01/10/12*. LEAF, UK.
 - McInnes, R., 2014. *Systemic solutions and the potential of wetlands*. Presentation at: *Environmental Sustainability Knowledge Transfer Network Systemic solutions at the landscape-water interface*. On 10.02.2014 at the Bristol Aquarium, Bristol, UK.
 - Newell Price, J.P. et al. (2011). *An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture*. UK, ADAS. Downloaded June 2013 from: [http://rpa.defra.gov.uk/rpa/index.nsf/0/2ba694d4a8a991478025768e005e67c0/\\$FILE/Cross%20Compliance%20Guide%20to%20Soil%20Management%202010%20edition.pdf](http://rpa.defra.gov.uk/rpa/index.nsf/0/2ba694d4a8a991478025768e005e67c0/$FILE/Cross%20Compliance%20Guide%20to%20Soil%20Management%202010%20edition.pdf)
 - Ross, M., 2014. *NGO/trusted partner perspective*. Presentation at: *Environmental Sustainability Knowledge Transfer Network Systemic solutions at the landscape-water interface*. On 10.02.2014 at the Bristol Aquarium, Bristol, UK.
 - Woodland Trust, 2013. *Planting trees to protect water The role of trees and woods on farms in managing water quality and quantity*. Report downloaded February 2014 from: <http://www.woodlandtrust.org.uk/mediafile/100083903/Planting-trees-to-protect-water-RBC-Bluewater-farming-report-evidence.pdf>

3.3.1 Catchment sensitive farming case studies

Tree planting in Pontbren, Wales

The Pontbren project (Pontbren Farmers, 2014) is a farmer initiative implemented outside of any agri-environment scheme, with some Millenium Grant money. A group of ten neighbouring famers undertook strategic tree-planting to reduce environmental pollution and improve resource-efficiency. Trees were planted to provide shelter from the wind, enabling fewer sheep to achieve same yield output in an upland context through improved health, productivity and lambing rate. Pontbren farmers planted thousands of trees and miles of hedging to improve shelter for livestock, allowing a shift from crossbred ewes to hardier native breeds that could lamb outdoors; planted shorter hedging species to windward side, backed with taller tree species to form an impregnable shelter belt. The hydrology of the land is vastly improved, with tree roots reducing runoff by 40%, meaning less soil, nutrients and chemicals are lost from the farm system into adjoining streams and rivers. On a wider scale, such management could lead to highly effective flood mitigation.



Tree planting for interception of runoff: hedge rows plated perpendicular to slope and parallel to water courses



Tree planting for stock protection from exposure to prevailing wind: hedge rows planted perpendicular to wind direction
Source: Williamson (2013)

Integrated constructed wetland: Anne Valley, Ireland

A large integrated constructed wetland was established in the Ann Valley of County Waterford, Ireland, treats 50% of domestic waste water, 40% of diffuse runoff water and 80% of farm yard runoff water generated within the catchment. It has been so successful in improving water quality that brown Trout and Salmon have returned to Anne River (McInnes, 2014).

Reference literature

- McInnes, R., 2014. *Systemic solutions and the potential of wetlands*. Presentation at: *Environmental Sustainability Knowledge Transfer Network Systemic solutions at the landscape-water interface*. On 10.02.2014 at the Bristol Aquarium, Bristol, UK.
- Pontbren Farmers, 2014. *Pontbren Farmers webpage*, last accessed February 2014: <http://www.pontbrenfarmers.co.uk/>

3.4 Landscape scale biodiversity management

Description

Agriculture and biodiversity

Agriculture can benefit biodiversity and support habitats, but a major challenge for agriculture in coming years is to reduce the negative impacts of intensive agriculture on environmental quality, and to reduce dependence on non-renewable resources, while maintaining Europe’s capacity to feed a growing population (EUBBD, 2010). The intensification of farmland has been linked to the decline of farmland birds and butterflies, poorer plant diversity as well as soil biodiversity (e.g. Kleijn et al., 2009; Stoate et al., 2009). Meanwhile, extensive agricultural land management, such as extensive cattle grazing, can maintain high nature value (HNV) habitats, and there is a risk that these farming systems are abandoned owing to low financial returns per hectare (Haddaway et al., 2014). Open landscapes, farmland habitats, and farmland biodiversity depend on well adapted forms of farming activity (EUBBD, 2010). Of the 231 habitat types of European interest targeted by Annex I of the EU Habitats Directive, 55 depend on extensive agricultural practices or can benefit from them. Similarly, eleven targeted mammal species, seven butterfly species and ten Orthoptera species (including grasshoppers and crickets), as well as 28 vascular plant species listed in Annex II of the EU Habitats Directive depend on a continuation of extensive agriculture (EUBBD, 2010).

Whilst there may be some trade-offs between maximising food production and maximising biodiversity on some farms, careful ecosystem management to maintain or enhance biodiversity can in some cases improve productivity, and often makes systems more resilient to long-term pressures such as climate change and soil degradation (Figure 3.16).

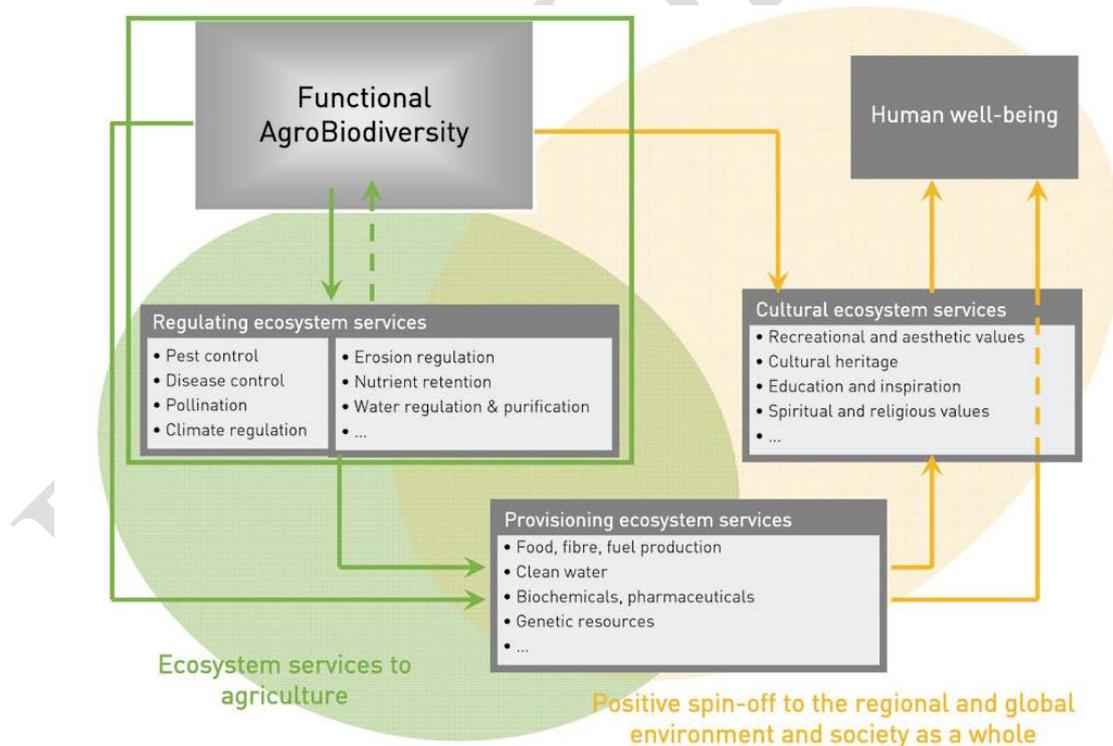


Figure 3.16. The relationship between functional agro-biodiversity and various ecosystem services (ENL-FAB no date)

Ecological focus areas

The primary aim of many Agri-Environment Schemes (AES) is to enhance biodiversity, but results of many AES are underwhelming (Poláková, et al., 2011). One reason for this may be because AES tend

to be administered at the farm scale, whilst realising measurable biodiversity benefits often requires landscape-scale schemes, especially for key farmland species such as bats, mammals and some important pollinators.

Discussion surrounding CAP reform has included the concept of ecological focus areas (EFA) as (potentially mandatory Pillar One) measures to improve/preserve biodiversity (Hamell, 2013). To qualify for the 30% of the direct payments budget that the Commission has earmarked for ‘greening’ the CAP, farmers with grazing livestock could be required to preserve permanent grasslands, whilst arable farmers could be required to cultivate a diversity of (three) crops and practice basic crop rotation. In addition, all farms may be required to designate seven per cent of their farmland as EFAs. EFAs draw on a Swiss policy in which farmers are paid a subsidy to dedicate a fixed percentage of the farm land to an environmental use rather than agricultural production. The aims include reversing the decline in farmland biodiversity, the loss of pollinating insects and farmland bird populations, reducing soil erosion and water pollution, all of which are known to be consequences of intensive agricultural production.

Legal framework

In addition to current and proposed CAP requirements, a range of legal frameworks apply to biodiversity and land management (Table 3.12). At the European level biodiversity strategy is summarised in the EU 2020 Biodiversity Strategy (COM (2011)244final). Environmental assessment of strategic plans at a regional level, as required under the SEA Directive and the assessment of projects under the Habitats and Birds Directive may influence aspects of regional development related to agriculture. Farm falling within SACs and SPAs may have additional responsibilities to ensure adequate protection of the nature values in compliance with the provisions of the Nature Directives¹⁶.

Table 3.12. International and European legal frameworks potentially important for tourism and biodiversity planning

Implementation level	Convention on Biological Diversity	Water Framework Directive (2000/60/EC)	Strategic Environmental Assessment Directive (2001/42/EC)	Environmental Impact Assessment Directive (85/337/EC)	Habitats Directive (92/43/EC & 2006/105/EC)	Birds Directive (79/409/EEC & 2009/147/EC)
Global	Conference of the Parties, Secretariat					
EU	Ecosystem approach to management, promoted through European Charter for Sustainable Tourism in Protected Areas	Water management at level of River Basin District	Assessment of regional development plans		Natura 2000 Network of SACs and SPAs	
National					Special Areas of Conservation (SAC) designated by member states	Special Protection Areas (SPAs) designated by member states
Regional					Over 1,000 animal and plant species and over 200 habitat types protected	Activities subject to specific protection provisions
Local			Assessment of local project plans			

Best practice for biodiversity management is a cross-cutting issue, involving a number of BEMPs through this report (Table 3.13). It could be argued that all measures to improve resource efficiency,

¹⁶ Further information on the Natura 2000 network as well as several guidance and best practice documents can be found in www.ec.europa.eu/environment/nature/home.htm. It is important to emphasise that best practice, by definition, goes beyond standard compliance with legislation.

especially in relation to output per hectare of land, lead to biodiversity benefits through reduced emissions per unit production and through “land sparing”. Nonetheless, in a local context, it is important not to breach critical load thresholds – e.g. NH₃ emissions in or adjacent to Natura 2000 sites.

Table 3.13. Important aspects of biodiversity management addressed elsewhere in this report

Aspect	BEMP	Relevant report section
Farm management	Strategic management planning	Section 3.1
	Catchment sensitive farming	Section 3.2
Maintaining soil quality and biodiversity	Assessing soil condition	Section 4.1
	Maximising organic matter amendments	Section 4.2
	Maintaining soil structure	Section 4.3
	Low impact soil preparation	Section 6.2
Grazing and animal management	Managing extensive grazing	Section 7.2
	Pasture renewal and legume inclusion	Section 7.3
	Locally productive breeds	Section 8.1
	Green procurement of feed	Section 8.5
Crop protection	Implement integrated pest management	Section 11.1
	Select less toxic active ingredients	Section 11.2

The Voluntary Initiative (2009) recommend four steps to protect farmland birds that can be considered as general best practice with respect to biodiversity, and consistent with proposed EFA measures:

1. Practise Integrated Farm Management
2. Select and apply pesticides responsibly
3. Provide field margin habitats
4. Provide in-field habitats.

Apart from the aforementioned listed steps, there are also some practical measures that farmers can apply. In particular, farmers within a given area can organise together with farm advisors and/or public administration suitable meetings or short workshops in order to exchange valuable information and eventually to obtain the required knowledge (Luscher et al., 2014). Likewise Hammerl et al., (2014) developed criteria/recommendations for best practices regarding the conservation of the biodiversity in the areas of: 1. Soil and fertilisation, 2. Livestock, 3. Pest management, 4. Optimise water-use, 5. Biodiversity friendly-farming, 6. Agrobiodiversity and finally 7. Wild harvesting¹⁷. A representative example, which was developed as a recommendation in this document for the soil and fertilisation area is that the farmer should cultivate the arable land throughout the year to avoid nutrient runoff and soil erosion and in parallel to map the areas with erosion and soil compaction risk. The farmers should inspect these areas annually in order to be able to develop and implement efficient soil protection measures in case of damage (Hammerl et al., 2014).

Achieved environmental benefits

The main environmental benefits of this BEMP relate to increased biodiversity and ecosystem functioning. The numbers and abundance of species present on a farm will depend on many factors, but should, in general, increase following implementation of best practice.

¹⁷ The fully developed best practices for each of the abovementioned areas are listed in the full version of the report in the link: <http://www.business-biodiversity.eu/global/download/%7BF5ADGQIAMK-12102014122755-XCHEEUWSWU%7D.pdf>

Appropriate environmental performance indicators

Indicators

The farmers can monitor the biodiversity value through the use of appropriate indicators. The main appropriate environmental indicators relating to biodiversity include¹⁸ (also based on Herzog et al., 2013):

- Stocking density (livestock units per hectare, see BEMP 7.2)
- Number of species present on farm by category (including also bird populations) e.g.:
 - Number and amount of wild bee and bumblebee species
 - Number and amount of spider species
 - Number and amount of earthworm species
- Abundance of key (indicator) species present on farm
- Absolute and relative areas of different habitat types e.g.:
 - Percentage of farmland with shrubs
 - Percentage of farmland with trees
 - Percentage of semi-natural habitats
 - Percentage of natural habitat compared to the total surface of the farm (%)
- Length of biotope corridors (linked with neighbouring farms)
- Percentage of area dedicated to nature or low input agriculture
- Accreditation with relevant scheme (organic certification, integrated farm management, Higher Level Stewardship, etc.)
- Farm management indicators
 - Total direct and indirect energy input
 - Intensification/extensification
 - N application rate (kg/ha/year)
 - Frequency of mechanical field operations
 - Applications of crop protection products (if and when it is necessary)
 - Average livestock rate
 - Grazing intensity

Cross-media effects

Measures to enhance local biodiversity need to be balanced against the risk of displacing food production to other areas, including to HNV areas within regions of the world where agricultural production is expanding into precious remaining natural habitat (e.g. Brazilian Amazon; Argentinian Pampas).

Operational data

Best practice guidance

According to EUBBD (2010), there are numerous opportunities for farmers, landowners and land managers to get engaged by shifting to more sustainable methods of farming and incorporating land management. They cite Bishop et al. (2008) who conclude that the promotion of biodiversity-friendly agriculture tends to involve some or all of the following practices:

- Creating biodiversity reserves or sanctuaries on farms.
- Developing habitat networks around and between farms. This can include the creation of ‘biological corridors’ that connect areas of significant biodiversity.
- Reducing conversion of wild habitat to agriculture by increasing farm productivity and by protecting priority areas, such as watersheds, forest fragments, rivers and wetlands.

¹⁸ For further specific indicators and best practice documentation you can also check BEMP 7.2 under Chapter 7; information based on EU BioBio project: <http://www.biobio-indicator.org/indicators.php>. Also Luscher et al., (2014) developed suitable metrics to inform farmers about species diversity.

- Taking marginal agricultural land out of production and assisting in the regeneration of natural habitats.
- Modifying farming systems to mimic natural ecosystems as much as possible.
- Low-input or less environmentally damaging agriculture practices, focusing on reduced erosion and chemical or waste ‘run off’, through ‘zero tillage’ planting techniques, contour ploughing, use of vegetation and trees as windbreaks, use of leguminous species, etc.
- Sustainable livestock practices that range from modified grazing and pasture management systems to promoting the incorporation of trees and other vegetation into livestock grazing areas.

Newell-Price et al. (2011) state the following measures as possible best practice related to biodiversity and habitat management.

Change the land use from arable cropping to permanent grassland, with a low stocking rate and low fertiliser inputs.
Change the land use from agricultural land to permanent woodland.
Grow perennial biomass crops (e.g. willow, poplar, miscanthus) to displace fossil fuel use, either through direct combustion or through biofuel generation (e.g. by gasification).

The following criteria and guidance are provided for LEAF Marque farmers (LEAF, 2012).

You must have a clearly-defined policy and plan for the conservation and management of wildlife habitats and biodiversity, and archaeological or historical sites, on your farm. This must include all the key environmental features as listed in the guidance notes of 8.1. The plan must aim to enhance the farm and encourage greater biodiversity. It must be linked to any Biodiversity Action Plans (BAPs) that exist in the local area or country. Consideration in the plan must be made to ensure that standard 8.24 is followed. It is recommended that this action plan is tabulated and can be printed in a way that it can be easily used and updated. The actions will be drawn from the management highlighted in the written report. The action plan and map will help to inform all staff of the features and management that is or will be carried out as well as your targeted key species. See also 8.21 and 8.22. Please see the LEAF Marque resource page for more information. http://www.leafuk.org/resources/000/
If you manage rented land under three years tenancy, (over three years the land must be included in your audit and plan), you must seek information on the conservation management that is practised by the Landlord. The following process must be followed: 1) Is your landlord a member of LEAF Marque, LEAF and have they carried out a LEAF Audit? If not, have you carried out an environmental assessment of the land you are renting/intend to rent including requesting any relevant documentation from your landlord (e.g. conservation plan, conservation audit etc.)? The land should be brought into your Conservation Management Plan: This enables you to respect the objectives of your landlord and protect habitats appropriately. If you do not have a copy of any relevant documentation from your landlord, can you provide evidence of communication / requests from you and their response?
You should encourage tenants to adopt integrated farming principles by joining LEAF and becoming LEAF Marque certified. Tenants who farm land approved under LEAF Marque where the certificate is held by the landlord cannot sell their produce as LEAF Marque, without being approved themselves.
An Environmental Impact Assessment (EIA) must be followed; this is a procedure for considering the potential environmental effects of land use change. The EIA helps inform decision making and enables decisions on land use change to be taken with full knowledge of the likely environmental consequences. The EIA and measures to minimise any negative consequences must be incorporated into the Whole Farm Conservation Plan and approved by any necessary local bodies or agencies. Planned work must be approved and advised prior to work being carried out. New sites: areas of habitat and margins as required by the LEAF Marque standard must be built into the site design, and include features that will protect and enhance the environment and biodiversity. Consideration must also be given to the landscape character and visual impact and ways of reducing negative impacts.
You must not remove or destroy any traditional field boundaries (e.g. hedges or stone walls), environmental/landscape features and other natural habitats such as rain forests or other high carbon stock land i.e. other wooded areas or secondary forest, peat lands on the farm.
Trimming of hedgerows on the farm must not be carried out during the observed nesting period. Boundaries must be managed in accordance with your Whole Farm Conservation Plan. Hedge cutting and boundary management more often than every two or three years should be justified. Where local management is more

intense due to highway safety this must be justified and explained.
Clearance of ditches on the farm must not be carried out during the bird nesting period. Only one side of the ditch should be re-profiled or cleared of vegetation in any one year. Where drainage clearance for unimpeded water flow is necessary, management may need to be more regular.
All work must be undertaken in accordance with any local restrictions. Trees must be retained wherever possible to maintain the landscape character. Consideration must be given to future planting where old trees exist.
You must retain all hedgerow, boundary, and in-field trees unless they cause a hazard.
You must not carry out deep cultivations under the canopy of in-field trees (unless they are deliberately grown or retained as shade trees. Where trees exist in a boundary or wood edge, you must ensure you have the required two-metre margin adjacent to this boundary (See 8.13).
You must retain a two-metre wide undisturbed (i.e. uncropped and uncultivated) margin on all permanent field boundaries between the middle of the hedge, fence or stone wall, edge of the water of the ditch and the crop. All field margins must be at least two metres. Grass fields need not be fenced but no application or operation should take place on this two metre margin, such as, fertiliser spreading, crop treatments and silage cutting. Where fields are less than two hectares and have permanent boundary features, two metre margins do not apply. Where there is not a boundary feature and the natural habitat extends from the crop or crop headland the need for two-metre margins is reduced. Where the Whole Farm Conservation Plan (8.2) has been completed by an external consultant and evidence exists in the conservation plan of the need for two-metre margins on all headlands may be reduced if other habitat features are used in the field, such as margins greater than two metres, or larger areas of habitat in corners of fields.
Field margins must be managed without fertiliser or pesticides (apart from spot control of noxious weeds) and cut late in the summer (or during the least destructive period for flora and fauna) with the cuttings removed wherever possible or grazed once every 2-3 years. Note: grass margins require regular cutting in the first summer (3-4 times); then no more than once every 2-3 years. Margins and other wildlife habitats around the fields should be managed to provide a diverse range of feeding and nesting opportunities for wildlife across the farm – i.e. flowering and seed-bearing plants, tussocky grasses.
You should aim to split fields greater than 20 ha with one habitat bank, or two habitat banks in fields larger than 30 ha, three habitat banks in fields larger than 40ha and four habitat banks in fields larger than 50 ha. Habitat banks are uncultivated grass mounds (or other plant species as appropriate) about two metres wide. They help to boost numbers of beneficial predatory insects, and provide habitat for ground-nesting birds and small mammals. If fields are larger than 20 ha and have 6m margins as part of the Whole Farm Conservation Plan this may negate the need for habitat banks.
You must use native species as far as possible for sowing in field margins, however it would be preferred if local provenance can be achieved. Natural regeneration of margins and other habitats are acceptable.
You must ensure that appropriate action is taken to avoid the contamination of hedge bottoms, watercourses and other vegetated field boundaries, and the two-metre field margins. You must make every attempt to minimise machinery movement on the field boundaries, this is to avoid habitat destruction.
If your crop rotation allows leaving some land uncropped this can lead to environmental benefits such as providing food for birds throughout the year. However, care should be taken to ensure that certain soil types have capping or surface sealing removed by light cultivation to avoid run-off during wetter periods and that you should be aware of the increased likelihood of compaction when working soils that are wet. Examples of this would be over-wintered stubbles and spring sowing of crops.
You must adjust field operations to avoid known nesting sites. You must adopt appropriate techniques such as marking nests (by putting 2 poles 10m either side of the nests) this should help to avoid marking the nests for predators, avoiding operations during nesting, spraying rather than cultivating fallowed fields and land out of production. Avoid cutting headlands in perennial crops such as orchards and avoid cutting windbreaks until after nesting.
To create ownership of environmental improvements such as habitat creation you should involve your staff in the planning and implementation. You must ensure environmental information is available to staff i.e. farm maps and conservation plans.
The need to monitor the environment will enable you to publicly state the effects you are having on your farm by the adoption of IFM. A number of local groups may be able to help with key indicator species.
You should ensure minimum area of 5% is available for wildlife habitat. This can include non-cropped areas managed for wildlife, ditches, hedges, margins, woodland, desert and forest, wild bird mixes etc.
You should adopt at least one measure for nesting habitats, summer (insect) food and winter (seed) food. The full list of measures can be found in the LEAF Audit. Consider other fauna as this may be more relevant in some circumstances.
<i>Source: LEAF (2012)</i>

Best practice guidance for arable farms is provided by HGCA at the following links:

- http://www.hgca.com/document.aspx?fn=load&media_id=3568&publicationId=3927
- http://archive.hgca.com/document.aspx?fn=load&media_id=7049&publicationId=8628

Summarising, best practice measures for different landscapes are presented below:

- Ponds:
 - Vegetation management or slit removal should be done during winter months
 - In case of the pond is used by livestock, parts of the shore could be protected from poaching in order to encourage development of marginal vegetation.
 - When a new pond is created, farmers should avoid locate it in a flower-rich wetland area
- Streams and ditches:
 - Farmers should protect all the watercourses from any potential run-off by the creation of vegetated buffer strips.
 - When cutting vegetation along the side of the streams/ditches, cut short sections should be undertaken during the late autumn or winter period (a related consultation from the local Environment Agency is also important).
- Grassland:
 - Maintain light grazing and particularly reduce grazing from May to June because during that period most of the plants are flowering.
 - Avoid use of synthetic fertilisers and use of crop protection products. If their use is required then apply them precisely (BEMP 11.1)

Applicability

This BEMP applies across all farm types, sizes and locations. The applicability and efficacy of specific measures will depend on local circumstances.

Economics

Typically there is a loss of revenue through provision of natural habitat areas on farms, through lost food production. However, the purpose of some agri-environmental payments is to compensate for this foregone income, and recognise the high intrinsic but non-market value of biodiversity and healthy functioning ecosystems.

Reduced biodiversity and ecosystem functioning at the landscape level can lead to large productivity losses for farmers, through e.g. flooding, soil degradation, poor pollination.

Driving forces for implementation

Biologically diverse soils are generally more productive for agriculture, whilst crop genetic diversity is a key factor in maintaining disease resistance and yields. In addition, EUBBD (2010) suggest that maintaining high levels of agro-biodiversity can:

- Increase productivity, food security, and economic returns.
- Reduce the pressure of agriculture on fragile areas, forests and endangered species.
- Make farming systems more stable, robust, and sustainable.
- Contribute to sound pest and disease management.
- Conserve soil and increase natural soil fertility and health.
- Contribute to sustainable intensification.
- Diversify products and income opportunities.
- Reduce or spread risks to individuals and countries.
- Help maximize effective use of resources and the environment.
- Reduce dependency on external inputs.
- Improve human nutrition and provide sources of medicines and vitamins.
- Conserve ecosystems' structure and stability of species' diversity.

Reference organisations

- EUBBD
- Hope Farm, UK
- The Global nature Fund together with the Bodenbsee Stiftung with funds from the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety developed Biodiversity Criteria in Standards and Quality Labels for the food industry including the agriculture stage (Hammerl et al., 2014).
- Upper Booth Farm, UK (see case study)

Reference literature

- Bishop J., Kapila S., Hicks F., Mitchell P., Vorhies F. (2008), *Building Biodiversity Business*. Shell International Limited and the International Union for Conservation of Nature: London, UK, and Gland, Switzerland.
- DEFRA (2012), Green Food Wheat Sub Group Report: Themes, Tensions and Recommendations. DEFRA, London.
- ENL-FAB (no date), *Functional AgroBiodiversity for a more sustainable agriculture and countryside in Europe*. The European Learning Network on Functional AgroBiodiversity, Tilberg.
- EUBBD (2010), *Agriculture Sector and Biodiversity Conservation Best Practice Benchmarking*. EUBBD. Available online: http://ec.europa.eu/environment/biodiversity/business/assets/pdf/sectors/FINAL_Agriculture.pdf
- Haddaway N.R., Styles D., Pullin A.S. (2013), What are the environmental impacts of farm land abandonment in high altitude/mountain regions: a systematic map of the evidence. *Environmental Evidence*, 2, 18: doi:10.1186/2047-2382-2-18
- Hammerl M., personal communication 15.03.2013, Brussels.
- Hammerl M., Trotscher P., Frohle K. (2014), Biodiversity criteria in standards and quality labels for the food industry, Recommendations, Project funded by the German federal agency for nature conservation with funds of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, available online: <http://www.business-biodiversity.eu/global/download/%7BFBSADGQIAMK-12102014122755-XCHEEUWSWU%7D.pdf>, last accessed June 2015.
- Herzog F. et al., (2013), Measuring farmland biodiversity, *Solutions*, 58, July-August.
- Kleijn D., Kohler F., Báldi A., Batáry P., Concepción E.D., Clough Y., Díaz M., Gabriel D., Holzschuh A., Knop E., Kovács A., Marshall E.J.P., Tschardt T., Verhulst J. (2009), On the relationship between farmland biodiversity and land-use intensity in Europe. *Proceedings of the Royal Society* 276: 903-909.
- LEAF (2012), *LEAF Marque Global Standard version 10.0 – issued 01/10/12*. LEAF, UK.
- Luscher G., Schneider M.K., Turnbull L.A., Arndorfer M., Bailey D., Herzog F., Pointereau P., Richner N., Jeanneret P. (2014), Appropriate metrics to inform farmers about species diversity. *Environmental science & policy* 41, 52-62.
- Poláková J., Tucker G., Hart K., Dwyer J., Rayment M. (2011), *Addressing biodiversity and habitat preservation through Measures applied under the Common Agricultural Policy*. Report Prepared for DG Agriculture and Rural Development, Contract No. 30-CE-0388497/00-44. Institute for European Environmental Policy: London.
- Stoate C., Baldi A., Beja P., Boatman N.D., Herzog I., van Doorn A., de Snoo G.R., Rakosy L., Ramwell C. (2009), Ecological impacts of early 21st century agricultural change in Europe – A review. *Journal of Environmental Management*, 91, 22–46.
- Voluntary initiative (2009), *Pesticides and Farmland Birds: Advice from the voluntary Initiative*. Available online: http://www.voluntaryinitiative.org.uk/importedmedia/library/1284_s4.pdf

3.4.1 Habitat management case studies

Case study: Upper Booth Farm, Peak District, UK

Upper Booth Farm is a small mixed sheep and cattle farm near the village of Edale in the Hope Valley of Derbyshire, managed by Robert Helliwell, a tenant farmer on National Trust land. The farm covers an area of approximately 54 hectares, of which 52 are dedicated to grazing, and is a LEAF Demonstration farm (subject to LEAF inspection and required to host at least six farm group visits per year to demonstrate environmental management). The case study below demonstrates aspects of best practice in landscape and biodiversity management in HNV areas, with the objective of maximising non-food-provisioning ecosystem services delivered in these areas.



The farm spans a gradient from 270 to 600 m above sea-level, and a range of HNV upland habitats including moorland grazing at the summit (left). Soils range from heavy waterlogged clay-loam soils at the bottom, though well-drained coarse mineral soils on the slope, to bog peat at the top. The farm has just come out of the ESA scheme (grants for walling, hedging, stock reductions, etc), and is now managed in accordance with HLS. Parts of the farm area are designated SSSI.



The farm is located on a section of the Pennine Way, with national Trust information points (above). Consequently, most fields have footpaths running through or adjacent to them (right). Walkers are not a problem, and sometimes provide a service by reporting stuck or sick animals.





The farm also hosts a 40-pitch campsite (open April to October), which contributes a similar income to the farming activities. New wash house pictured (left).

Livestock



The farm supports approximately 400 breeding ewes and 16-18 suckler cattle. Swales are cross-bred to produce Mules that obtain a good price at market when sold as store lambs September-October. Belted Galloway cattle (left) are a hardy breed tolerant of the cold and windy climate and able to digest coarse vegetation. Animal numbers may be reduced under the HLS scheme.

Live fluke can be a problem on the wet soils. Cattle are dosed for liver fluke two weeks after housing to maximise efficacy of the dosing. Last year, all sheep were dosed twice owing to the wet conditions. Animals often take 4-5 months to recover from liver fluke, and ewes who have recently hosted the parasite often abandon lambs because they cannot feed them.

It is expensive to keep lambs in shed over-winter and feed on hay and corn, but this might be a risk worth taking if autumn lamb price falls too low. Last winter price fell to £18 per lamb before rising to over £50 per lamb this spring.

Upland hay meadows



At the base of the slopes are upland acid-grass hay meadows (foreground, left) that receive no mineral fertiliser but an application of farm yard manure once every four years below the 12.5 t/ha limit set for hay meadows set under the HLS. Hay yields are low, with a maximum grass height c. 0.3 m. This is a rare and valued habitat, containing species such as yellow rattle, yellow buttercup, various daisies and red clover (clover limited to avoid excessive nutrient inputs).

Sheep graze this area early in the season, and are moved off in May to allow grass and flowers to grow over the summer before being mown and

harvested in later August/early September to provide hay for winter feeding. Robert notes that it is expensive to harvest the meadow for the low yields. One option could be to mob graze the meadow in August.

In the photo above, the effect of the cold and dry weather up to May 2013 can be seen in low grass growth and dry soils. The meadow was recently spiked to improve drainage through an iron-pan layer and reduce runoff. Such management improves the field productivity but also enhances the flood regulation service provided by these uplands areas.



Dry-stone walls originating from the mid 1800s represent important landscape features (left). The maintenance of these wall by skilled local craftsmen was supported through previous ESA grants, but not by HLS grants. To rebuild a dry-stone wall costs approximately £5 (€ 6) per meter.

Mid-slope rough grazing

Lambs are moved up the hillside towards the heathland in groups of 20-25 animals after the first bank holiday in May (reduces risk of disturbance by walkers during this busy period). They are then brought down for shearing in July and again in September for weaning.



Above is the rough pasture found mid-slope on the hillside, containing sedges, bilberries, *Molinia* and small quantities of heather. Cattle grazing is useful to pull off clumps of milina (above left).



The left picture shows an area that was fenced off 25 years ago because of high erosion rates, where natural tree regeneration is apparent. This area is sprayed to keep bracken down. A new area was fenced off three years ago to encourage woodland regeneration, as preferred by the National Trust. So far only a few small saplings are beginning to emerge, but the area is populated with an abundance of insects.

The picture to the right shows thistle growing another area of mid-slope grazing used for the suckler cows. The grass height is low (half the usual for May) because of the cold and dry spring preceding the visit. Thistle is controlled using a “weed-wipe”, which is essentially the application of herbicide using a roller set at a height above the grazed grass level to selectively target non-grazed vegetation such as thistles, bracken and brushes. Using a roller means that some thistle (and other weeds) survive. Despite HLS recommendations to remove all thistle, Robert notes that it provides a haven for blackfly that in turn attract ladybirds, and also for bees, butterflies and hoverflies, and gold finches when in seed. White clover in this pasture also attracts bees, but it is controlled to avoid excessive nutrient inputs.

Moorland grazing



The moorland commonage area hosts heather and bilberries amongst other plant species, and is SSSI designated and used for summer grazing at a low stocking density of just 1 ewe per 2 hectares. Currently, an area of the common moorland is fenced off whilst it is being improved through the addition of lime and some fertiliser along with alpine grass seed

Morley Farms, arable case study

Morley Farms is a large arable farm in southeast England. Wildflowers, sunflowers and granola were established on seven ha of the farm under the HLS scheme. There is no direct benefit to the farm – oil seed rape on the farm is mainly wind pollinated – but the farm manager can see wider social benefit. These flowers host a prolific variety of insects and birds in spring and summer, and provide feed for birds, which is the main objective under the HLS.

3.5 Energy and water efficiency

Description

Energy and water efficiency on farms are cross-cutting issues. From a lifecycle perspective, most energy consumed on farms is embodied in nitrogen fertilisers and imported animal feeds (Figure 3.17). Accurate nutrient management planning and precision application of manures and fertilisers are the best methods to reduce embodied energy use (sections 5.1, 5.3; 9.6 and 9.7). Similarly, a large portion of the lifecycle water footprint of dairy farm operations is water embodied in imported animal feed, and water required to dilute nutrient runoff down to acceptable stream nutrient concentrations. On arable and horticultural farms, targeted, efficient irrigation is a key factor for water efficiency (Chapter 10).

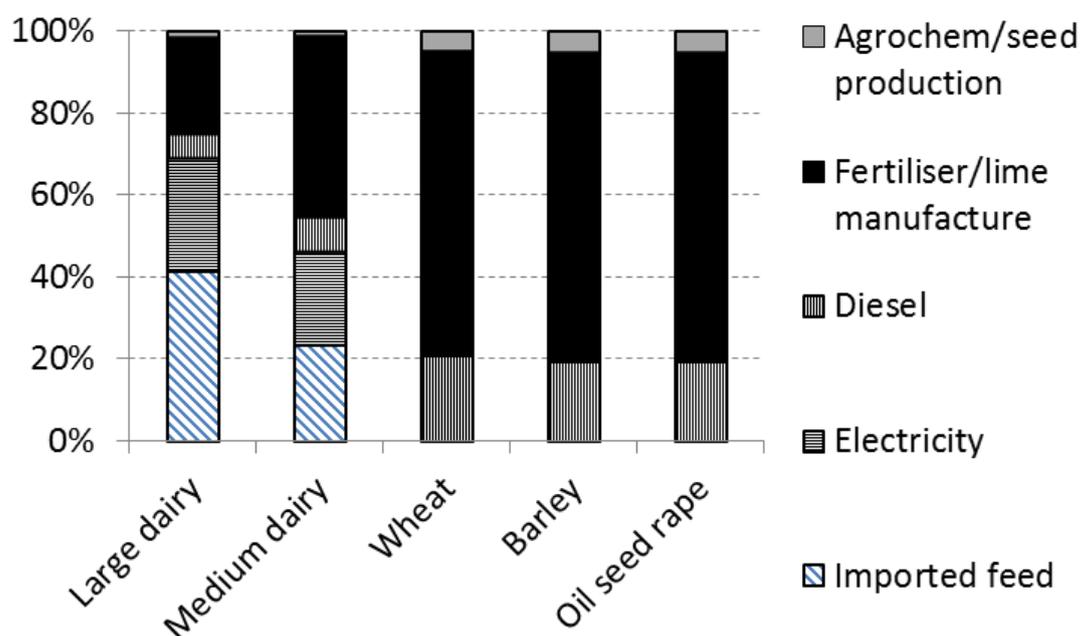


Figure 3.17. Major factors contributing to lifecycle fossil resource (energy) depletion for dairy and cereal production systems (Bangor University, 2014)

The main objective of this BEMP is to implement energy and water management plans including appropriate monitoring (sub-metering) and benchmarking of processes. Alongside this, a few widely applicable priority measures to reduce direct energy consumption and water consumption on farm systems are described, to supplement relevant BEMP described elsewhere in this report. Farms usually have opportunities for renewable energy installation, beyond the application of anaerobic digestion on large livestock farms to generate renewable biogas from organic wastes. Implementing the most appropriate renewable energy technologies on the farm is a final BEMP measure for energy. Table 3.14 summarises a list of cross-cutting BEMP measures for energy and water efficiency.

Table 3.14. Cross-cutting BEMP measures for energy and water efficiency (not addressed elsewhere in this report)

Aspect	Measure	Description
Energy	Energy management plan	An energy management plan is devised for the entire farm based on total energy use mapped across major energy-using processes, including indirect energy consumption, with targets for energy reduction.
	Benchmarking	Farm level total energy consumption calculated and benchmarked against output. Energy consumption for major energy-consuming

Aspect	Measure	Description
		processes benchmarked
	Metering and recording	Energy consumption for major energy-consuming processes is recorded on at least a monthly basis, using electricity sub-meters where necessary (see operational data).
	Green procurement	Certified energy efficient equipment is selected when buying new or replacing old equipment – especially tractors, milking pumps, chillers.
	Heat recovery	Heat recovery is used to capture waste heat from e.g. milk chillers and use for heating demand. In addition, use heat pumps where possible.
	Renewable energy	Install site-appropriate renewable energy generators on buildings and land, including solar thermal, solar photovoltaic, wind turbines, hydro turbines and/or biomass boilers fuelled with sustainably harvested biomass.
Water	Water management plan	A water management plan is devised for the entire farm based on total water use mapped across major water-using processes, including indirect water consumption, with targets for reducing abstracted water.
	Benchmarking	Water use from different sources (potable water, groundwater, river water, collected rain water) is benchmarked against output at the farm or crop level.
	Metering and recording	Water use for animal housing operations, animal-watering and crop irrigation is recorded separately, and by source, on at least a monthly basis, via appropriate water sub-meters.
	Rainwater storage	Rainwater capture, storage and use for animal watering, washing and irrigation can significantly reduce use of valuable potable- and ground-water supplies.
	Animal watering	Only use animal- or level- activated flow systems, and regularly check for and repair leaks.

The core of this BEMP is the establishment of a framework to monitor and reduce farm energy and water consumption. This BEMP does not provide a comprehensive technical description of energy and water saving technologies but gives an inspiration to the farmers of what is feasible and what can be implemented instead. In particular, several research projects and relevant literature provide technical descriptions of various energy and water saving technologies¹⁹. Likewise, the main principles of an energy management plan in farms should follow the three following points:

1. The main uses/processes of energy
2. Energy sources have to be identified and quantified through estimation or measurement
3. The consequences of their use in terms of direct and indirect emissions (e.g. from fertiliser production) understood.

Achieved environmental benefits

Reduced emissions to air

Reducing fuel and electricity consumption not only saves finite fossil energy, but reduces emissions of greenhouse gases, NO_x, SO_x and particulates, amongst other emissions. Table 3.15 summarises some of the environmental burdens for common energy carriers on farms.

Table 3.15. Environmental burdens for common energy carriers used on farms (DEFRA 2014).

Input	Reference unit	GWP kg CO ₂ e	EP kg PO ₄ e	AP kg SO ₂ e	ARDP Kg Sbe
Diesel upstream	kg	0.69	0.00089	0.0062	0.025
Diesel combustion	kg	3.05	0.001	0.002	NA

¹⁹ Readers are referred to literature and websites such as <http://efficient20.eu/> (available in various EU languages)

Input	Reference unit	GWP kg CO ₂ e	EP kg PO ₄ e	AP kg SO ₂ e	ARDP Kg Sbe
Consumed electricity	kWh _e	0.59	0.0076	0.0021	0.0046
Natural gas combined cycle electricity	kWh _e	0.42	0.000064	0.000226	0.00352
Oil heating	kWh _{th}	0.34	0.00011	0.00075	0.0022
Transport	tkm	0.081	0.000067	0.0003	0.000512

Tractor energy savings

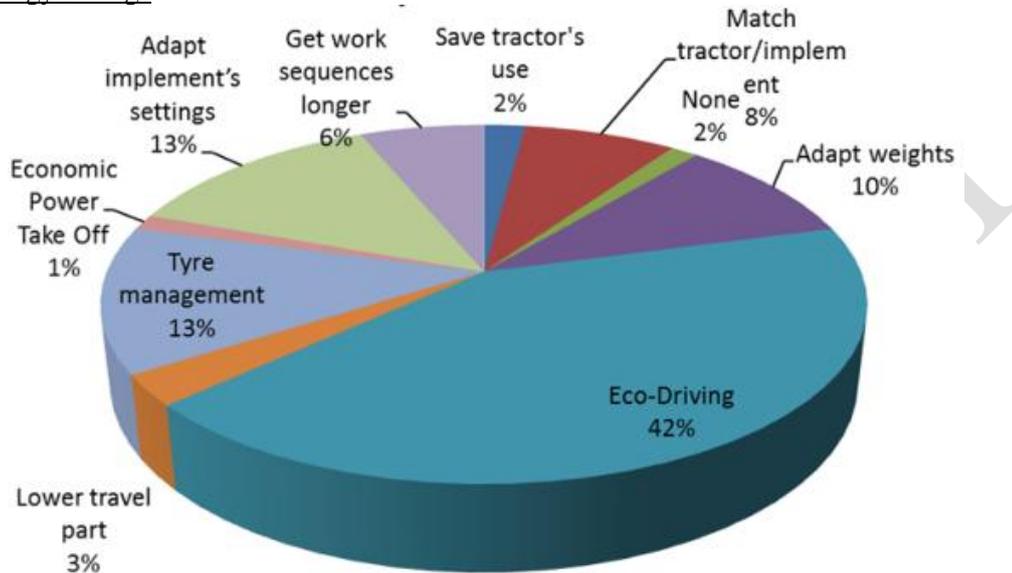


Figure 3.18 highlights the importance of eco-driving techniques to reduce tractor diesel consumption. Tyre pressure management, implement settings (e.g. plough depth and angle) and counter-weight adaptation are critical measures to reduce fuel consumption (Efficient 20, 2014).

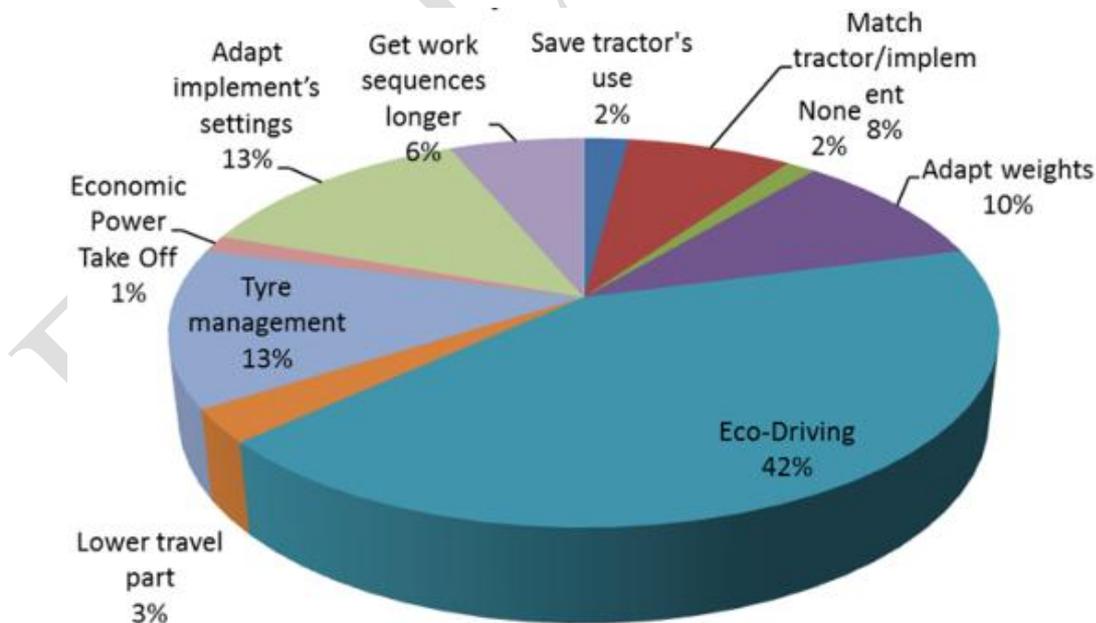


Figure 3.18. Breakdown of fuel consumption savings opportunities for tractor operation, based on 144 comparative tests in the EU Efficient 20 project (Efficient 20 2014)

Water efficiency

Water efficiency is particularly important in water stressed areas (and during times of water stress). Reduce water use, especially potable and groundwater use, during periods of water stress can avoid

high marginal environmental damage cause by exacerbated water stress, such as biodiversity loss, saline creep into freshwater aquifers, energy-intensive desalination operations or shipping of water, etc.

Reduced rates of water abstraction can make significant contributions to river and wetland habitats in all contexts. Reducing water use also reduces energy consumption, and potentially avoids chemical disinfection processes.

Appropriate environmental performance indicators

Farm level total energy consumption trends

Energy data will be recorded in a range of units, from litres of diesel, through to m³ of natural gas, to kWh of electricity, each representing varying quantities of: (i) useful energy (e.g. kWh lower heating value); (ii) primary energy consumption. Primary energy consumption is the ideal way to compare the overall energy efficiency across mixed energy sources, across farms and over time (Table 3.16). Contractor fuel consumption should be included in farm calculations.

Table 3.16. Common units of energy delivered to farms, and appropriate conversion factors to calculate final energy consumption, primary energy consumption and GHG emissions (Warwick HRI 2007; DEFRA 2012).

Energy source	Common unit	Net calorific value per unit (kWh _{final})	Primary energy ratio (kWh _{primary} /kWh _{final})	Lifecycle CO ₂ eq. (kg/kWh _{final})
Electricity mix(*)	kWh	1.0	2.5	0.590
Natural gas	m ³	7.4	1.1	0.204
LPG	kg	13.9	1.1	0.241
Gas oil	L	10.3	1.1	0.301

(*) primary energy ratio and lifecycle CO₂ emission factors vary depending on generation sources (UK factors shown)

Embodied energy

Table 3.17 summarises some important energy factors, including energy embodied in major inputs such as fertilisers. Note that these values must be multiplied by the application rates to derive embodied energy per hectare or at farm level. Fertiliser-N thus becomes a major source of indirect energy consumption. In particular, the embodied energy used to create fertilisers, machinery, CPPs, seed and other farm inputs is estimated around 1/3 to 1/2 of the total farm energy use.

Table 3.17. Non-diesel related energy requirements for farm operations and inputs (Dalgaard et al., 2001)

Process/input	Unit	Median value
Field irrigation	MJ mm ⁻¹	52
Drying	MJ t ⁻¹ %-pt ⁻¹	50
Fertiliser-N	MJ kg ⁻¹ N	50
Fertiliser-P	MJ kg ⁻¹ P	12
Fertiliser-K	MJ kg ⁻¹ K	7
Lime	MJ kg ⁻¹	30
Crop protection agents	MJ kg ⁻¹	40

Process energy efficiency

At the BEMP process level, simple indicators derived from readily available data in farm records should suffice, including:

- Tractor fuel (diesel) use (L/ha/y)

- Electricity consumption per animal equivalent (kWh/LU/y; kWh/milking-cow/y; kWh/sow/y)
- Lighting electricity consumption per m² (kWh/m²/y) and/or installed lighting capacity (W/m²)
- Heating (gas and oil) consumption per animal equivalent (e.g. kWh/LU/y)

Water use

Water use should be recorded at the farm and process level, to enable the following metrics to be used as a basis for benchmarking over time and across farms:

- Animal watering water use: m³/LU/y
- Irrigation water use: m³/ha/y
- Farm water use: m³/LU/y or m³/tonne product/y

In all cases, water use data should be broken down into abstracted (potable- and ground- water) and surface or collected rainwater sources. Based on these data, it could be possible to calculate water footprints for products.

Cross-media effects

Most energy and water efficiency measures do not incur significant cross-media effects. Embodied energy and carbon in energy-efficiency or renewable energy technologies is typically “paid back” within a year or so of operation. The use of land and fertilisers for bioenergy feedstock cultivation can lead to significant direct and indirect consequences, including land use change associated with displaced food. Measures described elsewhere in the report to reduce environmental burdens may lead to higher direct energy consumption – e.g. slurry application via injection or incorporation. Such measures lead to better environmental outcomes from a life cycle perspective (e.g. avoided ammonia emissions and fertiliser requirements for injection application), so care is required to ensure that measures to reduce direct energy use do not increase indirect energy use or lead to other environmental burdens.

Operational data

Field operations

Records of diesel consumption at the farm level, or contractor fuel consumption data, may be used to calculate total energy consumption for field operations and farm transport, etc. The Table 3.18 (according to Dalgaard et al. 2001) could be used to estimate the main sources of diesel consumption in terms of specific fields and crops, or to estimate fuel consumption by contractors undertaking specific operations. The fuel consumption ranges also indicate the potential for fuel saving via efficient machinery and management.

Table 3.18. Monitored diesel consumption recorded for various operations on farms, expressed as average and range (Dalgaard et al., 2001)

Operation	Unit	Average	Range
Tilling and sowing			
Ploughing 21 cm Spring	L ha ⁻¹	17	12-22
Ploughing 21 cm Autumn		22	15-27
Seedbed harrowing (heavy)		6.2	4.9-7.1
Sowing		3.2	3.0-3.4
Stubble cultivation		7.3	4-18
Fertiliser and liming			
Spreading and loading manure	L t ⁻¹	0.6	0.5-0.7
Spreading slurry		0.5	0.3-0.7
Spreading fertiliser	L ha ⁻¹	1.9	
Plant protection			
Pesticide spraying	L ha ⁻¹	1.2	1.1-1.4

Operation	Unit	Average	Range
Harvesting and baling			
Combine harvesting	L ha ⁻¹	14	11-19
Cutting, sugar beet top		10	7.4-13.0
Mowing		8	5-27
Chopping		1.7	1.2-3.3
Transport			
Machine transport	L km ⁻¹	1.2	0.2-2.3
Manure and fodder transport	L tkm ⁻¹	0.4	0.3-0.5
Loading and handling			
Loading	L t ⁻¹	0.3	0.2-0.3
Handling total		1.6	1.1-2.1

Note that use of GIS to ensure precise and even application of manures and agro-chemicals can help to avoid unnecessary fuel consumption from over-lapping field runs. However, use of precise slurry delivery via trailing shoe (section 9.7) and injection or incorporation (section 9.6) can increase fuel consumption compared with broad spread application (but the environmental benefits of the latter techniques, including avoided energy for fertiliser manufacture, are considerably greater than emissions from increased diesel consumption).

Energy saving measures for field operations

The Efficient 2020 project website is available in multiple EU languages and provides useful information for benchmarking key energy consuming processes on farms: <http://uk.efficient20.eu/>

Fuel use was recorded using diesel meters and data loggers on farm machinery, including machinery on Sandfields farm in the UK. Some key results from that farm are highlighted below.

- Farm ploughing trials showed 20% fuel savings by running tyres at the correct pressure. Reducing tyre pressure from 1.3 bar to 0.6 bar reduced fuel consumption to 21.6 L /ha, a fuel saving of 22% or 40 litres a day. The tractor also covered 15% more land from better traction, with further savings for labour and tractor maintenance, and reduced soil compaction. Every tractor has now been kitted out with a pressure gauge and there are air lines on those with air brakes (Farmers' Weekly, 2013). Auto-inflation/deflation systems can be useful to keep tyres pumped to the correct pressure.
- Limiting top speed to 30 mph was not successful because, while fuel consumption was reduced by 20%, increased labour costs eroded the financial savings and time pressures made compliance difficult in practice.
- Faster speeds result in more efficient operation, up to the point where the quality of the finish begins to be affected.
- Matching tractor size to each job is important but can be logistically challenging.
- Using fuel metering systems and specifying new tractors with on-board fuel monitoring can be a useful way to optimise operations.
- Selecting the most fuel efficient new tractors is important, given that 40% of a tractor's operating costs are in fuel consumption.
- Training days are important to inform operators of the torque curves of the tractors they use.
- Maintenance is importance, for example to keep air filters clean.

Electricity sub-metering

For large livestock housing units, electricity consumption may be separately metered to record and optimise the following demand sources:

- Lighting
- Ventilation and cooling demand
- Milking operations

- Milk chilling
- Other processes (e.gf. slurry pumping, floor scraping, etc.)

Milking operations and milk chilling

ADEME (2011) report on the use of a pre-cooler to reduce the energy requirements of cool storage, which amount to 80% of electricity consumption on a dairy farm. Cows' milk enters the pre-cooler at over 35°C, and is cooled via heat exchange with a counter-flow of cold water (Figure 3.19) to approximately 20°C, prior to entering the chilled storage tank where it is kept at approximately 4°C for collection. The cooling water can then be used for animal watering or other operations. The system saves 6,663 kWh per year, equivalent to 40-50% of electricity used for chilled milk storage, and worth around € 650.



Figure 3.19. Heat exchange system to pre-cool fresh, warm cows' milk prior to cool storage (ADEME, 2011)

In addition, and separately to the pre-cooler system, the farm referred to by ADEME (2011) installed a heat-exchanger to extract heat from the milk refrigeration condenser and compressor units. Water is heated to 55-60°C, reducing water heating energy demand by 70-90%.

Water saving

Environment Agency (2008) recommended:

- Sketch out your water supply network and check regularly for leaks.
- Check taps, drinkers, troughs and nozzles for leaks as part of a regular six-month audit; replace washers when necessary.
- Install trigger-operated hoses to avoid having uncontrolled running water.
- Install a control valve to reduce pressure in your system.
- Use a covered, contained area for mixing pesticides and filling sprayers.

Accreditation criteria

Various farm accreditation schemes include criteria related to energy and water efficiency. Examples of relevant criteria from LEAF (2012) are compiled and listed below:

All farms must complete an audit covering fuel, heating, cooling and lighting use, and identify ways of reducing dependency on non-renewable energy sources. The audit must be reviewed every year. The farmer, local energy

<p>organisation, or a consultant can complete the audit. If low energy user a short review of energy used and ways of improving efficiency must be completed. Definition – An energy audit identifies and evaluates energy management opportunities on the farm. During an audit, a baseline is developed to characterise and record energy use. Individual unit operations, processes, and major energy-consuming equipment are evaluated to identify energy management opportunities and high-return-on-investment projects. Typically an action report is produced that describes the baseline, each conservation opportunity area, an estimate of the cost to implement the changes, the savings that will be generated, and an estimation of the payback period.</p>
<p>To enable action to be taken on energy efficiency you must monitor your consumption to enable you to benchmark against previous years or industry standards. The monitoring can be on a kWh basis or energy used.</p>
<p>You should monitor CO₂ emissions based on your energy consumption records. Information can be found on our website. http://www.leafmarque.com/leaf/farmers/Inforesources.eb (type in “Energy” in the search box). This energy monitor will enable you to record energy used and convert to tonnes of CO₂ produced.</p>
<p>All businesses must complete a plan to show that they have considered the issue of water use and discharge. You must complete a Water Management Plan. This must identify where water is being used and plan how water use can be minimised and the environmental impact of water use mitigated. Justification of water use and sources must be included. Also consider the following: leakage; collection and re-use of some waters such as clean roof water or cooling water; irrigation scheduling. Water abstracted from streams, rivers, canals or boreholes etc. may require a licence from your regulatory organisation. Within the plan also consider discharges to the environment. For guidance LEAF/NFU/EA/DEFRA have published Waterwise on the farm and this can be obtained from the LEAF Audit or http://www.leafmarque.com/leaf/farmers/Inforesources.eb. It is a simple guide to implementing a Water Management Plan.</p>
<p>You must review your Water Management Plan every year to take account of changes to your farming practices and new ideas in resource management.</p>
<p>You must measure water efficiency of all irrigated water i.e. water that is either taken from the mains or from the environment and directly irrigated or stored for later use. A recording system must be implemented so that efficiency can be measured by litres (or m³) of water per tonne of output. Data must be uploaded to LEAF via the data portal on the LEAF website: http://www.leafuk.org/myleaf/services/Questionnaires.eb Farm Level Indicators.</p>
<p>You should review your water efficiency measurements annually to justify any changes and consider any agronomic or technological practices that may help to improve water efficiency. See LEAF Audit for information on IFM and water. Develop an action plan as part of the LEAF Audit or Water Management Plan. See Additional Guidance Notes for information on different practices that will improve water efficiency.</p>
<p>You should review your water efficiency data annually to ensure you monitor and seek to increase your water use from non-abstracted sources i.e. abundant flow storage reservoirs; rainwater collected on site and the re-use of water from other activities, thereby reducing reliance from direct abstraction or the mains supply. You should complete the LEAF questionnaire about water abstraction sources.</p>
<p><i>Source:</i> LEAF (2012)</p>

Tools

Various online benchmarking tools are available. Some carbon footprint tools contain useful information on energy benchmarks. For example, a range of E-CO₂ tools have been developed for different farming systems that benchmark factors such as fuel and feed consumption, against animal live weight gain or milk production (available online at: <http://www.eco2project.com/WhatIfTool.aspx>). Another tool is the 'The Cool Farm Tool', which was developed by the University of Aberdeen, Unilever UK and the Sustainable Food Lab (available online at: <http://www.coolfarmtool.org/CftExcel>).

Energy management plan sample

The main elements of a farm energy management plan were summarised and in-depth analysed in the above sections of this particular BEMP. Moreover, as it was mentioned in the description section, several aspects of an energy management plan are documented in other chapters of this report. Nevertheless, this BEMP provides a sample of an energy management plan in farms, which is presented in Table 3.19.

Initially, the first step to be taken is the implementation of energy audits in order to be identified the amount of energy and fuel is used and the processes where the main consumption occurs (e.g. tillage, pumping, transport etc.). The results from the energy audit may conclude to simple energy measures to be taken e.g. replace the existing equipment with high energy efficient one). The second step is the

measurement of the actual energy use. In particular, the energy and fuel use should be measured for all the activities and the processes within a farm. Therefore the identification of the critical hotspots of each farm is possible and eventually the proposal/suggestion to the farmers of alternative management scenarios and technologies to mitigate GHG emissions and/or to maximize the environmental performance. A draft template of an energy management plan is presented in table 3.18 including all the processes and aspects that should be measured during the compilation of an energy management plan. Similarly, Table 3.20 shows a template of water management plan for a farm.

Table 3.19. Sample of an energy management plan in farms

Aspects	Characteristics/measures	Comments/Notes
Farm: general info	Location Area Climate	
Energy audits	Identification of the energy use of the main processes/activities Energy mix used	Uses of energy Identification and quantification of the energy sources energy sources through estimation or measurement Direct and indirect emissions generation from energy use
Crop management	Crop type and management Soil Fertiliser use Pesticide application Tillage changes Cover crop Manure additions Residue incorporation	Changes in the crop management must be reported Embodied energy use
Livestock management	Manure management	Using appropriate machinery and equipment
Field energy use	Electricity demand Heat demand Fuel use	Fuel use in transporting inputs to the farm Fuel use for on-farm activities e.g. ploughing, spraying, tillage etc. Fuel use for post-harvest treatment and storage of products e.g. grain drying, milk refrigeration Transport of products to processing factory or depot; Fuel for domestic use, feeding and housing of farmers, employees and families.
Energy conservation measures	Improvement of building insulation Reduction of draughts Where ventilation is required, apply natural ventilation if possible Insulate hot water equipment e.g. pipes etc.	

Table 3.20. Template of a water management farm

Aspects	Characteristics/measures	Comments/Notes
Farm:	Location	

Aspects	Characteristics/measures	Comments/Notes
general info	Area Climate	
Water audit		Track the water use and implement an action plan
Water management	Water saving Protecting the available water sources Proper crops selection (water requirements)	Reduce and reuse water where possible and practical Recycle water such as collecting rainwater run-off from roofs and clean yard areas
Physical health	Soil management Drainage	Cultivation choice e.g. minimum tillage adopted and other measures like cover crops and margins put in place as part of an integrated soil management approach Maintain drainage strategy and take remedial actions if necessary
Monitoring	Tracking the water use in the field Water availability and sunshine hours	Monitoring of soil conditions as well as soil sampling for nutrients routinely undertaken as part of the management approach Analyse the water reading and look for trends and identify opportunities for improvement

Applicability

All farms can benefit from implementation of energy and water management plans. The larger and more varied the farm, the more detailed the plan may be.

Economics

Efficiency cost savings

Depending on the energy source, energy savings can result in significant cost savings per unit of energy consumption avoided, in the region of (energy.eu, 2014):

- 0.50 €/L for farm diesel (c. 0.05 €/kWh net energy content)
- 0.90 €/L for heating oil (c. 0.09 €/kWh net energy content)
- 0.15 €/kWh for electricity

However, it has been reported that the potable water savings are worth in the region of 2.50 €/m³, with smaller savings achieved for pumped groundwater depending on electricity prices and member state abstraction licence conditions and costs.

Environment Agency (2008) reported that livestock farmers may suffer the additional cost of extra slurry storage and application arising from poor water management. A single dripping tap can cost as much as £33 (around €39, cost data 2013) per year.

Therefore, there is a strong economic incentive to realise potential energy and water efficiency savings via the multitude of no- or low- implementation cost options described here and elsewhere.

Government grants and subsidies

Many EU Member State governments provide low interest loans and grants for equipment to improve farm energy and water efficiency. As an example from Wales, Glastir Agricultural Carbon Reduction and Efficiency Scheme provides capital funding for:

- Heat generation – such as heat-recovery systems; biomass boilers; ground/air source heat pumps; solar hot water panels.
- Energy efficiency - capital items which achieve at least a 20% efficiency saving – including variable speed drives, plate heat exchangers, ventilation/temperature controls, energy efficient lighting systems.
- Water efficiency – including rainwater harvesting equipment and water recycling systems e.g. fixed pumps, UV filtration systems, pipe work and storage tanks.

- Manure/slurry efficiency – includes capital items aimed at expanding storage capacity on-farm to enable better timing of applications to meet crop growth requirements, leading to savings in inorganic fertiliser. Also includes clean water separation, floating covers and slurry/manure storage. Applications for new or extended slurry storage would need to meet a 5 month storage capacity requirement on-farm.

Feed-In-Tariffs

Many EU Member State governments provide Feed-In-Tariffs and other incentives (e.g. Renewable Heat Incentive in the UK) to encourage renewable energy deployment. These subsidies can transform the economic viability of on-farm renewable energy options.

Tractor operations

Some economic data were compiled in the Energy 20 project for tractor operation fuel savings, including labour cost implications of reduced or increased operating times. These are summarised in the Table 3.21 (Farmers' Weekly, 2013):

Driving forces for implementation

Energy and water efficiency can lead to significant cost savings on farms. Capital investment grants for efficient equipment provides an additional incentive for the purchase of such equipment.

Table 3.21. Tractor operation fuel savings where labour cost linked to operating times (Farmers' Weekly, 2013)

Tyre pressure (psi)	Time	Area worked (ha)	Fuel used (l)	l/ha	Fuel cost/ha	Labour (£/ha)	Total cost/ha
24	1 h	1.34	37	27.69	£18.55	£7.48	£26.04
19	1 h	1.37	36	26.31	£17.63	£7.31	£24.93
14	1 h	1.50	35	23.36	£15.65	£6.68	£22.33
8.5	1 h	1.62	35	21.61	£14.48	£6.18	£20.66
Max speed (kph)	Time	Distance (km)	l/m	Fuel used (l)	Fuel (£)	Labour (£/ha)	£/km
67	75 min	72.3	0.44	32	£22.4	£12.50	£0.48
48	92 min	72.3	0.35	25	£17.50	£15.33	£0.45
Gear	Speed (kph)	ha/h	l/h	l/ha	Total (£/ha)	Labour (£/ha)	Fuel (£/ha)
1 st	2.6	1.35	23	17.01	£19.30	£7.40	£11.91
2 nd	3.1	1.61	27	16.75	£17.93	£6.20	£11.72
3 rd	3.7	1.92	30	15.59	£16.11	£5.20	£10.91
4 th	4.6	2.39	35	14.63	£14.42	£4.18	£10.24

Reference literature

- ADEME, 2011. Economies d'énergie grâce à un prérefroidisseur de lait à Guern (56). ADEME, France. Available to download at:
- Dalgaard, T., Halberg, N., Porter, J.R., 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. *Agriculture, Ecosystems and Environment*, 87, 51-65.
- Defra, 2012. 2012 *Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting*. London: Defra.

- Defra, 2014. Comparative life cycle assessment of anaerobic digestion. Project AC0410 webpage. Last accessed January 2014: <http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=18631>
- Environment Agency, 2008. *What's in it for you. Profit from a good environment. Best farming practices*. Environment Agency, Bristol.
- Farmers' Weekly, 2013. *How to cut your diesel costs*. Article published May 2013, and available to download at: <http://www.fwi.co.uk/articles/14/05/2013/139042/how-to-cut-your-diesel-costs.htm#.UbcS36ynerA>
- Klimatmärkning för mät, 2010. *Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010*. Sweden: Klimatmärkning för mät.
- LEAF, 2012. *LEAF Marque Global Standard version 10.0 – issued 01/10/12*. LEAF, UK.
- Warwick HRI, 2007. AC0401: Direct energy use in agriculture: opportunities for reducing fossil fuel inputs. Warwick HRI.

FINAL DRAFT

3.6 Waste management

Description

A multitude of potential wastes arise, or are used, on farms. DEFRA (2006) reported that approximately 25,000 tonnes of non-packaging plastic materials are supplied to UK farmers each year, often for single use²⁰. Recycling of these wastes is often impeded by soil and residue contamination.

Various BEMPs described in subsequent chapters address issues surrounding use of “wastes” as soil organic amendments (section 4.2) or feedstock for anaerobic digestion (section 9.2). An important aspect of waste management is to minimise use of, and carefully handle, crop protection products that may give rise to serious eco-toxicity effects if released in an uncontrolled manner (Chapter 11). Manure spreading (Chapter 9) should be regarded as nutrient recycling, rather than “waste” management – where it is regarded as the latter water pollution is more likely to arise from overloading of soils at inappropriate times (section 5.3). This BEMP focusses on cross-cutting aspects of waste management, and a few key measures not included elsewhere in this report, to achieve two main objectives: (i) avoid plastic waste contamination of the landscape and marine environment; (ii) avoid landfill. The main topics are:

1. Reduce, re-use, recycle and recover waste (according to the waste management hierarchy)
2. Digestion or composting of organic waste wherever possible
3. Careful handling of hazardous chemicals and packaging
4. Ensuring waste streams are separated and clean
5. Documented compliance with all relevant regulations

The last measure may be regarded more a basic, rather than best, practice. Nonetheless, there evidence of widespread non-compliance for e.g. plastic waste from silage production and horticulture which can be seen throughout the European environment (Figure 3.20). Plastic waste is a threat to terrestrial, and especially aquatic, life. DEFRA (2006) provides useful guidance on farm waste management.



Figure 3.20. An example of illegally dumped agricultural wastes (DEFRA, 2006).

Figure 3.21 summarises the waste management hierarchy for plastic wastes, an important farm waste category.

²⁰ In chapter 12, BEMP 12.3 data regarding waste management in protected horticulture sector are also presented.

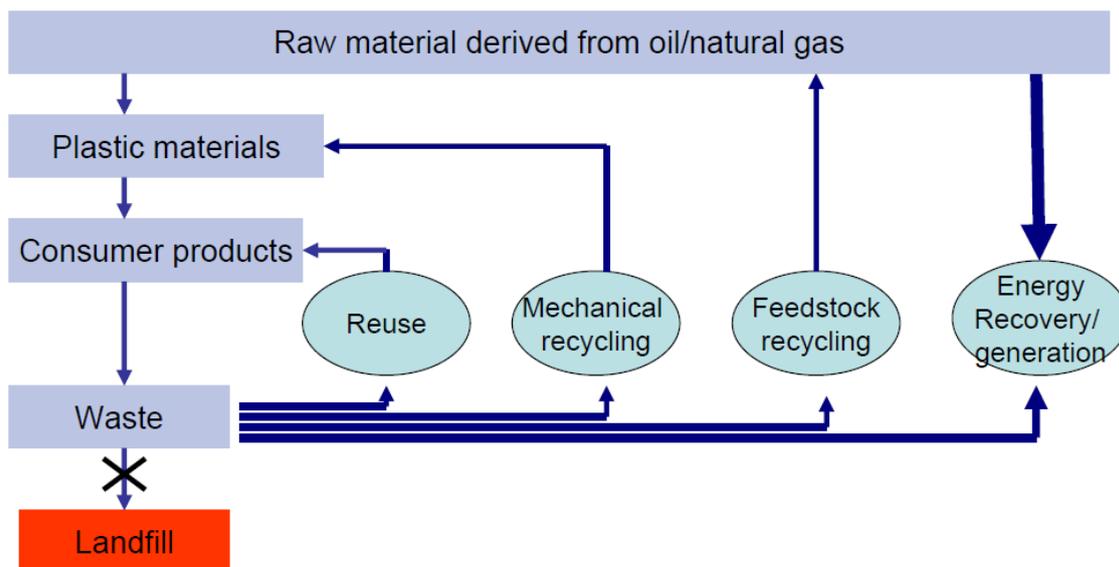


Figure 3.21. Management hierarchy for plastic materials following their initial use; landfilling is not an acceptable practice (Plastics Industry, 2007).

The list of measures below comes from ADAS (2007) 'Agricultural Waste Plastics Collection and Recovery programme good practice information sheet':

- Firstly, endeavour to minimise the amount of agricultural waste arising
- Consider reuse options
- Store silage bales on concrete areas where possible; remove wrap prior to transporting the bales to the feeding area. Handle all silage film from bags and clamp to avoid dragging on soiled areas
- Where possible, remove crop covers from the field in optimum dry conditions to avoid excessive contamination
- Empty, triple rinse and drain all agro-chemical containers; dispose of contaminated water safely
- Fully empty out packaging e.g. fertiliser and seed bags – shake or brush if appropriate. Segregate and bag or store the plastic waste as it arises (not after it has blown around the farm)
- Store agricultural waste products together at one site to ease collection/loading
- Segregate the waste according to type, i.e. wrap and sheeting, polytunnel and crop film, feed bags, fertilizer bags, string and netting
- Store AWP in appropriate areas to protect the material from wind and rain, e.g. use a fertiliser bag liner or a dedicated bin or a pen of pallets/hurdles so that it does not blow away
- Squash and flat pack packaging, e.g. fertilizer and feed bags, and tie into manageable bundles
- In some cases container tops need to be removed and kept in a separate bag
- All bags/liners should be labelled with their contents (and any contract number provided by a collector)
- Store on a firm surface, preferably on concrete. This reduces the likelihood of bagged waste ripping and slipping, as well as keeping the plastic cleaner
- Keep storage time to a reasonable minimum (The Waste Regulations stipulate a maximum of 12 months except for small quantities intended for recycling)

An important element of each waste management plan is the manure and/or forage waste. As far as the manure is concerned, best storage practices are presented in chapter 9 and in particular in BEMPs 9.4 and 9.5. In 'Operational Data' section more data are presented. For forage waste, best practices are also presented in the same section.

Achieved environmental benefits

Ensuring safe disposal of plastics and hazardous chemical wastes is of particular benefit to terrestrial and aquatic biodiversity via avoided eco-toxicity.

Re-use and recycling of materials reduces rates of resource depletion. Life cycle raw material, energy and water demand is typically lower for recycled than virgin materials (e.g. plastics).

Good management of organic “waste” is associated with improved nutrient use efficiency (section 5.1) and soil structure related to organic matter accumulation (section 4.2), improving the resource efficiency and reducing the lifecycle environmental burdens of agricultural production.

Appropriate environmental performance indicators

Performance indicators

- Plastic waste arising (t/ha/y)
- Hazardous waste arising (kg/ha/y)
- Organic waste arising (kg/ha/y)
- Percentage of waste separated into recyclable categories (%)
- Percentage of organic waste that is sent for digestion or composting (%)
- Percentage of waste sent to landfill (%)

Cross-media effects

Risk of silage spoilage, with associated environmental burdens for additional animal feed production, from use of less silage wrap or shift to clamp silage stores. This risk can be minimised through careful management of wrapped bales and careful sealing of clamps (section 7.4).

The stored silage can leach into the groundwater and eventually contaminate the watercourses especially when the run-offs are not controlled sufficiently. Moreover, the storage of silage waste can also result in creating nuisance odours.

Operational data

Main waste sources

DEFRA (2006) list the following main categories of waste arising on farms (check also Figure 3.22):

Wastes from Crop Production

- Pesticide application
- Inorganic fertiliser
- Plastic crop covers
- Crops and produce

Wastes from Livestock Production

- Plastic silage wrap/sheet
- Feed
- Used sheep dip
- Veterinary products
- Carcasses
- Manure or silage effluent (best practice is to utilise as a nutrient source, not a waste; e.g. section 5.2)

General Farm Wastes

- Scrap metals
- Fuel oil and lubricants
- Tyres
- Packaging

Waste minimisation

Clamp silage can significantly reduce the quantity of plastic silage wrap used on farms (DEFRA, 2006), although care must be taken to ensure no additional loss of silage dry matter or quality during clamp storage compared with bale storage (section 7.4).

Relevant criteria from the LEAF (2012) related to waste minimisation are listed in the box below.

Do you clearly identify and document market outlets and requirements for your products prior to production, and integrate this within your enterprise planning process?

Understanding and delivery of your customers' requirements is essential. Customers' requirements in terms of quality and quantity and environmental considerations must be documented, and you need to show how you intend to meet these requirements through your production plan. This will help to reduce overproduction and waste in the food chain and help towards a more viable business.

Have you completed a waste minimisation process on the farm?

All farms produce some waste and by-products. Some such as slurries and manures can be recycled on the farm. Others need to be taken off-farm for disposal. By minimising the quantities of waste and by-products produced, you can save money on storage, handling, and disposal. You should identify waste minimisation opportunities, which could include:-

- Reducing the quantity of rainfall entering slurry/dirty water storage systems;
- Re-using some water collected from roofs etc;
- Purchasing materials in appropriate quantities to reduce packaging waste;
- Avoiding spoilage of materials not used immediately.

Plastic re-use guidance

Examples of plastic waste minimisation on farms are (ADAS, 2007):

- Consider re-use of fertiliser bags and liners (e.g. use liners to contain other AWP)
- Handle crop cover carefully to facilitate re-use a second or third season
- Optimise the number of wraps used on a bale with the quality of silage expected
- Re-use clamp film (e.g. use this year's top cover down the side of clamps next year)

Contamination of agricultural waste such as plastic adds considerably to its total weight, increasing costs of transportation and devaluing the material (ADAS, 2007). It can account for over 80% of silage and crop cover plastics' weight. The dirtier the plastic, the more cleaning is required to be carried out by a re-processor before it can be recycled. Heavily soiled material can be rejected.

ADAS (2007) make the following recommendations to minimise waste contamination:

- Store silage bales on concrete areas where possible and remove wrap prior to transporting the bales to the feeding area.
- Handle all silage film from bags and clamp to avoid dragging on soiled areas
- Where possible, remove crop covers from the field in optimum dry conditions to avoid excessive contamination
- Empty, triple rinse and drain all agro-chemical containers; dispose of contaminated water safely
- Diligence to fully empty out packaging e.g. fertiliser and seed bags – shake or brush if appropriate
- Segregate and bag or store the plastic waste as it arises (not after it has blown around the farm)

Hazardous chemicals

Chapter 11 deals in more detail with the avoidance, selection and application of crop protection agents. The figure below primarily relates to chemical management on farms, but includes many important aspects of best practice for waste management.

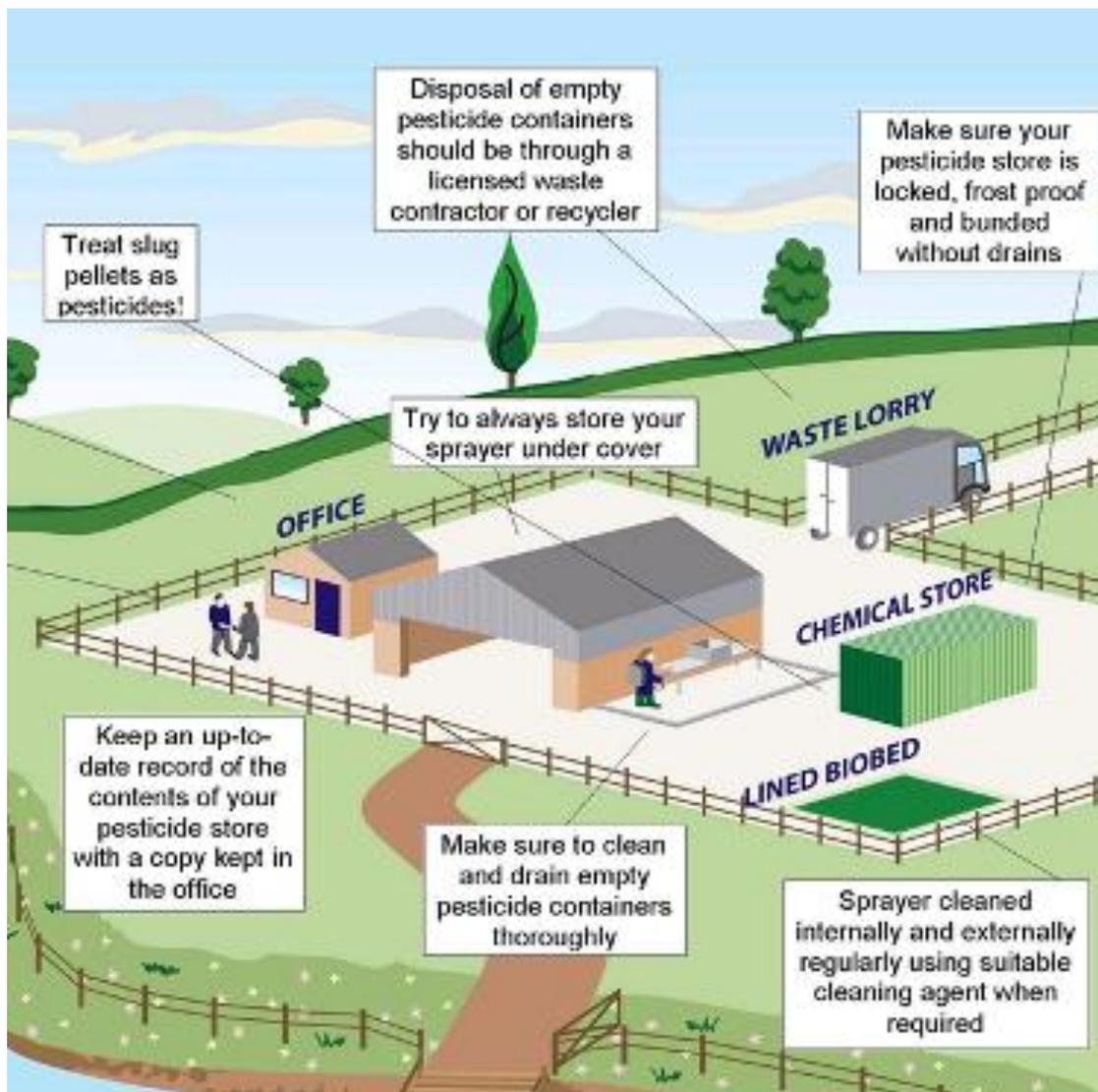


Figure 3.22. Aspects of a crop protection management plan relevant to waste management (Voluntary Initiative, 2011).

The box below contains relevant criteria from LEAF (2012) related to management of potential pollutants.

Have you identified, documented and recorded on a map(s) all potential pollutants on the farm by means of a Farm Pollution Risk Assessment?

You must carry out a comprehensive Risk Assessment to identify and record all potential pollutant materials on your farm at each stage of their use from unloading to disposal. This will help you to make provision to store, use and dispose of them and their risk to the environment. The Assessment must indicate what is at risk and prioritise based on the risk.

Step 1 – Hazard identification.

Step 2 – Decision on what might be harmed and how.

Step 3 – Evaluation of the risks and deciding on precautions.

Step 4 – Record and implement precautions in an Action Plan.

Step 5 – Routinely review and update your Risk Assessment and Action Plan.

A hazard is anything that may cause harm, such as chemicals, nutrients, etc; and the risk is the chance, high or low, that the environment could be harmed by these and other hazards, together with

an indication of how serious the impact on the farm and wider environment. Consideration must be given to air, noise, light and those that pollute surface water, groundwater and soil. It must also include pesticides, fertilisers, sheep or cattle dips, organic wastes, non-biodegradable wastes, run-off washings and sources of

Do you have an action plan to reduce the impact of these potential pollutants on the environment?

You must develop an action plan based on your Risk Assessment of all possible pollutants and put into action improvements you can make to the storage, use and disposal of potential pollutants.

Waste storage

The farm waste are distinguished into two categories: i. waste forage and ii. manure. Some general indicative best practices for each of the two aforementioned categories are presented in the box below (Jacobs & Associates Ltd., 2003)

Waste forage

- Reduction of waste by storing bales of hay under cover
- Harvest and store only as much forage as will be required for the following year/needs
- Harvest silage at the optimum moisture content to minimise the potential for seepage
- Use waste forage as a mulch to provide protection from soil erosion in recently harvested e.g. potato fields rather than hauling it to the woods or burning it.
- Compost waste hay and silage
- Silage seepage:
 - Seepage from silo with the surface water run-off from open bunker silos should be collected and stored since the material is highly contaminated; during the cropping season, this material can be applied on the land
 - Silos should be covered properly in order to prevent rain water from entering and eventually leaching through the silage
 - Implement measures to divert all surface water away from the silo
 - For new silos install seepage collections and storage systems

Livestock manure, classified into solid, semi-solid and liquid (in fact the moisture content defines the type of the manure system):

- The manure storage facility should have a minimum capacity of 210 days (one year is the optimal capacity)
- Surface run-off should be diverted away from livestock and manure storage areas
- Run-off from soil manure storage, silo seepage, and livestock housing washwater must be properly handled in order to ensure that other surface waters are not in contact and eventually be polluted

Applicability

Waste management is applicable to all farm types and sizes. All farms should have a waste management plan. Plastic waste management is especially relevant to protected cropping farms and farms producing silage bales.

Economics

Reduction and re-use of raw materials can save money twice:

- avoided material purchase
- avoided disposal costs.

The value of recycled plastic is approximately 70% that of virgin plastic (Plastics Europe, 2007). Waste management companies can take clean, separated waste fractions from farms for a lower charge than sending waste to landfill. As of April 2013, landfill tax in the UK stood at £72 (€85) per tonne.

Redundant machinery, scrap piping and other metals can be sent to a scrap merchant in exchange for cash.

Driving forces for implementation

- Resource efficiency
- Economics (avoided material purchase and disposal charges)
- Waste Directive and
- Member state regulations and initiatives

Leading European countries including Switzerland, Sweden, Denmark, Germany, Belgium, Austria, Luxembourg and the Netherlands recycle up to 33% of plastic waste, and either recycle or recover energy from over 80% of plastic waste (Plastics Europe, 2007).

Reference organisations

Useful information can be found at the following website: <http://www.agwasteplastics.org.uk/>

Local waste recycling centres and directories will contain information on how and where different wastes can be recycled. The following example is for the UK: www.wasterecycling.org.uk

Reference literature

- ADAS, 2007. *Agricultural Waste Plastics Collection and Recovery Programme. Good Practice Information*. Chartered Institution of Wastes Management Environmental Body, UK.
- DEFRA, 2006. Saving money by reducing waste. *Waste minimisation manual: a practical guide for farmers and growers*. DEFRA, London
- Environment Agency, 2008. *What's in it for you... Profit from a good environment. Best farming practices*. Environment Agency, Bristol.
- Jacobs P. & Associates Ltd., 2003. Best management practices: Agricultural waste management. Environment Canada, Canada-Prince Edward Island, available online: http://www.gov.pe.ca/photos/original/af_bmp_wastemgt.pdf, accessed February 2015.
- LEAF, 2012. *LEAF Marque Global Standard version 10.0 – issued 01/10/12*. LEAF, UK.
- Plastics Europe, 2007. *Resource efficiency: best practice for the recovery of plastics waste in Europe*. Presentation delivered by Aafko Schanssema, September 2007. <http://www.plasticseurope.org/Documents/Document/20100224161413-PresentationASBAPExternalFINALSeptember2007-20071009-007-EN-v1.pdf>
- Voluntary Initiative, 2011. *Crop protection Management Plan*. National Farmers' union, Stoneleigh Park.

3.7 Engage consumers with responsible production and consumption

Description

Abstract consumerism

Consumers have become removed from food production so that they are often unaware of the source of the food they purchase and the activities involved in farming and processing that food. Access to huge assortments of food products available throughout the year in large supermarkets, and the high time pressure of modern lifestyles, are reasons why consumers often have little awareness of more sustainable consumption patterns, such as seasonal purchasing and food management to avoid excess calorie intake and waste.

The food waste challenge

Of the four billion metric tonnes of food produced annually in the world, 30-50% (1.2 to 2 billion metric tonnes) is lost or wasted every year before being consumed (FAO, 2011). Annual food waste generation in the EU27 is approximately 89 Mt, or 280 kg per capita per year (Figure 3.23).

Vast environmental burdens are incurred for no useful nutritional gain. For example, it is estimated that 550 billion m³ of water is wasted globally in growing crops that never reach the consumer (FAO, 2011). Food wastage occurs throughout each stage of food production from initial agricultural production through to final household consumption (Figure 3.23). At the production level, up to 30% of crops in the UK are never harvested owing to failure to comply with exacting marketing standards on e.g. physical characteristics. Once purchased it is further estimated that between 30% and 50% of what has been bought in supermarkets in developed countries is thrown away before being consumed often at the direction of conservative 'use by' labelling. Reducing food waste throughout the food chain requires, above all, behaviour change by retailers and consumers (Styles et al., 2012a; EC, 2013). Farmers may play a limited but important role to play in this behaviour change through engaging consumers with food production.

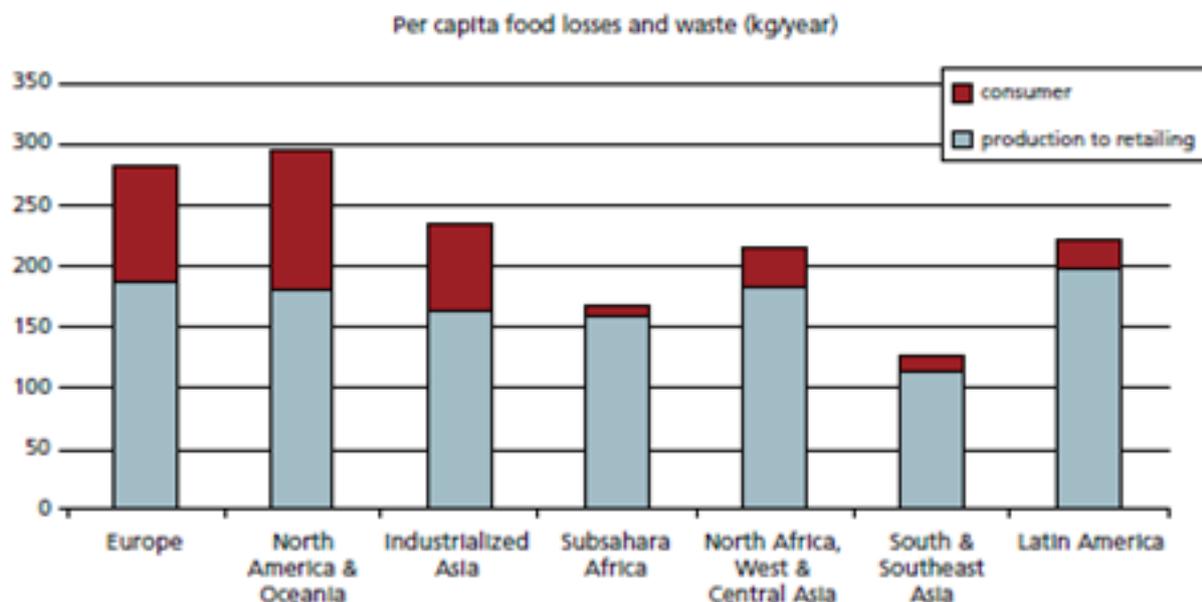


Figure 3.23. Per capita food losses and waste, at consumption and pre-consumptions stages, in different regions (FAO, 2011)

The nutrition challenge

Obesity, partly caused by excess calorie intake, is imposing massive social and economic costs in developed societies. Consumer behaviour, specifically sustainable nutrition, could play a fundamental role in facilitating sustainable food production.

EU average per capita consumption of animal proteins in the form of meat, fish and dairy produce is about twice the global average. The main source of animal protein is meat, of which the average consumption in Europe is about 52 kilograms per capita per year (corresponding to 85 kilograms in carcass weight). Dairy is the second source of animal protein; average dairy consumption in the EU is equivalent to 300 kilograms of milk per capita per year. Energy and protein intake from animal and vegetable products in the EU is 70% higher than recommended in WHO guidelines (PBL, 2011). Given the high environmental burdens of livestock production (Chapters 1 and 2), reduced meat consumption could be beneficial for health and the environment, and could be particularly important to mitigate against the large global increase in demand for animal production forecast over the next few decades as industrialising countries such as India and China become more affluent, based on the relationship between income and meat consumption (Figure 3.24).

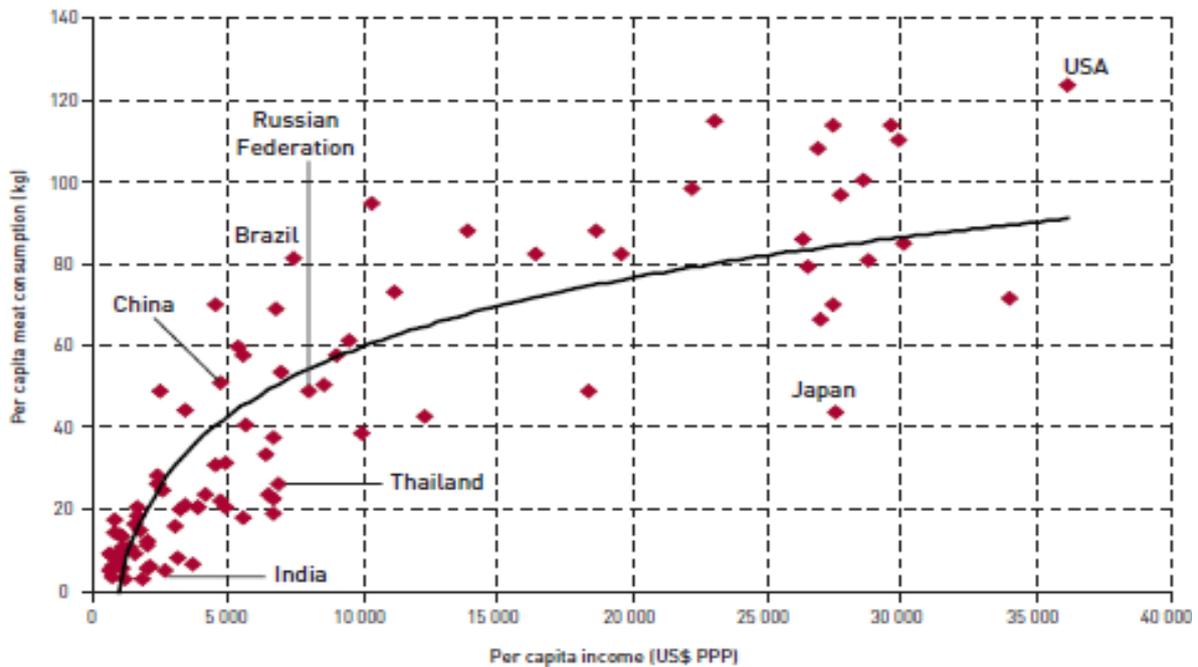


Figure 3.24. Relationship between national average per capita income and meat consumption (FAO, 2006)

Role for farmers

Many actors will need to engage with the challenge of sustainable nutrition, not least consumers, retailers and governments (Styles et al., 2012a,b; EC, 2013). However, there is also an important role for farmers, which is the subject of this BEMP.

Farmers can re-engage and educate consumers in farming and food production via:

- Direct sale of produce from farm shops, local farmers' markets, vegetable box schemes.
- Hosting farm open days and guided tours for members of the public.
- Engagement with community supported agriculture.

Direct marketing

Gilg and Battershill (2000) proposed various linkages between direct selling of produce from farms to consumers and more environmental sustainable food production. One benefit includes higher revenue for farmers, potentially providing greater scope for investment in efficient technology. Another benefit is greater transparency in the food supply chain, potentially avoiding some highly visible bad management practices. However, Edwards-Jones et al. (2008) noted that local food is not necessarily more sustainable according to various metrics such as lifecycle GHG emissions. Nonetheless, given the important contribution of glasshouse heating and transport to the lifecycle GHG and energy

burdens on many horticultural products (section 2.9), seasonal consumption of fruit and vegetables – encouraged by direct selling – could make an important contribution to sustainable production²¹.

Some key conclusions from the study were:

- Traditional co-operative strategies run counter to changing market contexts, societal demands and internal management challenges.
- Collective action by farmers has been important throughout the history of European agriculture
- Marketing and buying co-operatives lead to
 - improved market access
 - higher farm incomes
 - higher regional employment
- Farmer study groups lead to
 - technological innovation,
 - spread of sustainable production methods

Online platforms for direct selling

The social media is a modern and great tool that can be used by farmers in order to share information, create marketing strategies and build information with the potential customers. Nowadays (2015), there are several social media/appropriate platforms e.g. Facebook, Twitter, blogs etc., which can be used properly by farmers as well as customers.

From the farmers' perspective, those social media can be used to inform people about the applied agricultural practices, to inform the customers about the growth of the plants (or to provide info about the cultivation, by sharing photos etc.) or even to share ideas about crop varieties and innovative practices regarding pest control (ATRA, 2012).

Achieved environmental benefits

Land sparing

According to PBL (2011), both a shift to a healthier diet and a 50% reduction in the consumption of animal products would lead to an actual reduction in, or avoided expansion of total arable area of, 45 million hectares, equivalent to one third of the EU arable area. The same options would also result in an avoided expansion of grassland use outside the EU of around 60 million hectares, being about equal to the total EU grassland area (Figure 3.25). Diet change could also significantly reduce the global warming, eutrophication, acidification and biodiversity loss burdens associated with livestock production (Chapter 2).

Seasonal consumption

Seasonal consumption can avoid the high environmental arising from the supply of out-of-season produce, especially produce with a short shelf life that many be grown in heated glasshouses or flown from distant production locations (section 2.9). Asparagus flown from Peru to Switzerland was found to have a lifecycle GWP of 12 kg CO₂e per kg, compared with 0.5 kg CO₂e per kg for in-season asparagus transported from Hungary to Switzerland by truck (EC, 2013).

²¹ A recent EU project, Encouraging Collective Farmers Marketing Initiatives (COFAMI) studied collective farmer marketing across the EU. Extensive documentation is available at: <http://www.cofami.org/publications.html>

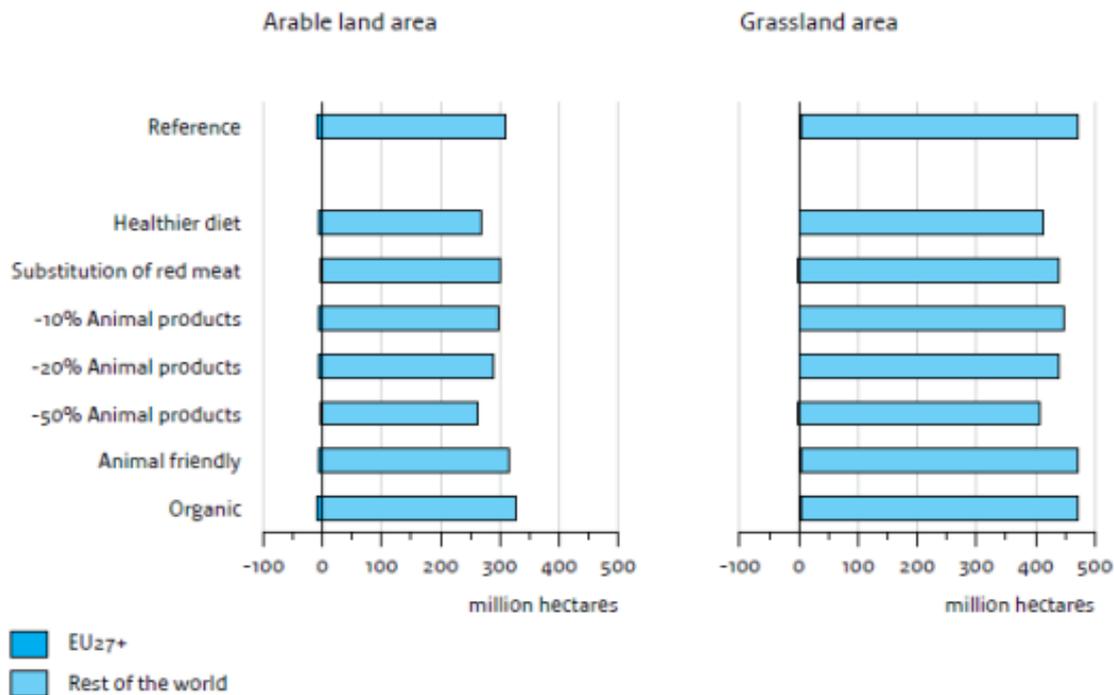


Figure 3.25. Effects of EU options regarding agricultural land use, 2000-2030 (PBL, 2011)

Appropriate environmental performance indicators

Farmer engagement with consumers

- Number of farm open days per year
- Presence of an on-farm shop
- Percentage of products sold on a defined market (%)

Food chain sustainability

- Quantity of primary agricultural production intended for human consumption (crops and animal live weight) that is not consumed by humans (pre- and post- consumer purchase waste), kg/capita/year
- Average population calorie intake, kcal/capita/day
- Average population meat and dairy product intake, kg/capita/y
- National/EU obesity rates (% population classified as obese)

Cross-media effects

Local versus efficient production

Edwards-Jones et al. (2009) demonstrate that food miles are not a reliable indicator of lifecycle GHG emissions, and that e.g. lamb from New Zealand can have a lower carbon footprint at the point of sale in the UK than lamb from Wales. In addition, whilst local food supply chains may avoid long-distance transport to food retailers, they may incur greater consumer transport distances using highly inefficient modes of transport (partially-loaded cars versus fully-loaded 33 tonne trucks). However, Mundler and Rumpus (2012) note that localised supply networks often optimise their transport and logistics to mitigate the lower efficiency of short-distance transport modes, leading to similar oil consumption per euro of product value as for long-distance supply chains.

However, the main benefits of direct sales and local consumption could arise from improved consumer awareness of food provenance, leading to consumption of more seasonal produce and less waste.

If consumers pay a premium for local produce, they will either: (i) buy (waste) less food; (ii) buy less of something else that drives environmental impact.

Operational data

Selling directly to consumers

There are a multitude of arrangements for direct and cooperative selling of produce to consumers. Various case study examples are available in the network²².

Produce sold directly may command a price premium over equivalent products sold in the supermarket, depending on the local consumer market. In addition, there are many ways to add value to local produce, including marketing via local stores and eateries (e.g. Figure 3.26). Working within a cooperative can be an efficient way to pool skills and resources, and to generate a critical mass for marketing.

Selling food products directly using social media

The use of social media can be used to drive consumer traffic for online purchases. In particular, an indicative set of pictures can be uploaded in order to create/establish a marketing strategy, which eventually will help customers to interact virtually with the process of growing the plants/crops.

The selection of each tool should be done under certain criteria. For instance, the more tools/platforms are used, the broader the audience may be attracted and the more the visibility it is achieved. On the contrary, each tool requires a significant time and effort and as a general remark it should not be taken on more than the farm capacity or the staff duties.

• ²² <http://www.cofami.org/publications.html>
• <http://www.reseau-amap.org/>



Figure 3.26. Bodnant Welsh Food farm shop and tea room, specialising in regional produce (Williamson, 2013).

Farm open days and community engagement

A range of local schemes provide information and support for community engagement activities. For example, in the UK, the LEAF Marque facilitates the organisation of:

- Open Farm Sunday events: <http://www.farmsunday.org/ofs12b/home.eb>
- School visits: <http://www.farmsunday.org/ofs12b/visit/group.eb>

Consumer waste minimisation (beyond the farm gate)

DEFRA (2012) quote WRAP data on reasons for food waste from UK households:

- Left on the plate after meal – 34%
- Passed its date – 22%
- Looked, smelt or tasted bad – 21%
- Went mouldy – 13%
- Left over from cooking – 10%.

DEFRA (2012) propose the following measures to reduce food waste (some of which may be implemented by consumers who have re-engaged with food supply chains via farm initiatives):

- Continued technological improvements to increase the shelf life of products.
- The removal of 'best before' dates on packaging to ensure consumers do not throw away food early.
- Improving consumer knowledge and packaging instructions on food storage and freezing.
- Increasing the range of product sizes will ensure consumers do not buy more than they need.
- Retailers limiting offers on perishable foods again will stop consumers buying more food than they need that is likely to go off.
- Greater consumer education on; what to do with leftover food, portion sizes, the effect food waste has on the environment.

Applicability

- Any farmer may decide to host open days for the public.
- Any farmer may participate join a direct selling scheme, though it is more viable for smaller farms and for horticulture farms.
- Cereal and livestock farmers may establish cooperatives including local processors (mills, bakeries, abattoirs, dairies, etc).

Economics

Direct or cooperative selling

King et al. (2010) report that, relative to mainstream chains, local supply chains appear to retain a greater share of wages, income, and farm revenues within local areas. However, farmers do take on greater processing and marketing burdens, with associated costs, so that farm profitability is not always significantly higher.

The main effects of direct/cooperative selling are summarised below:

- Higher product margins, somewhat offset by processing costs
- Potential product premium for (certified) local produce
- Increased farm/local food chain turnover and employment
- Enhanced potential for food-related tourism.

Open days

Open days may cost a day's labour, plus any relevant insurance premium, but may generate some economic return if produce can be displayed and sold. Local publically funded initiatives may fund open day costs. In the UK, support for hosting farm open days is available from a range of organisations: <http://www.farmsunday.org/ofs12b/open/resources.eb>

Directly selling food products via social media

Usually the subscription costs for joining those online platforms are null. The same is also applicable for creating the marketing strategy or using (e.g. interacting) the tools for other purposes. However, it should be clearly mentioned that for small farmers these costs are significantly low but for large farms higher costs will arise.

Driving forces for implementation

- Higher margins on value-added products
- Share in retail margins
- Greater autonomy
- Reduced exposure to price pressures arising from supermarket “price wars”
- Social responsibility

Reference organisations

- Association pour le Maintien de l’Agriculture Paysanne (AMAP): <http://www.amap-france.org/>

Reference literature

- ATRA 2012. Social Media Tools for Farm Product Marketing. Edited by Emily Post, National Center for Appropriate Technology (NCAT) Agriculture, publication reference: IP435, Slot 435, Version 081512.
- DEFRA, 2012. Green food project: dairy subgroup. DEFRA, London.
- EC 2013. Best Environmental Management Practice in the Retail Trade Sector: Learning from frontrunners. JRC Scientific Report. IPTS, Seville. ISBN 978-92-79-30495-8
- Edwards-Jones, G., Canals, L.M., Hounsome, N., Truninger, M., Koerbera, G., Hounsome, B., Cross, P., York, E.H., Hospido, A., Plassmann, K., Harris, I.M., Edwards, R.T., Dayd, G.A.S., Tomos, A.D., Cowell, S.J., Jones, D.L., 2008. Testing the assertion that ‘local food is best’: the challenges of an evidence-based approach. *Trends in Food Science & Technology* 19, 265-274.
- FAO, 2011. Global food losses and food waste, Extent causes and prevention. FAO, Rome.
- Gilg, A.W., Battershill, M., 2000. To what extent can direct selling of farm produce offer a more environmentally friendly type of farming? Some evidence from France. *Journal of Environmental Management* 60, 195–214.
- King, R.P., Hand, M.S., DiGiacomo, G., Clancy, K., Gómez, M.I., Hardesty, S.D., Lev, L., McLaughlin, E.W., 2010. Comparing the Structure, Size, and Performance of Local and Mainstream Food Supply Chains. United States Department of Agriculture.
- Mundler, P., Rumpus, L., 2012. The energy efficiency of local food systems: A comparison between different modes of distribution. *Food Policy* 37, 609–615.
- PBL, 2011. The protein puzzle: The consumption and production of meat, dairy and fish in the European Union. Netherlands Environmental Assessment Agency, The Hague. ISBN 978-90-78645-61-0.
- Styles, D., Schoenberger, H., Galvez-Martos, J.L., 2012a. Environmental improvement of product supply chains: proposed best practice techniques, quantitative indicators and benchmarks of excellence for retailers. *Journal of Environmental Management* 110: 135-150.
- Styles, D., Schoenberger, H., Galvez-Martos, J.L., 2012b. Environmental improvement of product supply chains: a review of European retailers' performance. *Resources, Conservation and Recycling* 65: 57-58.

4 SOIL QUALITY MANAGEMENT

Introduction

Healthy soils underpin agricultural production. Maintaining good soil quality is critical for resource-efficient farming. Soil itself is a resource, so its degradation represents one component of resource inefficiency. But fundamentally, soil degradation leads directly to inefficient use of other resources, such as fertilisers, in agricultural production, and damage to surrounding environmental resource including water bodies. Haygarth and Ritz (2009), amongst others, demonstrate the key role of soils in the delivery of ecosystem services such as flood regulation, water quality regulation, climate regulation and provisioning (agricultural production), amongst many others. Daily et al. (2009) developed a decision loop which can be used for the policy development accounting for ecosystem services whereas Hedlund and Harris (2012) put this approach into soil context (Figure 4.1).

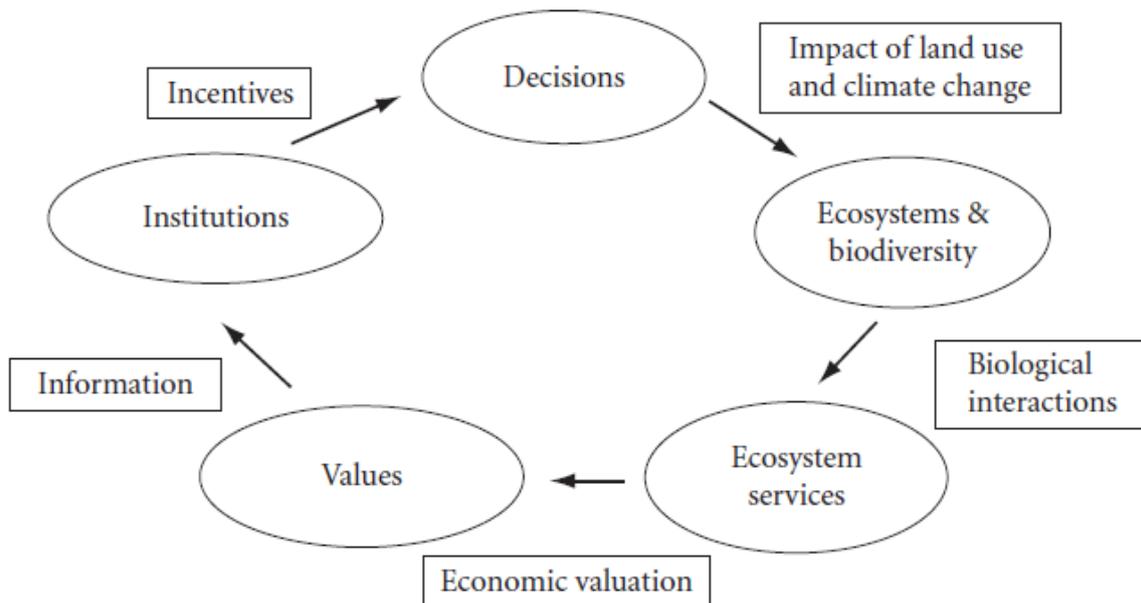


Figure 4.1. A decision loop which can be used for policy development accounting for ecosystem services when taking actions and decision on soil natural capital (Hedlund and Harris 2012).

Agricultural threats to soil quality

Forty percent of EU27 land is farmed (Eurostat, 2011). Soil erosion on agricultural land is a particular threat to soil quality in Europe, impeding the ability of soils to support higher agricultural productivity and environmental services. Soil erosion leads to direct off-site impacts from runoff water and eroded soil, principally eutrophication of water bodies, sedimentation of gravel-bedded rivers, loss of reservoir capacity, muddy flooding of roads and communities (Boardman et al., 2009). Various risk-assessment procedures have been introduced to encourage better erosion risk management by farmers, including a manual for the assessment and management of agricultural land at risk of water erosion in lowland England (DEFRA, 2005) – referred to in Chapter 3. Boardman et al. (2009) associated the following crops with an increased risk of erosion in the area they studied: potatoes, winter cereals, maize and grazed turnips.

In the EU, an estimated 52 million hectares, representing more than 16% of the total land area, are affected by some kind of degradation process (COM, 2002) and the inclusion of accession countries since this estimate was made will have increased this area significantly. Compaction is an important component of soil degradation in Europe (Figure 4.2) that impedes crop root development and yields

along with many other environmental services. The risk of significant runoff and erosion is greatly increased where soils are compacted.

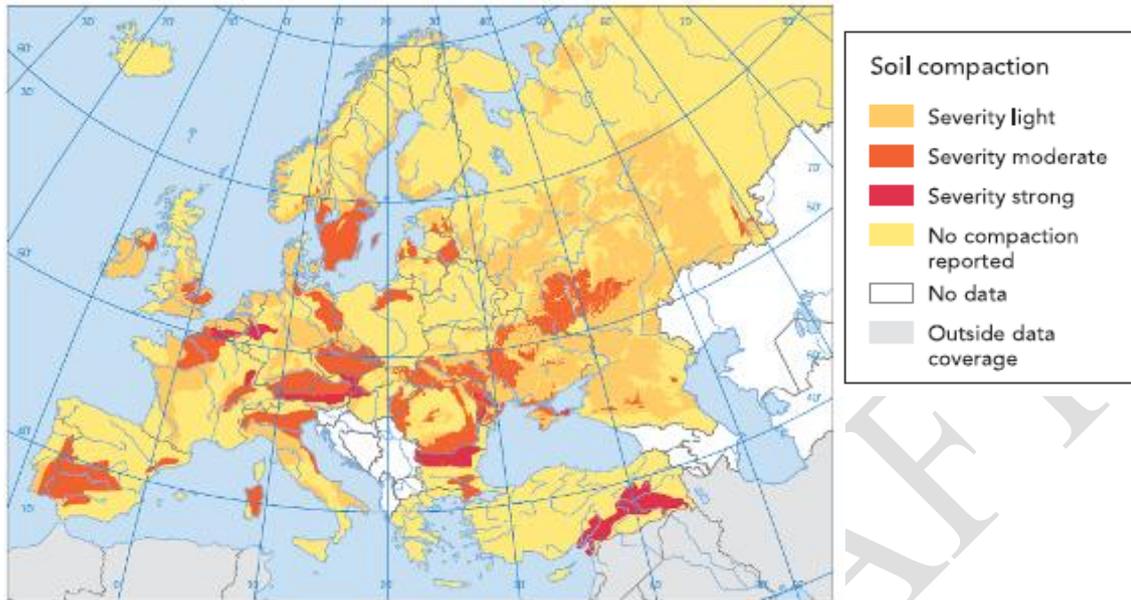


Figure 4.2. The degree and extent of soil compaction in Europe (EEA, 2012)

Soil organic matter decline

Throughout Europe, soil organic matter (SOM) has been decreasing at an alarming rate and was a key factor in producing a Strategy for Soil Protection and a proposal for the Soil Framework Directive. 50% of EU soil is impoverished in OM and >10 M ha subject to erosion (Hamell, 2012). European soils (EU27) contain $73-79 \times 10^9$ tonnes of carbon (Klik, 2012), providing an important regulatory function for global climate (Figure 4.3). The organic component of soil is equally as important as mineral fertiliser additions for productivity and yet it rarely receives the same attention. Soil organic matter includes all living soil organisms, decomposing plant and animal material and humus (decomposed material). In addition to providing nutrients and habitat to organisms living in the soil, organic matter also binds soil particles into aggregates which improves structure, drainage and aeration; it also improves the water holding capacity of soil, soil fertility, microbial function and carbon sequestration. It also increases buffering capacity against mineral inputs, increases the potential for biodegradation of pollutant molecules, reduces risk of erosion and resilience to compaction. Better nutrient retention, especially in sandy soils. More than 16% of the EU's total land area is considered degraded in one or more of these soil functions (Jones et al, 2013).

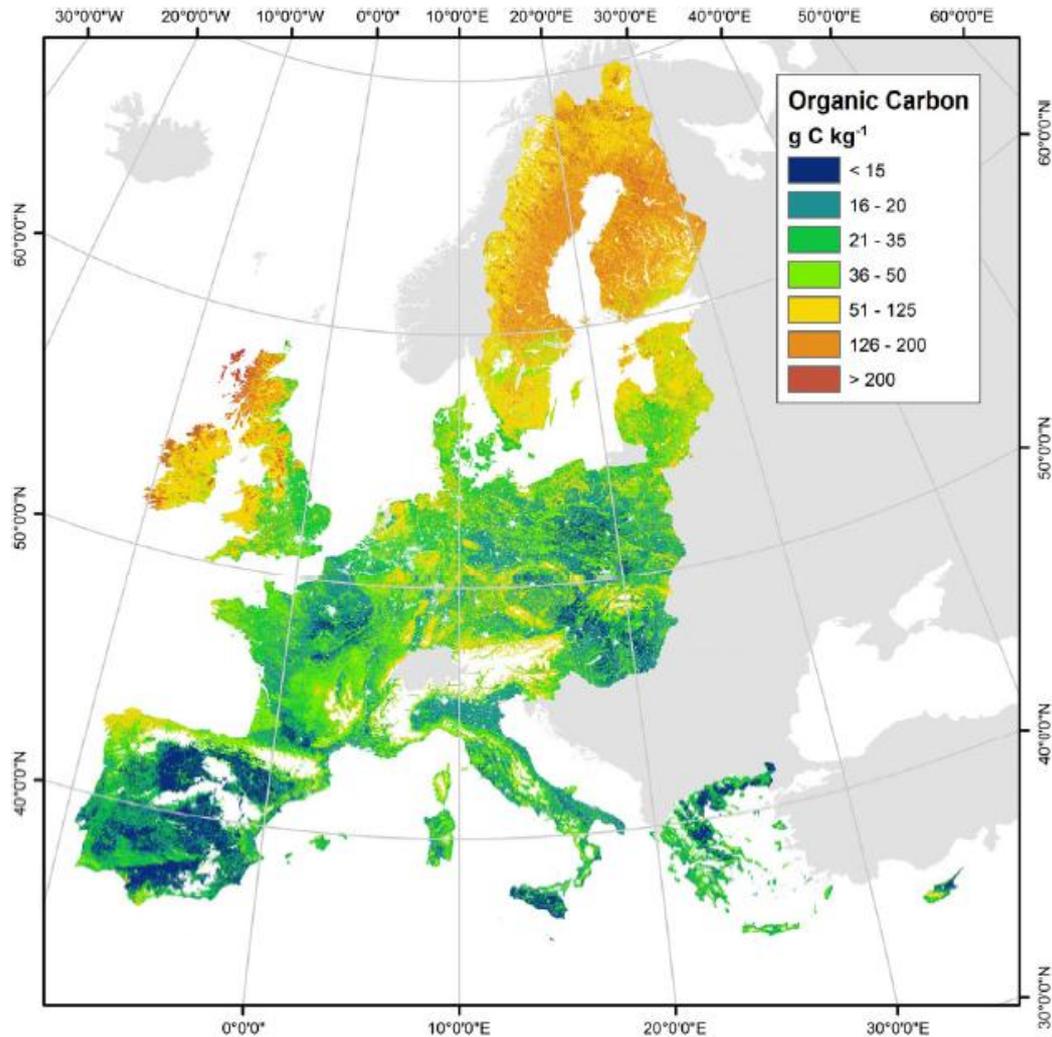


Figure 4.3. Map of predicted soil organic content in g C/kg (Brogniez et al., 2015)

Southern European countries have lower SOM than Northern ones, due to climate (soil temperature, rainfall), agricultural practice, crop types, farm types. Most UK soils contain 2 –10% organic matter. The level of organic matter is influenced by many factors and represents a balance between gains from fresh residues and losses from decomposition and erosion. Building up SOM levels requires decades so it is better to prevent its loss: applying slurry, farmyard manures and other locally available organic materials helps maintain SOM. Soil microbial biomass C accounts for around 5% of soil total C and this living portion is largely responsible for converting organic matter into plant-available nutrients.

As well as adding organic matter to soil for improvement to structure, organic materials provide a valuable and necessary source of nutrients. It is critical to sustainable agriculture that organic wastes are returned to agricultural land to avoid soil nutrient ‘mining’. The spatial disconnects caused by the segregation and industrialisation of livestock systems, between rural areas (where food is produced) and urban areas (where food is consumed and human waste treated) are identified as a major constraint to sustainable nutrient recycling (Jones et al, 2013).

Soil quality management

Having a Soil Protection Plan is fundamental to farm sustainability to maximise resource use efficiencies by maintaining soil quality and functionality. A plan should include measures that address

components highlighted in the European Soil Protection Strategy as the main threats to soil (COM, 2002) namely erosion, decline in organic matter, contamination (point source and diffuse), compaction, decline in soil biodiversity, salinization, floods/landslides and soil sealing. In the CAP (2014-2020, (EU) 1306/2013), the cross compliances (GAEC 4-6) are concerned with keeping the organic matter of the soil, and reducing. There are a number of managements suggested that potentially can increase the quality and organic content of agricultural soils in Europe, as low tillage, cover crops, green manure, grass leys in rotations (Lugato et al., 2014).

Organic farming provides an example of how a system based only on organic inputs offers sustainable productivity where the function of the soil is central to its ethos. Organic farming is the only type of “sustainable farming system” that is legally defined. Within the EU, crop and livestock products sold as organic must be certified as such under EC Regulation 834/2007. In the UK, it is the role of the UK Register of Organic Food Standards (UKROFS) to implement this legislation. UKROFS licences a number of certification bodies, such as the Soil Association, to certify and inspect organic farms to ensure that organic production practices are followed. Certified products are marketed at a premium.

Maintaining soil quality involves management of the following components to produce a functional medium capable of supporting economic animal and crop productivity in an environmentally and socially beneficial way (Figure 4.4):

- Fertility (organic matter and mineral nutrients); is addressed in chapter 5.
- Structure
- Drainage
- Contamination

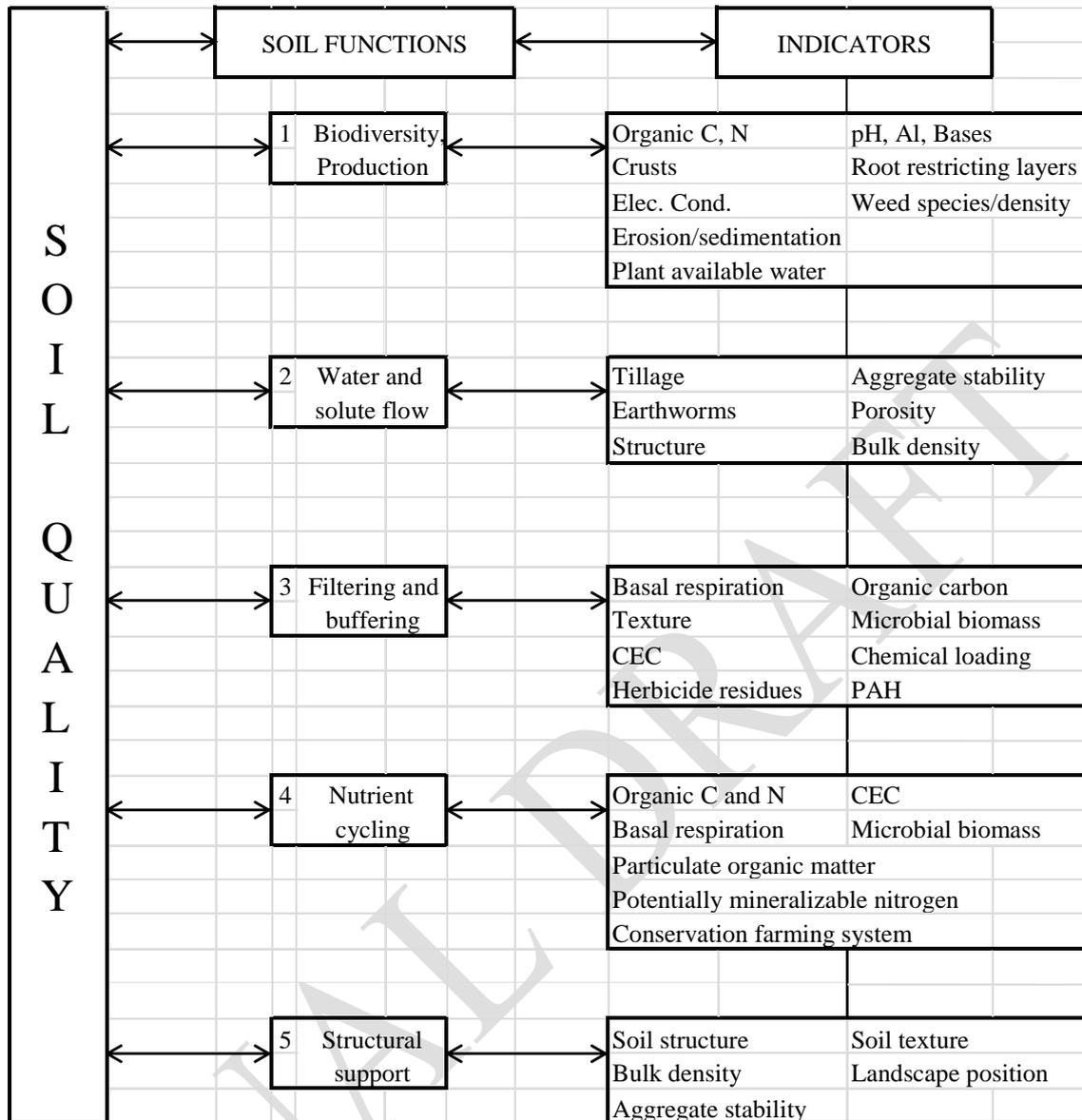


Figure 4.4. The relationship between key soil functions and soil properties/indicators (adapted from Klik, 2012, citing Mausbach and Seybold, 1998).

This chapter is relevant to all farm types and covers four BEMPs, namely:

- Assess soil physical condition;
- Maximise organic matter amendments, especially in tillage soils;
- Maintain soil structure (avoid erosion and compaction);
- Control Soil drainage

Reference literature

- Boardman J., Shepherd M.L., Walker E., Foster I.D.L. (2009). Soil erosion and risk assessment for on- and off-farm impacts: A test case using the Midhurst area, West Sussex, UK. *Journal of Environmental Management*, 90, 2578-2588.

- Brogniez D., Ballabio C., Stevens A., Jones R.J.A., Montanarella L. and van Wesemael B. (2015). A map of the topsoil organic carbon content of Europe generated by a generalized additive model. *European Journal of Soil Science*, 66, 121-134.
- COM 2002. 'Towards a Thematic Strategy for Soil Protection' 179 - C5-0328/2002 - 2002/2172 (COS) of 19/11/2003. The European Parliament.
- Daily G.C., Polasky S., Goldstein J., et al. (2009). Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment* 7:21–8.
- DEFRA (2005). *Controlling soil erosion: a manual for the assessment and management of agricultural land at risk of water erosion in lowland England*. London, DEFRA. Downloaded October 2013 from: <http://archive.defra.gov.uk/environment/quality/land/soil/documents/soilerosion-lowlandmanual.pdf>
- EEA (European Environment Agency), 2012. *Soil compaction in Europe* Accessed January 2013 from: <http://www.eea.europa.eu/data-and-maps/figures/soil-compaction-in-europe>
- Eurostat (2011). *Food: from farm to fork*. Eurostat pocketbooks, European Commission. http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-32-11-743/EN/KS-32-11-743-EN.PDF
- FAO Stat, (2013). *Agri-environmental indicators home page*. Accessed November 2013: http://faostat3.fao.org/faostat-gateway/go/to/download/E/*/*
- Hamell M., (2013). Challenges in the agri-environment relationship in the period to 2030. In: *Teagasc, Agri Environment Conference 2012 'Sustainable Pathways to Food Harvest 2020'*, December 2012, Farmleigh, Dublin, Ireland.
- Haygarth P.M. and Ritz K. (2009). The future of soils and land use in the UK: Soil systems for the provision of land-based ecosystem services. *Land Use Policy* 26S, S187-197.
- Hedlund K and Harris J. (2012). Delivery of Soil Ecosystem Services: From Gaia to Genes. In: Wall, D.H., et al. (2012). *Soil Ecology and Ecosystem Services*. pp 98-109, Oxford University Press, UK.
- Jones D.L., P. Cross, P.J.A. Withers, T.H. DeLuca, D.A. Robinson, R.S. Quilliam, I.M. Harris, D.R. Chadwick and G. Edwards-Jones (2013). Nutrient stripping: the global disparity between food security and soil nutrient stocks. *Journal of Applied Ecology* (In Press).
- Klik A. (2012). *Soil Conservation and Soil Protection* VU 815.321. Institut für Hydraulik und landeskulturelle Wasserwirtschaft, Universität für Bodenkultur Wien.

4.1 Assess soil physical condition

Description

Within this BEMP, the following measures are described:

- Regular field soil testing to maintain appropriate organic matter and pH values
- Regular visual inspections of fields for signs of compaction, erosion, surface ponding
- Know farm soil types – referring to publically available soil maps

Regular soil testing

Regular checking of soil nutrient reserves and pH helps to reduce fertiliser costs and encourage the availability of nutrients (BEMP 5.1). Soil pH strongly impacts on nutrient availability for plant root uptake with near neutral soils (pH 6.5-7.5) being optimum (Figure 4.5). With mineral fertiliser applications, soils tend to become more acidic over time, and for this reason, liming is an important modification practice in agricultural production systems. The finer the lime applied, the more reactive it is and the further soil pH is elevated; granular lime is slower acting but less expensive. Regular testing of soil fertility at the field level will inform best practice in soil pH management through lime application.

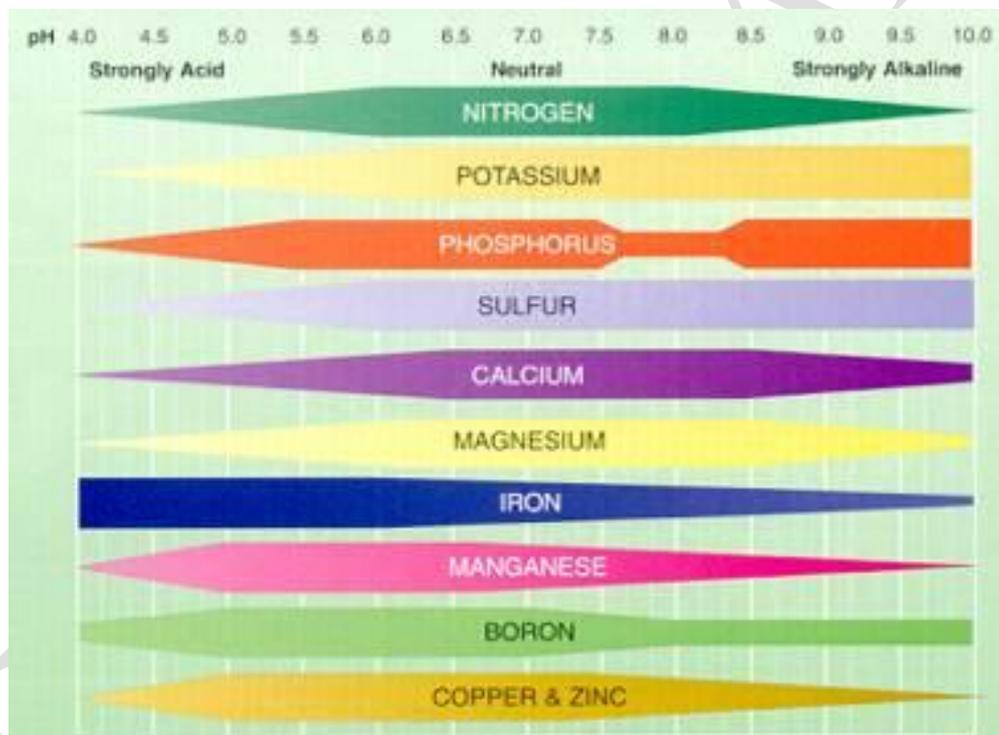


Figure 4.5. Availability of nutrients at different soil pH levels (Extension.org, 2013).

Assess soil physical condition

It is best practice to walk fields with a spade regularly (depending on the soil local characteristics) to assess soil physical condition: this can be combined with checking on / moving stock and assessing crop condition for harvesting, grazing, pests, weeds, fertiliser top-up (Figure 4.6 and Figure 4.7).

Compaction may be prevalent where crops appear to be doing less well in area/s of field. Check rooting depth by digging out a sod to 60 cm depth; if most roots do not penetrate to 30 cm depth then compaction may be problematic as in Figure 4.8. Also check for earthworm presence and burrows; depletion often indicates compaction.

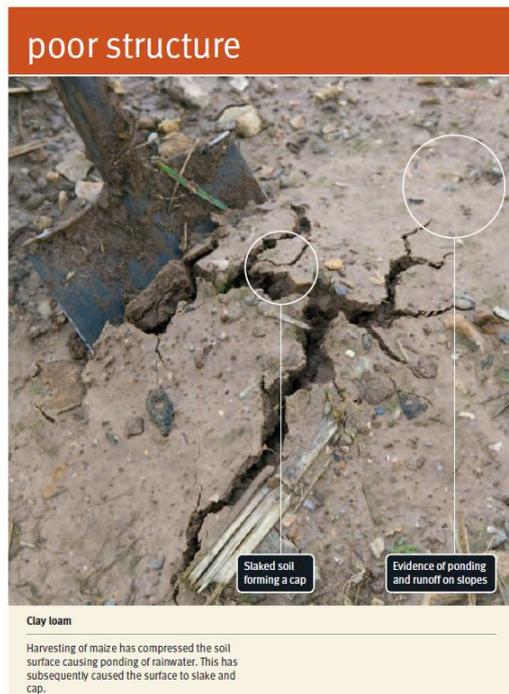


Figure 4.6. Clay loam: harvesting maize compressed the soil surface resulting in surface ponding. This subsequently led to slaking and soil capping (Environment Agency, 2008)



Figure 4.7. Sandy loam: heavy traffic during harvesting potatoes compressed soil. Cultivation is required to remove compaction (Environment Agency, 2008)

Compaction can be measured by a penetrometer which detects the pressure necessary to push a cone through a soil profile. e.g. <http://agrisupplyservices.co.uk/soil-testing.htm>.

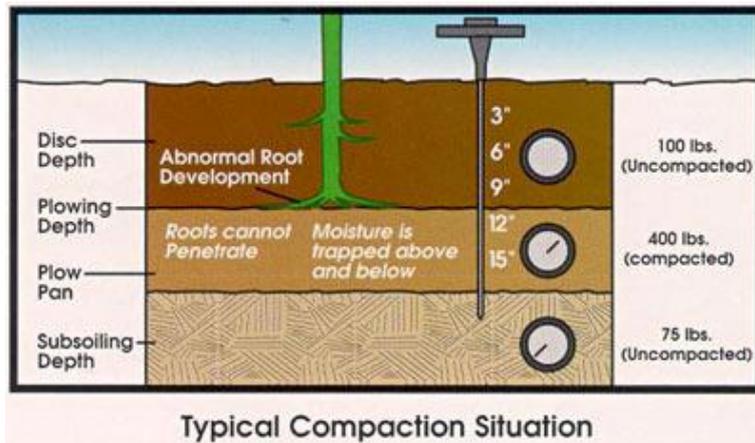


Figure 4.8. Using a penetrometer to measure compaction, demonstrating poor root structure (Agricultural Supply Services, 2014)

Erosion is easy to see and examples of which include gulying, rills, slumping, surface run-off (overland flow), sediment deposition, surface capping, wind-blown erosion.

Surface ponding is also easy to see and often related to compaction; it can also result in soil erosion on slopes. Check for underlying compaction by digging to 60 cm; if the soil below the surface is dry/drier, then soil is compacted and water cannot migrate vertically due to lack of soil pores and natural fissures.

Map farm soil types

It is best practice to map the different soil types that exist on the farm to use in deciding which soils are best suited to which land use type. Figure 4.9 shows an example soils map for England²³ and Wales whilst Figure 4.10 shows an example soils map for Austria (below).

²³ Moreover in UK all the outdoor pig producers are encouraged to develop a comprehensive Soil Management Plan (SMP) for the land on which they are keeping pigs. The main objective of the SMP is to describe all the possible and feasible measures for soil management in order to avoid the surface runoff and soil erosion, to record the success and the results of those measures and eventually to report potential mitigation measures. The SMPs consist of three main steps: i. production of a map showing the risk class for each field (or part of the field), which is occupied by pigs, ii. mention for each field measures and steps to be taken to minimise the run off and erosion and iii. retain the plan and review it in an annual basis.

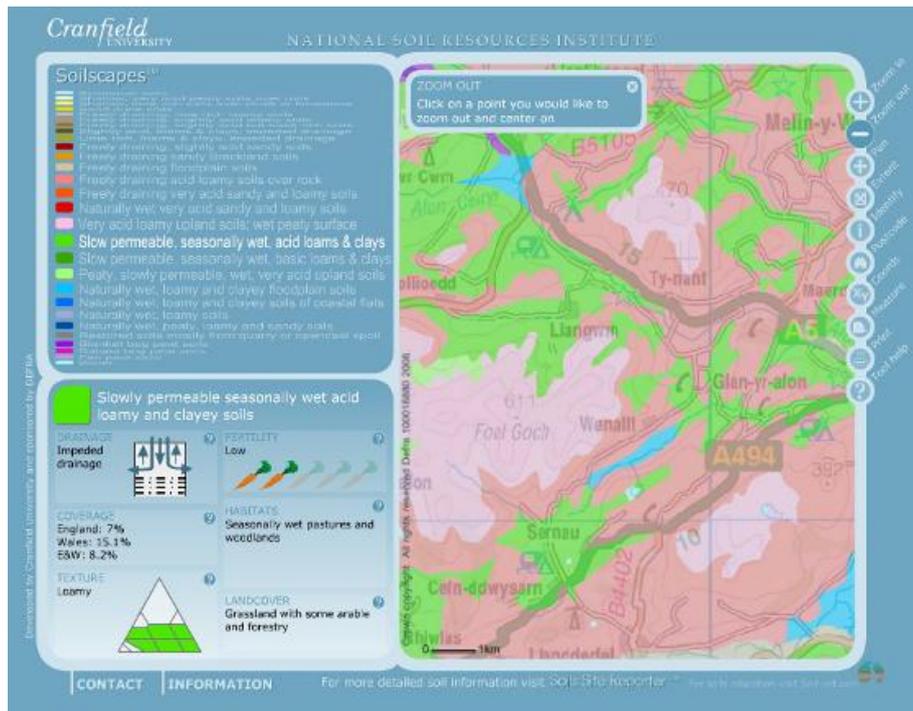


Figure 4.9. An example map provided by Soilscales, for England and Wales (National Soil Research Institute, 2014).

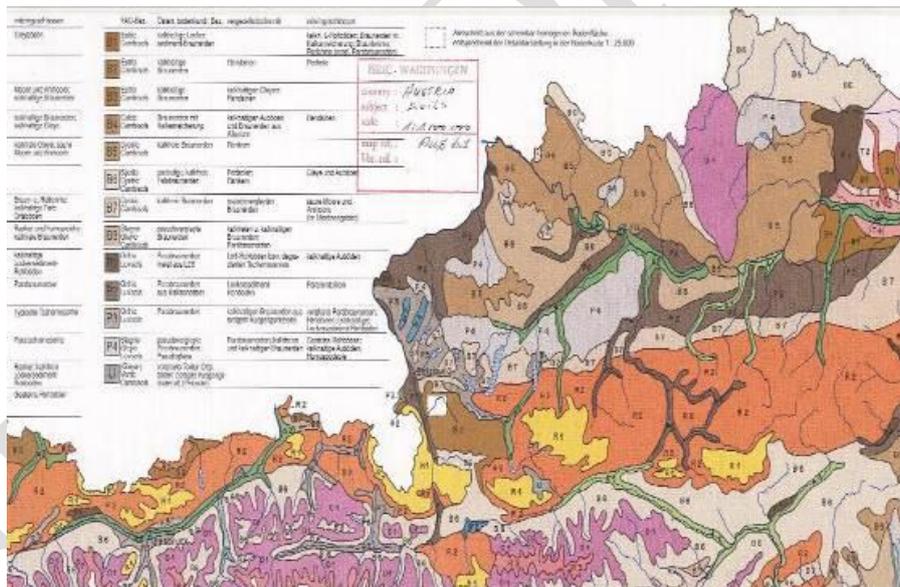


Figure 4.10. An example soil map provided by the EC soil map library (EC, 2014a)

Figure 4.11 illustrates the five soil groups that categorises soils as sandy and light soils prone to erosion according to the different soil texture for lowland of England (BPEX, 2014).

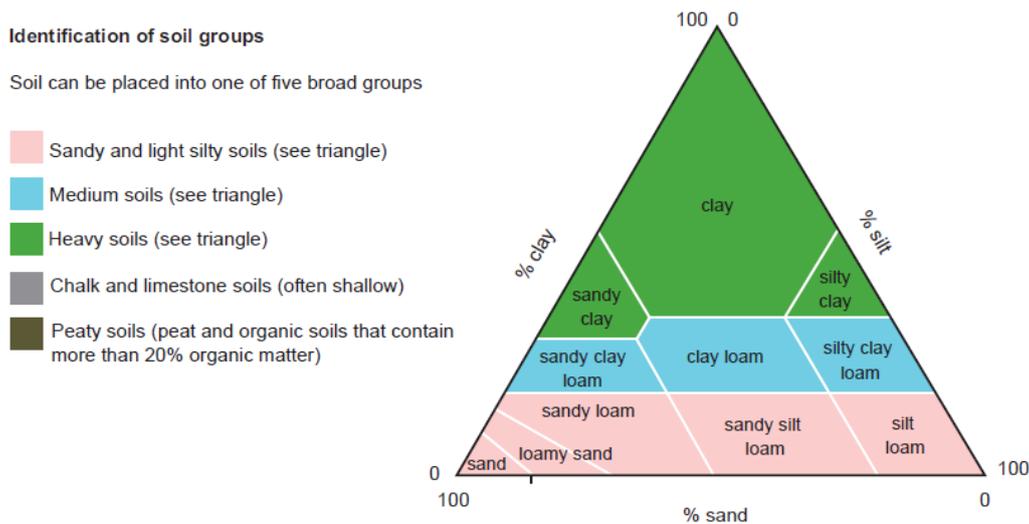


Figure 4.11. Indication of soil groups in England (DEFRA, 2005; BPEX, 2014)

Achieved environmental benefits

The proper assessment of the physical condition of the soil encourages the availability of nutrients. It avoids over-application of lime and fertiliser, and associated upstream and downstream pollution (manufacturing and soil emissions). It also facilitates the optimum application of individual minerals to ensure maximum crop yield response.

Maintaining correct soil pH

As described above, nutrient availability is dependent on soil pH, so that sub-optimum soil pH can greatly reduce productivity and nutrient use efficiency. The estimated loss in grazing yield at a mean field pH of 5.6 compared with the optimal pH of 6.0 is 15% (Winham and Beaverstock, 1984), because of reduced capacity of grass to take up applied N at sub-optimum soil pH. Therefore, liming would improve yield at a given nutrient application rate, or allow the same yield at a lower nutrient application rate (and also incur emissions from producing and spreading lime). Data on silage grass yield deficits at different soil pH ranges are shown in Table 4.1 (EBLEX 2013).

Table 4.1. Silage grass yield deficits at different soil pH ranges (EBLEX 2013)

pH	< 4.5	4.5 - 5.0	5.0 - 5.5	5.5 - 6.0	6.0 - 6.5
% max yield	87%	88%	91%	96%	100%

The environmental efficiency of production is directly related to these yield effects. For the same resource inputs (nutrients, energy, water, etc.), silage grass outputs are reduced by up to 13% in the above example, resulting in a 15% increase in all inputs (and associated emissions) per tonne of silage grass produced.

Appropriate environmental performance indicators

Indicators of soil structure

- Rooting depth (mm)
- Penetrometer or other bulk density (kg/m^3) reading
- Visual evaluation of soil structure
- Macro-porosity
- Aggregate stability
- Above-ground plant biomass (kg/m^2)
- Soil water holding capacity (% of dry weight),

- Infiltration capacity (mm/hour)

Soil contamination

- Heavy metal concentrations (mg/kg)
- Plastic contamination

Management indicators

- Test fields every 3–5 years for P, K, Mg, pH, Om and bulk density; test every year for SNS
- Walk fields weekly to inspect signs of compaction, erosion, surface ponding
- Produce a soils map for the farm
- Maintain environmentally appropriate levels of soil P, K, Mg, (index or kg/ha), pH, SNS (kg/ha), trace elements
- Soil Organic Matter balance (+/-); the relation of SOC of a specific field towards a grassland can be used as the maximum level of SOC of a specific site

Cross media effects

There are no cross media effects reported for that technique.

Operational data

Testing for soil physical condition

The main steps for implementing a testing for soil physical condition are listed: Assess the condition of each profile; look at the texture, structure, drainage and organic matter content of the soil; soil texture refers to the balance of sand, silt and clay particles in the soil; soil structure refers to the aggregation of soil particles. Use the data in Table 4.2 and

Table 4.3 (The WestcountryRivers Trust undated; DEFRA 2005; EBLEX, 2012) to help with the assessment. However, it should be mentioned that the measures in table 4.3 are remedies that are dealing with soil compaction and have good results with short term changes. To get long term changes, there needs to be more vegetation and organic amendments on the fields and less ploughing. For instance, the soil resist compaction is improved by practising no tillage for a long period. The no-tillage also results in organic matter accumulation at the soil surface, which eventually contributes to the reduction of the effects of the surface compaction because soil with high organic matter content is 'spongy' and less compactable. Moreover the permanent burrows of old root channels and prolific activity of earthworms help the soil to resist compaction, while the living roots are most likely the best protection against compaction (Duiker, 2012).

Table 4.2. Common attributes of good and poor condition soils (The WestcountryRivers Trust, undated)

Good condition	Poor condition
Crumbly, friable and porous structure	Cloddy, dense and compacted structure
No compacted zones e.g. plough pans, wheeling pans	Compacted zones e.g. plough pans, wheeling pans
Deep, branching roots that grow downwards	Horizontal, stunted or restricted roots
Cracks that allow rooting and drainage	No cracks
Worm holes	No worm holes
Freely draining, brownish soil	Grey, yellow and mottled anaerobic (oxygen depleted) layers

Table 4.3. Common types, causes, and remedies for compaction (EBLEX, 2012)

Compaction type	Typical cause	Remedy
Surface capping (0-10cm deep)	Grazing in wet conditions. High stocking densities. Rainfall on new cultivations.	Lime/introduce organic matter to encourage earthworm activity to break cap. Soil aerator with spikes or knives. Plough ^a .
Machinery (10-15cm deep)	Silage and mucker-spreading operations. NB the first wheeling creates 70% of the damage so use tramlines if possible.	Soil aerator with spikes or knives. Subsoiler or sward lifter. Plough ^a .
Plough pans (15cm + deep)	Repeated re-seeding at one depth.	Subsoiler or sward lifter. Mole-plough (heavy soils only). Deeper plough just below pan.

^a Those measures give only short term uncompaction, but kill worms and other organisms that makes the soil porosity

ZALF (2007) compiled a method that assesses the soil quality based on the classes of soil quality, which are presented in table 4.4.

Table 4.4. Diagnostic check of the final rating score of cropping land (ZALF, 2007)

Soil quality rating score	Soil quality assessment	Criteria to meet
< 20	Very poor	
20 – 40	Poor	Save cropping of a main basic crop ¹
40 – 60	Moderate	Criteria of unique farmland ² Save cropping of corn ³
60 – 80	Good	Criteria of farmland of state-wide importance ² Save cropping of winter wheat in Eurasia and Northern America
> 80	Very good	Criteria of prime farmland ² Acceptable risk of water and wind erosion ³ Save cropping of maize or corn

¹. Crop adapted to local conditions that provides subsistence farming (basic food of humans, for animal husbandry or a cash crop like potato, buckwheat or others)
². Cereal of highest local importance (maize, wheat, barley, rye, millet and others)
³. Soil loss less than tolerable limit, for example methodics of water erosion risk assessment acc. to Deutsche Norm, DIN 19708 (2005) and Bavarian LfL (2004), wind erosion acc. to Deutsche Norm, DIN 19706 (2004)
⁴. http://en.wikipedia.org/wiki/Prime_farmland, Soil Survey Staff (1993). Soil Survey Manual. Soil Conservation Service. U.S. Department of Agriculture Handbook 18. Retrieved on 2006-08-30.

Some general remarks that arise from the soil assessment are described below. For instance, regular field walking to prevent or rapidly ameliorate deteriorating soil physical condition results in better plant growth and therefore improved resource use efficiency, better drainage and soil aeration for biological activity. Moreover, mapping the soil type of each field and using the map to decide on appropriate land use and soil management strategies ensures optimum productivity whilst safe-

guarding the receiving environment. Soil structure can be graded quickly in the field through a simple grading method²⁴. BPEX (2014) proposed appropriate summary sheets to ensure producers (farmers) consider all the important factors effecting soil when completing their risk assessment map (Table 4.5).

Table 4.5. Farm summary sheet to ensure farmers that they consider all the important factors effecting soil (BPEX, 2014)

Number of pigs		
Stocking density		
Farm size		
Duration site occupied		
Dates pigs moved on/off land		
Designations applying to site and surroundings (distance) – for more information visit maglc.defra.gov.uk	Nitrogen Vulnerable Zones (NVZ)	
	Site of Special Scientific Interest (SSSI)	
	Area of Outstanding Natural Beauty (AONB)	
	Source Protection Zones (SPZ)	
	Other	
Field name/number	Soil texture/type	
	Top Soil	Sub Soil
Signs of waterlogging/ponding/capping/compaction/mottling		
Drainage: (type/location/maintenance)		
Connectivity to water courses/boreholes: (location and distance)		
Annual rainfall		
Location: Exposed/windy Residential housing		
Signs of erosion/runoff		
Buffer zones		
Traffic management		
Tyre pressure/type		
Crops	Previous	Planned
Site and paddock layout: Feeders/troughs Tracks/roads/gates		
Soil Management Training	Training provider	Date

Applicability

Assessing soil fertility and physical condition is highly desirable and applicable to all farm types.

²⁴ For more details about the simple grading method you can find in the following links SRUC (2014):

- http://www.soils-scotland.gov.uk/documents/64130612_soilstructure.pdf
- http://www.sruc.ac.uk/info/120062/crop_and_soils_systems/412/visual_evaluation_of_soil_structure

Economics

Soil testing costs

Basic soil testing works out at approximately 12 €/field (assuming one soil sample) in the UK which includes analysis for P, K, Mg and pH accompanied by fertiliser and lime recommendations based on RB209 Fertiliser Manual (DEFRA, 2010) for a specified crop following a specified previous crop, specified soil type and specified level of productivity. A penetrometer can measure compaction and costs from 82 € which could be shared amongst neighbouring farms. Cultivating compacted soils takes longer and uses more fuel. Soil maps are usually free via the internet, libraries and academic institutes.

Yield benefits

Yield benefits from improved soil quality (and in parallel implementing fertility improvement measures) can be significant, potentially increasing crop/animal production revenue by up to 50% in the long term depending on the extent of degradation and subsequent soil improvement although 10-20% may be more likely in most cases. However, it may take a number of years for the full benefits of better soil management to be realised following initial soil degradation.

Driving forces for implementation

The main driving forces for this technique are:

- Maintaining farm productivity and profitability
- Regulatory compliance to protect water quality (Water Framework Directive)
- Cross compliance in CAP (both GAECs and regulatory compliance)

One major challenge to implementation of this technique is land ownership and rental agreements. Where land is not owned by the farmer, there is little incentive to invest resources into management of long-term soil quality and fertility.

Reference literature

- Agricultural Supply Services, 2014. Website accessed Feb 2014: <http://agrisupplyservices.co.uk/soil-testing.htm>
- BPLEX (2014), Soil management plan for outdoor pig keepers, available online: <http://www.bplex.org.uk/environment-hub/soil-water/SoilManagementPlan.aspx>, accessed 16 September 2014.
- DEFRA 2005. Controlling soil erosion. A manual for the assessment and management of agricultural land at risk of water erosion in lowland England. Project reference number: PB4093, Crown copyright.
- DEFRA, 2010. *Fertiliser Manual RB209*. UK: TSO. Retrievable at <http://www.defra.gov.uk/publications/2011/03/25/fertiliser-manual-rb209/>
- Duiker S. (2012). Soil Compaction Management. Penn State Extension. Field Crop News, 12:02, February 7.
- EBLEX, 2012. *Improving pasture for better returns*. Accessed Aug 2013 from: http://www.eblex.org.uk/wp/wp-content/uploads/2013/07/brp_b_BRPManual1-Improving_pasture_for_better_returns190713.pdf
- EBLEX, 2013. *Silage decisions factsheet: soil pH*. Accessed August 2013 from: <http://www.silagedecisions.co.uk/pdfs/Soil%20pH%20factsheet%202.pdf>
- EC, 2014a. JPEG map of Austria. Website accessed Feb 2014: http://eussoils.jrc.ec.europa.eu/EuDASM/AT/AT_12001.jpg
- EC, 2014b. Website accessed Feb 2014: http://eussoils.jrc.ec.europa.eu/library/maps/country_maps/metadata.cfm?mycountry=EU
- Environment Agency, 2008. *Think Soils*. Bristol, EA. Downloaded October 2013 from: <http://www.ahdb.org.uk/projects/documents/ThinkSoils.pdf>

- Extension.org, 2013. *Soil pH webpage*, accessed May 2013: <http://www.extension.org/pages/13064/soil-ph-modification>
- Farming Online, 2011. Fertiliser Recommendation Calculator Based on DEFRA RB209. Website accessed Feb 2014: www.fertiliser-recommendations.co.uk/
- IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>
- National Soil Research Institute, 2014. Cranfield University. Website accessed Feb 2014: www.landis.org.uk/soilscapes/
- NRM Laboratories, 2014. Website accessed Feb 2014: www.nrm.uk.com/
- The Westcountry Rivers Trust (undated). Website accessed Feb 2014: http://www.therivertrust.org/pinpoint/info_sheets/Pinpoint%20-%2030.0%20Nutrient%20management%20-%20Soil%20nutrient%20testing.pdf
- The Westcountry Rivers Trust, 2012. PINPOINT. Website accessed Feb 2014: http://www.therivertrust.org/pinpoint/info_sheets.html
- Winham, W.N., Beaverstock, D.G., 1984. *The effects of pH and high rates of nitrogen on grass*. Ministry of Agriculture, Fisheries and Food, Agricultural Development and Advisory Service. Conference of Soil Scientists
- ZALF (2007). The Muencheberg Soil Quality Rating (SQR), field manual for detecting and assessing properties and limitations of soils for cropping and grazing, edited by: Mueller L., Schindler U., Behrendt A., Eulenstein F. and Dannowski F. Leibniz-Zentrum fuer Agrarlandschaftsforschung (ZALF), Muencheberg, Germany.

4.2 Maintain/improve soil organic matter on cropland

Description

Within this BEMP, the following measures are described:

- Sources of organic material (on-farm and imported) and plant nutrient content;
- Certification of imported organic materials;
- Use of catch and cover crops, green manures and crop residues as organic inputs;
- Transport of manure to arable land.

Organic matter is a critical component of healthy soils, contributing to soil structure, fertility and resilience, therefore its conservation is critical to soil fertility. Organic matter concentrations have been steadily decreasing on many tilled soils, leading to reduced water holding capacity, greater susceptibility to erosion, compaction and impeded drainage, lower microbial activity, fewer soil fauna such as earthworms, and lower reserves of organic nutrients (natural fertility). Soil organic matter decline is of particular concern in Mediterranean areas: nearly 75% of the total area analysed in Southern Europe has either a low (3.4%) or very low (1.7%) soil organic matter (SOM) content. Agronomists consider soils with less than 1.7% organic matter to be in pre-desertification stage (COM, 2012). Organic matter may also be lost through over-grazing of grassland soils, where heavy trampling can lead to erosion and oxidation of organic matter. The drainage and conversion of the world's peatlands alone causes emissions of up to 0.8 billion tonnes of carbon a year, much of which could be avoided through restoration (COM, 2012).

Cultivation (tillage) of peat (> 30% organic matter content soils) leads to high rates of organic matter oxidation and erosion; it is best practice to avoid cultivation of peat soils, as described in other BEMP techniques (refer to Chapter 6). Nevertheless, a significant proportion of agricultural land area in N W Europe is on former wetlands. Almost 10% of the Netherlands is classified as peat soils and of these, ca. 80% are in use as permanent grassland for dairy farming. The CO₂ emission caused by peat oxidation from these areas is responsible for around 2 – 3% of the national CO₂ emissions (Verhagen et al. 2009).

For mineral soils, best practice is to conserve and augment soil organic matter through the following measures:

- Minimum soil disturbance (Section 6.2)
- Retain residues, and subsequently turn in
- Diversify crop rotations (Section 6.4)
- Establish cover crops (Section 6.5)
- Implement integrated pest management (Section 11.1)
- Implement precision irrigation (Chapter 10)

This BEMP specifically refers to the selective addition of organic amendments to soils where the benefits for structure and fertility are likely to be high. The main pathways through which organic matter may be added to agricultural soils are: (i) incorporation of crop residues and legumes; (ii) decay of vegetative litter on non-tilled soils; (iii) application of animal and other organic manures; (iv) application of alternative organic matter sources, such as composted materials, digestate from anaerobic digestion plants (Section 9.2), sewage sludge and other wastes.

There are two primary elements to this BEMP:

1. Targeted additions of organic matter. Animal manures are usually recycled back onto soils. Best practice described here is to ensure that they are returned to soils where: (i) nutrients are required for crop/grass growth; (ii) organic matter is most required. This involves good nutrient management planning (Sections 5.1; 8.2), and can be facilitated by appropriate storage facilities (Section 9.4) and slurry separation (Section 9.3).

2. Sourcing and importing onto the farm additional, high-quality (certified) organic materials to add to soils (especially for tillage farms).

More detailed recommendations include (WAG, 2011):

- Include a 12 month grass ley in arable rotations once every 5 years, or incorporate 20 t/ha of bulky organic manure one year in five.
- Aim to provide up to 50-60% of the crop's expected N requirement for optimum yield from applied organic material, with inorganic fertiliser N used to top up crop needs (except organic farms).
- Produce a Farm Manure Management Plan which is linked to Farm Fertiliser Plan (except for organic farms); this can be a requirement for organic certification and some agri-environmental schemes.
- Composting of FYM produces a more friable and sanitised (animal and plant pathogens) material that protects the mineral-N component within the organic matrix (reducing odour and protecting it from immediate loss following spreading).
- When a spring-sown crop is to follow a crop harvested early the previous autumn, sow a green manure crop following harvest, such as mustard, rye or vetch.
- Do not plough too deep (deep is 25 cm) as this can dilute the topsoil with subsoil, which is lower in organic matter, or use minimum tillage (10 cm) or direct drilling where appropriate.
- Apply regular amounts of manure to arable and silage fields.

Achieved environmental benefits

Arable soil benefits

Arable soil benefits from organic matter additions:

- Improved soil structure and water retention
- More resilient soil structure
- Increased water infiltration
- Reduced waterlogging
- Reduced runoff and erosion
- Prevention of soil capping
- Easier working of the land with less need for cultivation and inputs
- Greater buffering capacity against acidifying agents e.g. mineral fertilisers
- Improved fertility.
- Reduce compaction

These benefits translate into various environmental quality improvements, such as reduced eutrophication and sedimentation of water bodies, reduced GHG emissions, and a multitude of indirect benefits arising from improved production efficiency. Calculating the aforementioned indirect benefits is challenging, because it is difficult to identify the contribution of organic matter to soil fertility and production efficiency.

The effects of SOM accumulation or loss are manifested over decades. However, some studies have identified benefits specifically attributable to organic matter amendments. For example, Stradnick et al. (2013) concluded that long-term farmyard manure applications maintained a higher functional diversity of soil microorganisms in a tilled sandy soil in Germany compared with long-term mineral fertilization with straw incorporation alone. This higher functional diversity of soil microorganisms translates into better nutrient regulation in soils, and greater resilience to environmental stress, thus increasing the nutrient use efficiency and reducing the environmental burdens of production over crop lifecycles. Organic amendments in a long term experiment in Sweden (The Ultuna LTE) has shown that increased SOM levels also decrease compaction and increase pore structure (Kätterer et al 2011).

Aguilera (2012) calculated a 23% reduction in N₂O emissions from organic fertilised soil compared to mineral fertilised in Mediterranean soil. The most promising practices for reducing N₂O through

organic fertilization include: (i) minimizing water applications; (ii) minimizing bare soil; (iii) improving waste management; and (iv) tightening N cycling through N immobilization.

Livestock farm benefits of manure export

In addition to improving the quality of arable soils, the export of manures from livestock farms where organic nutrients are often in surplus, to arable farms, can lead to significant environmental benefits on the livestock farms. Newell-Price et al. (2011) estimated that leaching losses can be reduced by 10% through the export of 25% of manure from a typical dairy farm.

Appropriate environmental performance indicators

A key indicator is SOM content which is a useful proxy for soil quality (Mila`i Canals & Brandao, 2007). SOM is typically c.55% C but is not regularly measured on farms so benchmarking is not easy. However, dry matter % data are available for most organic amendments to soil which are periodically analysed for NPK analysis. Dry matter is mainly organic matter for most amendments listed above, except water treatment sewage sludge where the nature of the dry matter can be highly variable.

Main indicators

- Soil organic matter content (%LOI or % C)
- Organic matter application rate t/ha/yr. dry matter
- Organic nutrient application rates kg/ha/y total and available nutrients
- Transport distance of organic matter to/from the farm
- % of nutrient demand met via organic sources
- % crop area with cover crop
- Certification of imported organic matter (e.g. UK BSI PAS for compost and digestate)

With current manure applications and 50% more compost available for application, this would provide a “C-rich solution” and with just 25% more compost would represent a “C-medium solution” (<http://ec.europa.eu/environment/soil/pdf/som/Chapter1-3.pdf>).

Management indicators

- Apply sustainable (certified) organic materials to soils as a conditioner and nutrient source
- Frequency of catch and cover- crop establishment
- Cooperation with livestock farms to import manure onto stockless farms
- Use of recognised nutrient management tool to calculate/plan for organic nutrients applied.
- Return of crop residues to the soil within farm

Cross-media effects

Soil contamination

The use of biosolids (often referred to as digested sewage cake in the UK) must take into account the heavy metal content of both the amendment and receiving soils which should be tested and analyses appended to the permit application to the authorising body to avoid build-up. Table 4.6 gives the maximum permissible concentrations of PTEs whilst Table 4.8 provides an indication of nutrient provision.

Table 4.6. Maximum permissible and advisable concentrations of potentially toxic elements (PTEs) in soil after application of sewage sludge to agricultural land and maximum annual rates of addition (DEFRA, 1998).

	Maximum pH ¹ 5.0-5.5	Permissible pH ¹ 5.5.-6.0	Concentrations of pH 6.0-7.0	PTE (mg/kg) pH ² >7.0	Maximum permissible average over a 10-year period (kg/ha) ³
Zinc	200	200 ⁴	200 ⁴	300 ⁴	15
Copper	80	100	135	200	7.5

	Maximum pH ¹ 5.0-5.5	Permissible pH ¹ 5.5-6.0	Concentrations of pH 6.0-7.0	PTE (mg/kg) pH ² >7.0	Maximum permissible average over a 10-year period (kg/ha) ³	
Nickel	50	60	75	110	3	
	For pH 5.0 and above					
Cadmium	3				0.15	
Lead	300				15	
Mercury	1				0.1	
Chromium	400		(Provisional)		15	(Provisional)
*Molybdenum ⁵	4				0.2	
*Selenium	3				0.15	
*Arsenic	50				0.7	
*Fluoride	500				20	
<p>1. For soils in the pH ranges 5.0-5.5 and 5.5-6.0 the permitted concentrations for lead, zinc, copper, nickel and cadmium are provisional and will be reviewed when current research into their effects on certain crops and livestock is completed.</p> <p>2 The increased permissible PTE concentrations in soil of pH greater than 7.0 apply only to soils containing more than 5% calcium carbonate.</p> <p>3 The annual rate of application of PTE to any site shall be determined by averaging over the ten-year period ending with the year of calculation.</p> <p>4 These zinc concentrations are advisable limits as given in The Code of Practice for Agricultural Use of Sewage Sludge (revised 1996).</p> <p>5 The accepted safe concentration of molybdenum in agricultural soils is 4 mg/kg. However, there are some areas in UK where, because of local geology, the natural concentration of this element in the soil exceeds this level. In such cases there may be no additional problems as a result of applying sludge, but this should not be done except when in accordance with expert advice. This advice will take account of existing soil molybdenum levels and current arrangements to provide copper supplements to livestock. Soil samples must be taken before spreading to show soil is not already high in heavy metals such as Cu and Zn.</p>						

Other negative environmental consequences

The composting process, by definition, is aerobic and produces high CO₂ emissions, particularly in forced-aeration, in-vessel facilities commonly used at municipal plants. Meanwhile, transporting and applying organic materials usually requires more energy than fertilisers, and can give rise to higher emissions to air and water (Table 4.7).

Table 4.7. Change in emissions to air and water values in order to maintain and enhance soil organic matter levels (Newell-Price et al., 2011)

	Nitrate	Nitrite	Ammonium	Particulates	Solubles	Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Maintain and enhance soil organic matter levels	↑	↑	↑	(↓↑)	↑	↓	↑	↑	↑	↑	~	↑

However, these effects need to be considered:

- in the context of counterfactual management (e.g. landfill, in which case emissions may also arise but no fertilisation benefit achieved)
- against the benefits of soil improvement and crop productivity benefits, leading to better overall resource use efficiency in the long term.

Operational data

In addition to information below, operational data is contained in the case studies referred to in the next section.

Organic amendments, certification and uses

Commonly applied sources of organic matter in agriculture:

- On-farm: FYM, Slurry, dirty water, Anaerobic Digestion (AD) (PAS110) solid and liquid, legumes, green manures;
- Imported: biosolids (digested sewage cake; lime-stabilised), compost (green waste or food/green waste: BSI PAS100, QCP), sewage sludge, paper crumb.

Refer to PAS 110/PAS 100 and Environment Agency (England & Wales) quality protocols for AD and compost: it is important to know origins and composition (heavy metal limits, traceability). Quality Protocols are based partly on BSI (rather than CE) standards, and may not be compliant/consistent with forthcoming End-of-Waste regulations from the EU.

AD certification is costly (4,000 €/year for monitoring and paperwork) but is no longer treated as a waste. Liquid AD contains the majority of the digestate nutrients, whilst the solid fibre containing fraction contains organic matter (Section 9.2).

Dewatering manures to produce concentrated fertilisers can increase NUE of both N and P by increasing fertiliser replacement value up to 76-97% of CAN-N. Scenario analyses on national scale showed that large scale use of mineral concentrate and the attending solid fraction in the Netherlands decreased the need for mineral N and P fertilisers up to 15% and 82%, respectively.

70% of the organic matter in compost is lignin material which is recalcitrant and remains in soil for a prolonged period. A 30 t/ha application contains 6 -7 t/ha of organic matter. Compost also a source of trace elements and has liming properties.

Table 4.8. Available nutrients following application of 20 t/ha biosolids from wastewater treatment (TES Ltd., 2012)

	N	P	K
	kg/ha		
Total	220	360	12
Available	32	180	10

It is good practice that farmers consider the efficient coupling of C with other nutrient cycles (Drinkwater, 2004). This can be viewed in simple terms as the need to build, maintain and better manage SOM, especially the living part of that, the Soil Microbial Biomass (SMB). This is plain good practice for many aspects of soil quality as well as nutrient supply, including soil structure and minimizing energy use in tillage, and possibly pest and disease control. This may mean a return to more diverse crop rotations and the greater use of cover or catch crops (Jarvis, 2008).

Laverstoke Park Farm, as an organic enterprise, focuses strongly on promoting an active SMB and has developed an analytical laboratory with capacity to monitor SMB, particularly important for organic farms that cannot resort to mineral fertiliser to supply depleted soil nutrients (Laverstoke Park, accessed June 2013).

Maintaining soil fertility through soil organic matter management is fundamental to organic farming. For example, IFOAM provides accreditation of organic produce status. Its Organic Guarantee System (OGS) is designed to: (i) facilitate the development of organic standards and third-party certification worldwide; (ii) provide an international guarantee of these standards and organic certification. The IFOAM EU Group promotes the potential of organic agriculture as an efficient and sustainable farming system at EU level. By avoiding the use of synthetic fertilizers and pesticides, organic agriculture has proven to be 20% to 56% more efficient in terms of energy use and 64% more efficient in terms of CO₂ emissions than the chemical-intensive industrial farming system.

The project *Carbon Credits from Sustainable Land Use Systems (CaLas²⁵)* assessed the potential of organic agriculture for soil carbon sequestration and for generating carbon credits from sustainable land use systems. This project encloses sustainable agricultural practices, the carbon markets and climate friendly farming practices for smallholder communities in the global south. Furthermore promotes the case for organic agriculture as a method to increase Soil Organic Carbon (SOC) sequestration.

Plant returns for soil organic matter provision. Crop residues, cover crops

Crop residues e.g. maize stalks, straw and stubble should be retained over winter to reduce soil erosion rather than over-winter bare soil and provide high molecular weight C (lignin) with high C:N ratio when incorporated in Spring. A ryegrass cover crop can be seeded between maize rows which can be grazed or returned to the soil in spring (refer to Section 6.5).

Grass-clover ley are invaluable as in crop rotation as an organic source of N by virtue of symbiotic bacteria that fix atmospheric N. Ploughing in grass-clover leys adds to soil organic matter, though care has to be taken to avoid N-mineralisation leading to leaching (see Section 5.2).

Cover crops reduce both wind and water erosion, by increasing SOC through above and below ground plant parts over winter and at the same time retains N and P in the root zone for use by the following crop (see 6.5).

Catch crops immobilise available nitrogen remaining in the soil after the harvest of the main crop by taking it up and storing it in the catch crop root and shoot (see 6.5).

Additionally, the tillage of cover and catch crops in spring adds organic matter to soil from the above ground parts.

Transport of manures to arable land

Traditionally farming includes production of both crops and life stock. This was efficient for nutrient cycling as the manure could be easily transported to cropping fields to even out the soil organic matter and nutrients across the entire farm. In more recent decades, farming is geared to maximise productivity which has led to larger farm enterprises and specialization governed by climatic and soil conditions. In the UK, the west has high rainfall, heavier soils and mild climate ideal for grazing whilst the east is drier, has light sandy soils and warmer summers and better suited to cereal production. As a result, manure surplus has become spatially separated from tillage farms. The challenge is to avoid nutrient surpluses in the west and depletion of SOM in the east. Manure from the Netherlands (dairy, pig, poultry) is often transported hundreds of kilometres into Germany to avoid nutrient surplus but the sustainability of such practice is questionable, though necessary to avoid eutrophication locally. For instance, the Netherlands applies around 500 kg N/ha on average), which is the highest value in Europe (early 2015 situation).

Examples of best practice are where livestock farms maximise home-grown winter feed production from own manures reducing the amount of concentrate and synthetic fertiliser imported on to the farm and any surplus is transported to local tillage fields/farms. This in turn reduces the pressure on over-winter storage and inappropriate timing of spreading. Cereal farms can make best use of locally available organic matter from e.g., landless farms that are heavy users of grain e.g. pig and poultry units. Transport should be within 5-20 km and involve a load in each direction. Slurries are costly to transport; only transport solid manures and dried products e.g. from slurry separation.

Morley Farms UK (MF) is a farm and is adjacent to dairy, beef, turkey and pig farms and exchanges straw for manures (pays for nutrient rich turkey manure). Livestock farmers cut, bale and transport

²⁵ More information about this project can be found online: <https://www.youtube.com/watch?v=aUKARFZ7VI8>

MF cereal straw to their farms and MF transports and spreads solid FYM from neighbouring livestock farms on his farm (see picture of spreader). Farms are 2-3 miles apart (Table 4.9).

The primary driving force at Marian Bach farm, Wales to import sewage sludge is improved soil structure. The land used for arable crops is effectively at the far end of the farm with the result that carriage of the locally available digested sewage cake was being undertaken by the contractor rather than the farmer. This allowed the farmer to utilise the slurry produced on the farm as a source of nutrients for the grazing land which was closer to the main holding. Any manure produced on farm from loose housing was utilised for the maize crop which, again, was much closer to the farm yard. This has led to an overall reduction in fuel and labour costs with less “road time” for the spreaders/tankers.

Table 4.9. Reducing diffuse pollution loss at modelled farm scale for sandy and clay loam soils. (Baseline in brackets) (DWPA, 2007)

Livestock	Sandy soils				Clay loam soils			
	Kg N/ha		Kg (P/ha)		Kg N/ha		Kg P/ha	
Dairy	6	(61)	3	(34)	0.10	(0.2)	1.16	(2.8)
Beef	2	(18)	1	(12)	0.07	(0.2)	0.41	(1.0)
Broilers	16	(82)	11	(68)	0.04	(0.4)	0.45	(3.2)
Indoor pigs	20	(89)	14	(74)	0.06	(0.5)	0.71	(3.7)

NB: N Losses would be reduced by up to 10% on the dairy and beef farms with both soil types.

Refer to PAS 110/PAS 100 and EA quality protocols (ADQP) for digestate and compost: these accreditations are voluntary and confer the advantage of the material becoming a product as opposed to a waste and can be sold/exported off-farm. It guarantees the origins and composition of source materials. Quality protocols are based partly on BSI (rather than CE) standards and may not be compliant/consistent with forthcoming End-of-Waste regulations from EU. PAS110 digestate will be acceptable to organic certified farmers, as long as technical issue of food waste source can be resolved (commercial hotel and rest food waste in AD a problem for organic certification rules) (EU German Biowaste Ordinance; Swedish Certification Rules for Digestate; Pan-European proposed End of Waste Criteria for Biowaste under the Waste Framework Directive-2008/98/EC). The rate of compost application is also restricted by 170 (250 with derogation) kg N/ha limit in NVZs, despite most N (95%) being in unavailable and non-labile organic fraction: c. 30 t/ha. Ideally, ten times this amount could be spread to maximise the OM accumulation benefits. Compost can be finely screened (5 mm) and applied to surface of grassland soils (including sports turf) to level and improve structure.

Applicability

- Maximising soil organic matter through organic amendments is applicable to all farms and in particular, stockless systems.
- Sewage sludge applications depend on soil heavy metal concentrations and potential residues of pharmaceuticals and are not permitted on organic certified farms.
- Establishing cover and catch crops will increase SOC as well as decrease leaching of nutrients, but is dependent on the choice of crops in the crop rotation
- Establishing cover and catch crops will not be applicable to far northern EU countries.

In the past, anaerobically digested sewage sludge has been offered to farmers for land spreading on grazing land in north Wales. However, even with the 3-week post application non-grazing condition problems were being encountered with the sludge coating the grass, particularly during dry weather. This resulted in the animals rejecting the sward as it was unpalatable. This can also occur with slurry application to pasture and can be largely negated by using trailing shoe or injection techniques

Economics

Compost nutrient values

The P and K value of compost is 180 €/ha @ 30 t/ha (5.90 €/t). Compost can also displace from 1 to 2 t/ha lime. Less than 5% N is plant available at first, but becomes mineralised over time and subsequently available for plant uptake (Martin Wood, pers. comm., 2013).

For green waste compost, less than 2.5% N is plant available initially, with a fertiliser replacement value of 10.60 to 11.80 €/t; for green waste plus food waste compost, 5.5% N is plant available, with a fertiliser replacement value of 15.30 €/t (WRAP, 2008).

Economic data are extracted from the case studies in the following section.

Case Study 1: Manures on arable farms, England.

The cost of transport and spreading for cattle manure is approximately 4.70 €/t to transport plus 2.35 €/t to spread, at a rate of 30 t/ha = 211.50 €/ha (every 1-3 y where soils appear to most need additional OM and in accordance with NMP), plus labour and maintenance costs (1 month per year labour for manure spreading). The plant available nutrient content of the manure is approximately equal to transport and spreading costs.

For turkey manure, available nutrients are half the price of synthetic fertiliser. Turkey manure is spread at a rate of 8 t/ha, at a cost of approximately 26 €/t.

Case Study 2 On-farm composting, Wales

Composting is associated with a heavy burden of paperwork to demonstrate compliance with various regulations.

One additional FTE employee is required to work with the compost processing, in addition to part-time work by the farmer himself.

To set-up, the farmer needed to surface 280 m² hard-standing, put in a weighbridge (47,000 €), and install a full weather system on site. Planning had to be via a 'bespoke' Permit, due to the nature of local receptors. Together with bio-aerosol monitoring and an expert consultant fees, obtaining planning cost 20,600 €.

Uses a robust tele-handler putting in 12-1,400 hour per year, which only lasts two years at this rate of use with the necessary large buckets and grabbers leads to depreciation costs of at least 12 €/hour.

The farmer hires in a shredder and screener 7-8 times per year to do 3 compost cycles. Use of shredder (41,000 €) has a cost rate of 159 € whereas uses 60-80 L diesel/hour which amounts to approximately 765 € worth of diesel per day, for a work rate of 60-70 t compost per hour. The screener is hired in at a rate of 1,760 €/week.

Both shredder and screener are EU category 5 or 6 emissions rated, thus minimising air emissions from their operation.

Case study 5 Marian Bach farm

Indicative costs from the contractor undertaking the spreading on behalf of the sludge cake producer are 59 €/ha giving a cost benefit in the region of 350 €/ha which would otherwise have to be made up by the purchase of inorganic fertiliser.

Examples of economic gain from manure amendments

Table 4.10 shows that applying layer manure saves on fertiliser cost for first cut by 85 € and for later cuts (allowing for surplus P and K supplied to first cut) by 66 €, making a total NPK saving of up to 151 €/ha.

Table 4.10. Manure applied in early spring before first-cut silage (adapted from DEFRA, 2007)

	N	P ₂ O ₅	K ₂ O	Value €/ha
Total nutrients in manure kg/t	16.0	13.0	9.0	
Available nutrients in manure kg/t	5.6	7.8	8.1	
Crop requirement kg/ha	120	40	110	
Manure supply of nutrients kg/ha	70	160	100	
Inorganic fertiliser top-up kg/ha (supplied as 200 kg /ha 25:0:16)	50	0	32	
Saving in NPK fertiliser input, this crop				85
Saving in PK fertiliser input, later crops				66

* with cost of NPK fertiliser updated to January 2013

Table 4.11. Nutrient content and fertiliser replacement value per fresh tonne of different organic fertilisers (CEFN Conwy project, Bangor University, 2013)

	Poultry layer manure	Sheep FYM	Broiler litter	Beef FYM	Sewage cake	AD liquid	Dairy slurry	Compost
Total N	15.26	5.41	19.4	5.62	13.83	2.06	2.64	7.8
P ₂ O ₅	9.48	3.43	11.61	3.22	5.79	0.44	0.61	3.13
K ₂ O	10.28	2.28	11.35	3.53	0.64	2.14	2.73	3.93
Fertiliser value (€)	32.34	10.56	39.48	11.47	20.54	4.11	5.29	14

Economics of transporting manure

The costs for livestock farms to export manures are estimate for “typical” UK livestock farms in Newell-Price et al. (2011) (Table 4.12).

Table 4.12. Farm costs for manure export from livestock farms (Newell-Price et al., 2011)

Total system cost for farm (€/farm)	Mixed dairy	Indoor pigs	Poultry
Farm characteristics	215 cows + 104 sheep	3,524 pigs	81,351 birds
Annual	2,600	18,800	8,200

Costs calculated according to transport distance of 5-10 km (for 25% of dairy slurry) assuming 5.88 €/m³ slurry and 4.71 €/m³ solid manure.

Driving forces for implementation

- Need for livestock farms to export manures to avoid nutrient surplus (Nitrates Directive, etc.)
- Cross-compliance measure to maintain SOM
- Improving soil structure and fertility
- Improving soil drainage and water holding capacity
- Potential lower cost source of nutrients

The manager of Morley Farms (pers. comm. 2013) notes that manure management requires more effort than fertiliser spreading, and is perceived to be more risky in terms of water pollution incident risks, etc. However, the benefits are long-term improvement in soil quality. After four years applying

OM to soils, the farm manager thinks he has seen some improvement in yield reliability; in particular resilience to a recent dry summer in the sandier soils.

One barrier to soil improvement measures in particular is contractual land renting (1 or 3 years contracts common in the UK, accounting for 25-50% land in Norfolk, perhaps more in other areas such as Oxfordshire where large traditional landowners still hold a large share of land they do not manage themselves). Neither farmers nor land owners then have a strong incentive to manage long-term soil quality (also, farmers may expect to sell land for development in some areas).

There are also claims that land owners and land agents do not allow farm managers free reign to make decisions based on long-term returns and sustainability (Morley Farms, 2013).

In the past, low margins were the main barrier to investment, although margins have improved for arable farmers in recent years.

Reference organisations

- Caerhun Farm, Wales
- Morley Farm, England
- Marian Bach Farm, Wales
- Laverstoke Park Farm, England
- BSI
- IFOAM EU Group
- Fertilizers Europe
- EFMA
- Earthcare

Reference literature

- Aguilera, E., Lassaletta, L., Sanz-Cobena, A., Garnier, J., Vallejo, A., 2012. The potential of organic fertilizers and water management to reduce N₂O emissions in Mediterranean climate cropping systems. A review. *Agriculture, Ecosystems, and Environment*. 164: 32-52.
- WAG, 2011. The Code of Good Agricultural Practice For the Protection of Water, Soil and Air for Wales. Welsh Assembly Government.
- CEFN Conwy project, 2013. Project website, accessed July 2013: <http://cefnconwy.bangor.ac.uk/documents/cefnconwy-web-en.pdf>
- Code of Good Agricultural Practice for the Protection of Soil, PB 0617, MAFF/WOAD, 1993, Revised 1998. Available free of charge from DEFRA publications.
- Code of Practice for Agricultural Use of Sewage Sludge. Department of Environment, 1989. Revised 1996. (ISBN 185112005 x).
- COM, 2012. The implementation of the Soil Thematic Strategy and ongoing activities. European Commission, Brussels. 15pp.
- DEFRA, 2010. Fertiliser Manual RB209. UK: TSO. Retrievable at <http://www.defra.gov.uk/publications/2011/03/25/fertiliser-manual-rb209/>
- DEFRA, 2008. Code of practice for agricultural use of sewage sludge, updated 2006. <http://adlib.everysite.co.uk/adlib/defra/content.aspx?doc=4196&id=4197>
- DEFRA, 2007. Managing Livestock Manures. 2. Making better use of livestock manures on grassland. Updated 2007. ADAS, Mansfield, UK. 24 pp.
- Drinkwater, L. E. 2004. Improving fertilizer nitrogen use efficiency through an ecosystem-based approach. In: *Agriculture and the nitrogen cycle. Assessing the impacts of fertilizer use on food production and the environment* (eds. A.R. Mosier, J.K. Syers and J.R. Freney). SCOPE 65, ch. 6, pp 93-102. Washington DC, Island Press.

- DWPA, 2007. *An Inventory of Methods to Control Diffuse Water Pollution from Agriculture (DWPA): User Manual*. January, 2007: DEFRA Project ES0203.
- Europe Commission <http://ec.europa.eu/environment/soil/pdf/som/Chapter1-3.pdf>
- Goulding, K., Jarvis, S., Whitmore, A. 2008. Optimising nutrient management for farm systems. *Phil. Trans. R. Soc. B*. 363, 667-680.
- Laverstone Park Farm. Website accessed Feb 2014: http://www.laverstokepark.co.uk/soil_testing_laboratory.aspx
- Mila`i Canals, L., Brandao, M., 2007. Chapter 7.2: Life cycle impact assessment (LCIA) methodology for land use impacts. In: Mila` i Canals, L., (Editor), *LCA methodology and modelling considerations for vegetable production and consumption*. CES Working Papers 02/07, Guildford.
- Morley Farms, 2013. Personal communication with farm manager, February 2013.
- Moss S. and Lutman P. 2013. Black-grass: the potential of non-chemical control, Rothamsted technical publication. Available online: <http://www.rothamsted.ac.uk/sites/default/files/attachments/2014-01-09/1%20Blackgrass%20non-chemical%20control%20compressed%20easy%20read%2028May13.pdf>, accessed January 2015.
- Newell Price, J.P., Harris, D., Chadwick, D.R, Misselbrook, T.H, Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., and Chambers, B.J., 2011. *Mitigation methods – user guide. An inventory of mitigation methods and guide to their effects on diffuse water pollution, greenhouse gas emissions and ammonia emissions from agriculture*. Prepared as part of DEFRA Project WQ0106, 158 pp.
- Stradnick, A., Murugan, R., Oltmanns, M., Raupp, J., Joergensen, R.G., 2013. Changes in functional diversity of the soil microbial community in a heterogeneous sandy soil after long-term fertilization with cattle manure and mineral fertilizer. *Applied Soil Ecology*. 63: 23– 28.
- TES Ltd., 2012. *Biosolids information sheet*. Trade Effluent Services Ltd, Wrexham.
- Verhagen, A., van den Akker, J.J.H., Blok, C., Diemont, W.H., Joosten, J.H.J., Shouten, M.A., Schrijver, R.A.M., den Uyl, R.M., Verweij, P.A., Wösten, J.H.M., 2009. *Climate Change. Scientific Assessment and Policy Analysis. Peatlands and carbon flows*. Outlook and importance for the Netherlands. Netherlands Environmental Assessment Agency. www.rivm.nl/bibliotheek/rapporten/500102027.pdf
- WRAP, 2008. Using quality compost to benefit crops. WRAP, Oxon. U.K. 11pp.
- Wood, Martin. Eathcare, pers comm., April 2013.

4.2.1 Organic matter input case studies

Case study 1: Arable farm manure imports, England

Morley Farm soils had almost no organic additions over the previous 30 years of management, partly owing to use for NIAB TAG trials; synthetic fertiliser preferred to achieve precisely defined and homogenous soil nutrient application rates. However, Morley Farms is adjacent to dairy, beef, turkey and pig farms (latter two not so unusual in Norfolk – e.g. Bernard Matthews), and exchanges straw for manures (pays for nutrient rich turkey manure). Livestock farmers cut, bale and transport straw to their farms, and the farm manager transports and spreads solid farm yard manure on his farm (figure 4.12) (Farms within 2-3 miles).

Manure management requires more effort than fertiliser spreading, and is perceived to be a little more risky in terms of water pollution incident risks, etc. However, the benefits are long-term improvement in soil quality that are difficult to quantify and to see. After four years applying OM to soils, the farm manager thinks he has seen some improvement in yield reliability; in particular resilience to a recent dry summer in the sandier soils.

Case Study 2: Livestock farm producing compost, Wales.

Farm: 770 ha, 162 ha of lowland, 608 ha of upland. Mixed – sheep, cattle, crops (pasture, spring and winter barley for home consumption and sale offsite). Range: salt marsh to 800 m a.s.l.

Production: Takes green waste from municipal Council from a radius of ca. 10 miles – since 2010 (currently 280 m² of hard-standing, but planning for extension). Takes 3,000 t waste pa. 3000 t divided into 3 x 12 week composting cycles. The site is Permit regulated at present. He will become WAMITAB (industry accreditation to demonstrate a level of competence in waste management) later this year and PAS100 in about 18 mo. With PAS100, he intends to sell compost off site, if he gets extension to take more green waste. Moves fresh compost off hard standing for maturation (ca. 10 mo.) in a field; a Deployment application is required for every 50 ha receiving compost, and lab analysis of receiving soil and compost must be attached.

Usage: Compost is used on spring and winter barley stubble, at rate 24 t/ha, then incorporated to 12.5 cm. Averages 6.8 t/ha barley yield. Compost graded to 40 mm at present but this is not sufficient to rid of all plastic therefore he does not put on grazing or silage pasture. To use it on these he needs to screen down to 25 mm to plough under for pasture or 10 mm to use as top-dressing for pasture. The compost analysis results are illustrated in Table 4.13.

Table 4.13. Compost analysis; reference year 2013

	Amount per fresh tonne	Kg in a 250 kg N/ha application
DM %	50	
Total N kg	9.4	250
Total P kg	3.9	105
Total K kg	4.7	125

Using this compost on his winter and spring barley, at 24 t/ha, it provided 226 kg/ha N, 94 kg/ha P and 113 kg/ha K. Assuming <2.5% of N, 50% of phosphate and 80% potash is *available* to a crop in the first season, this amounts to ca. £100 /ha fertiliser saving (January 2013 prices).

None of his fields have yet received two applications of compost, the first ones will do so later this summer. No noticeable difference in yield or soil. However, he has been told he can expect to see differences in soil after 3 or 4 applications, though not in yield. Earliest noticeable change is usually resistance to compaction from trafficking and improved soil moisture holding and porosity.

Case Study 3: Benefit Statement submission to Environment Agency (UK) in 2011 to spread compost to agricultural land.

A local farmer has produced green waste compost which he proposes to spread onto agricultural land which has previously only ever been grazed (during living memory). He proposes to improve this land to grow barley using the green waste compost. Compost will be spread at the rate 30 tonnes/ha to deliver 250 kg N/ha and incorporated to a depth of 12 cm.

Soil analysis indicates that the field has a very low pH (5.1; optimum is 6.0) and below optimum levels of both phosphate and potash (index 1 for both: optimum indices are 2 and 2-, respectively), whilst levels of potentially toxic elements (PTEs) (7 heavy metals) are all well below maximum permissible in soil (Code of Practice for Agricultural Use of Sewage Sludge, 1996).

Compost analysis indicates typically useful levels of N, P and K, with an alkaline pH, whilst levels of PTEs are all well below PAS 100 maxima (Table 4.14).

The benefits of adding this compost to this soil are as follows:

- Increase in soil available nutrients N, P and K for plant growth.
- Increase in soil pH for improved plant uptake of nutrients and wider soil function.
- Increase in soil organic matter and therefore increase in soil microbial biomass for healthy soil function
- Increase in soil aeration which will promote earthworm numbers and activity
- Increase in soil buffering capacity against soil acidification
- Increase in stable soil C like lignin and hemi cellulose which promote soil structure and resilience against compaction.

Table 4.14. Value of Total Nutrient content of compost applied at 30 t/ha

	kg/ha	*Fertiliser value £/ha
Total N	250	180
Total P ₂ O ₅	100	82
Total K ₂ O	127	70
Total		332
*Ammonium nitrate = £250/t (72p/kg); Triple Super Phosphate = £380/t (82p/kg); Muriate of Potash = £330/t (55p/kg); (FAS, February 2011)		

Increase in soil PTEs as a result of compost applied at 30 t/ha. Example calculation for Cu: New soil Cu (mg/kg) = 20.4 + ((30,000 * 62.9)/(12*1.33*100,000)) = 21.6. Therefore, at this rate of application, it would take 50 annual applications of this compost before the current maximum permissible level for soil Cu is exceeded. Westrope farm e.g. (Martin Wood, pers. comm., 2013): 12% OM increase after 2-10 y of compost application and a 5% increase in soil water holding capacity.

Case study 4: Laverstoke farm

Laverstoke Farm, Hampshire, (<http://www.laverstokepark.co.uk/composting.aspx>) aims to use 10 t/ac (25 t/ha) compost (green waste, manure, woodchip and biodynamic preps). The 2,500 acres of Laverstoke Park Farm and the parkland at Laverstoke are certified as biodynamic by Demeter and is classed as organic by the Soil Association. The Laverstoke ethos focuses on healthy soil and promotes their products accordingly: “Good Soil = Good Grass = Good Quality Animals = Better Tasting Food = Happy People”. Laverstoke has a licensed five acre compost site where it makes its own compost and compost teas. The site is currently licensed to accept 40,000 tonnes of green waste per year and is accredited with PAS 100 and the Quality Protocol. Compost and Compost Tea are spread on the whole farm four times a year and biodynamic preparations at least twice a year.

Case Study 5: Digested sewage cake applied to maize, Marian Bach Farm, Wales

The sewage sludge cake is used for all 32 ha of arable ground, on a 180 ha mixed Beef, sheep and arable farm. The material has been used for a number of years to assist soil fertility and structure, the

latter particularly as the land is predominantly of the Denbigh and East Keswick soil types, both soil types subject to seasonal waterlogging and, as such, the introduction of organic matter is seen as a major benefit to soil structure. The sludge cake spread at the farm is primarily from an urban domestic source with minimal industrial effluents therefore is considered to be very low in PTE's.

Consideration has been given in the past to using sludge cake on grassland due for re-seeds however farmer has decided to restrict use to arable land only. The sludge producer, Dwr Cymru Welsh Water, has indicated that from 2013 it now intends to charge for sludge cake, a product that was always delivered and spread free of charge in the past to avoid transporting the cake to landfill which was not economically viable or the environmentally preferred option.

Current spreading rates are stated at 30 t/ha which, under current fertiliser indicative prices, provides some £350/ha in fertiliser benefit with the added soil organic matter to improve soil structure. Soil analysis is undertaken by the contractor pre-application of sludge cake to ensure that Potentially Toxic Element (PTE's) levels do not exceed the levels indicated under the terms of the Sludge (Use in Agriculture) Regulations 1989, updated 2006.

The farm lies within a Nitrate Vulnerable Zone and, as such, is required to comply with the Action Programme Measures of the Nitrate Pollution Prevention (Wales) Regulations which, from May 2013, require that all sources of organic wastes must be taken into account when ensuring that the 170 Kg/Ha Total Nitrogen limit is not exceeded.

The farmer has successfully used the sludge cake for a number of years to reduce costs on bought in fertiliser and improve soil organic matter. With the land overlying limestone and shale and at an elevated altitude of around 250 metres, retention of moisture, particularly in the summer months to aid crop yield is a major benefit. Some areas of the farm that previously suffered from "scorching" in the summer months are noticeably less prone to this problem since the sludge cake was utilised. Applications of inorganic fertiliser in the past were somewhat unpredictable due to the dry nature of the land, especially where the wind was a crucial element and by placing nutrients in rather than on the soil the yields were improved.

Generally, the sludge producer's contractor has spread the cake. However, on occasion, the farmer has undertaken the work when ground conditions are unsuitable for spreading and incorporating into the seedbed, therefore, fuel costs to the farmer are normally nil unless there are exceptional weather conditions such as in 2012.

Cake can be stockpiled in a safe area with minimal pollution risk to await spreading and ploughing in as part of the arable cultivation process which comprises autumn sown wheat and barley. Where stockpiling occurs, field heap locations are rotated to ensure that no site is used more than once every 5 years to assist biota recovery.

Sludge is stored, where necessary, in safe areas where there is minimal risk to the environment. The land lies within the catchment for the Ffynnon Asaph Spring, a potable (drinking) water supply that is the source for Prestatyn and neighbouring areas. The farm lies within the originally designated NVZ area in North Wales and this potable source is particularly vulnerable and sensitive to groundwater pollution. Very careful thought and planning has gone into identifying low risk storage sites as most of the watercourses in the vicinity discharge into swallow holes at some point with surface and groundwater being in hydraulic continuity. Lime treated cake was generally applied at the rate of 32 t/ha on all the arable land (some 16 ha in total) last autumn including on 4.5 ha of whole crop spring wheat silage. Some fields received up to 45 t/ha where they had not previously received cake.

The primary driving force for this farmer to import sewage sludge cake was improved soil structure, with nutrient content being of secondary importance. The land used for arable crops is effectively at the far end of the farm with the result that carriage of the sludge cake was being undertaken by the contractor rather than the farmer. This allowed the farmer to utilise the slurry produced on the farm as

a source of nutrients for the grazing land which was closer to the main holding (Figure 4.13). Any manure produced on farm from loose housing was utilised for the maize crop which, again, was much closer to the farm yard. This has led to an overall reduction in fuel and labour costs with less “road time” for the spreaders/tankers. Slurry is spread using an injector to minimise coating of grass, reduce nitrogen loss and improve root take up of nutrients (Figure 4. 12).



Figure 4. 12. Trailing shoe application of slurry leaving most of grass uncontaminated



Figure 4.13. Injector disc makes a slot in pasture to receive slurry application from trailing shoe

The farmer considered stopping use of the sludge before the nutrient value of the material had been identified. A new green waste processing plant is due to come on line within 5 miles of the farm in the near future and the farmer is keen to utilise some of the composted material as well as the liquid fraction given that the nutrient value is significantly greater than that provided by sewage cake. Ultimately it is possible that the farmer will have a mixture of the two waste streams utilising the liquor from the green waste plant on N-hungry grassland whilst continuing to use the sludge cake on the arable crops. The farmer is weighing up whether to give the land a "rest" from sludge cake following applications for 6 years which appears to be a recommendation from his agronomist.

Case study 6: Sweden The Swedish University of Agricultural Sciences performed an experiment in order to increase the soil organic matter. The main objective of the experiment was to quantify the effects of six different organic amendments and mineral N fertilizers on the crop and soil. During the experiment the C inputs from the amendments were measured and clustered into seven different categories. The main outcome was that the root-derived C contributes more to relatively stable soil C pools as compared with the same amount of crop residue derived C (Kätterer et al., 2011).

Reference literature

- DEFRA, 1996. Code of Practice for Agricultural Use of Sewage Sludge. Department of Environment, 1989. Revised 1996. (ISBN 185112005 x).
- FAS, Defra 2011. Spring N advice, Feb 2011.
- Kätterer T., Bolinder M.A., Andrén O., Kirchmann H., Menichetti L. (2011), Roots contribute more to refractory soil organic matter than aboveground crop residues, as revealed by a long-term field experiment, *Agriculture Ecosystems and Environment*, 141(1-2), 184–192.
- Wood, M. (Earthcare consultant), 2013. Personal communication March 2013.

4.3 Maintain soil structure (avoid erosion and compaction)

Description

Soil erosion on agricultural land is a growing problem in Europe and constitutes a threat to soil quality and provisioning of ecosystem services. Vectors of soil erosion include water and wind. Offsite impacts include eutrophication of water bodies, sedimentation of river beds and muddy floods. Bare peat-rich soils are particularly vulnerable to wind erosion.

Twelve percent, 115 M ha of Europe's total land area is subjected to accelerated water erosion and 42 M ha to wind erosion (EC, 2008a). By 2050, it is expected that, on a "business-as-usual" basis, there will be an 80% increase in erosion risk in EU agricultural areas (EEA, 2000). Panagos et al. (2014) calculated that the mean K-factor for the 25 EU Member States was $0.032 \text{ t ha h ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ with a standard deviation of $0.009 \text{ t ha h ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ (Figure 4.14). The range of values is $0.004\text{--}0.076 \text{ t ha h ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ whilst it should be mentioned that figure 4.15 does not include lakes, bare rocks, glaciers and urban areas.

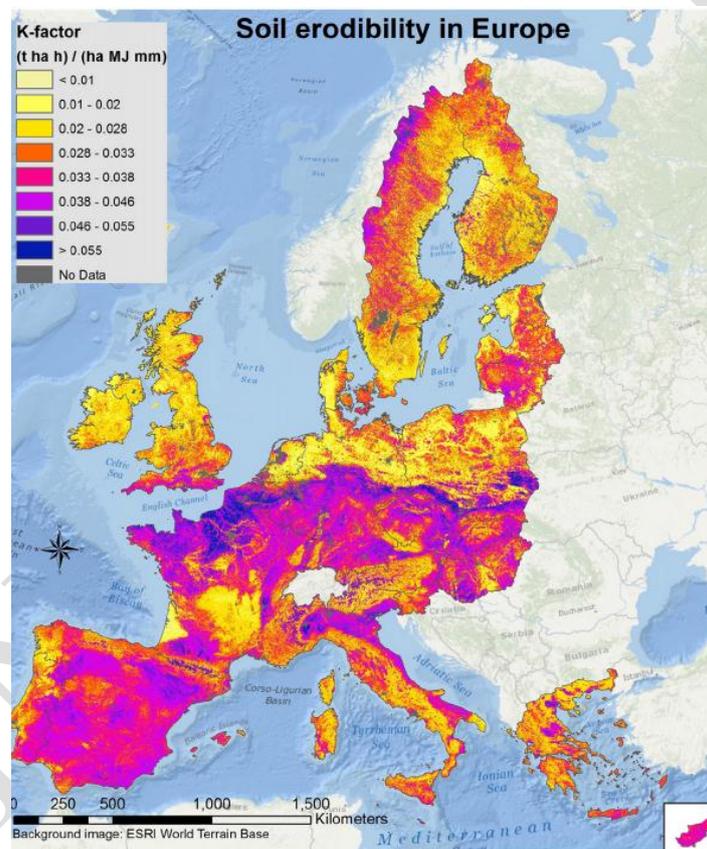


Figure 4.14. Soil erodibility in 25 EU member states (Panagos et al., 2014)

A recent new model of soil erosion by water constructed by the European Commission Joint Research Institute has estimated the surface area affected in EU27 at 1.3 million km². Almost 20% of these are subjected to a soil loss in excess of 10 t/ha/y. Erosion is not only a serious problem for soil functions (estimated to cost 53 € million per year in the United Kingdom alone); it also has an impact on the quality of freshwater, as it transfers nutrients and pesticides to water bodies. For example, agricultural losses of phosphorus exceed 0.1 kg/ha/year across much of Europe, but reach levels in excess of 1 kg/ha/y in hotspots (EC, 2012)

Good soil management concerning low tillage, crop rotations and cover crops are essential to avoid erosion and maintain a productive and sustainable farming system. Poor soil structure (Figure 4.15) leads to poor crop growth and compaction leads to poor drainage which is often a key factor in run-off and erosion, which can impact on surface waters and other sensitive habitats.



Figure 4.15. Compacted grassland soil, showing poor crumb structure (Environment Agency, 2008)

Within this BEMP, the following measures are described:

- Erosion risk planning for the farm (more detail in Section 3.3)
- Timely and appropriate cultivations (soil condition, subsoiling, field contours)
- Maintain seedbed for water infiltration
- Soil ‘spiking’ (soil aerator, sward lifter) in permanent pasture
- Reduce impact of machinery on soil structure
- Increase SOC, (see BEMP 4.2)

Preparing a soil management plan will help to manage and protect soils on a field-by-field basis. It can also help identify any areas where special action may be needed. Take soil conditions into account whenever travelling over or cultivating the soil. For heavy plant, consider using flotation tyres to minimise compaction. Select management systems and approaches that will protect the structure of the soil and manage it to minimise run-off and erosion from both water and wind.

Some form of aeration should be considered on all arable and grassland areas over a wide range of farming types. Soil aerators can achieve significant benefits for compacted soils, especially heavy clay soils, and to remove arable pans. Overcoming the plough pan problem on heavier clay land can be a principle use however pasture land where sheep are grazing is often the subject of compaction in the upper soil layers. Slitter-type implement may be of significant use here to improve vertical passage of rainwater, reduce surface run-off and subsequently minimise risk of pollution run-off to surface waters. Table 4.15 summarises best practices for remediating compaction suggested by EBLEX (2012).

Table 4.15. Best practice for remediating compaction (EBLEX, 2012)

Compaction type	Remedy
Surface capping (0-10cm deep)	Lime/introduce organic matter to encourage earthworm activity to break cap. Soil aerator with spikes or knives. Plough.
Machinery (10-15cm deep)	Soil aerator with spikes or knives. Subsoiler or sward lifter. Plough.
Plough pans (15cm+ deep)	Subsoiler or sward lifter. Mole-plough (heavy soils only). Deeper plough just below pan.

DEFRA (2009) proposes best practices regarding soil structure:

- Undertake any soil loosening or sub-soiling that is needed when soils are dry (but not hard) to depth
- Do not cultivate more deeply than is necessary (avoid raising subsoil or damage to drains)
- Plough or cultivate across the slope to avoid soil erosion downslope
- To increase work rates and reduce fuel consumption, select a cultivation system which uses the minimum number of passes consistent with creating soil conditions suitable for the crop to be grown. Consider direct drilling or reduced tillage systems and using a furrow-press if ploughing
- To minimise run-off and erosion before spring sown crops, establish temporary green cover or leave the land in stubble or roughly cultivated over winter
- Make annual organic matter additions to improve structure.

Achieved environmental benefit

Overview

Some of the main environmental benefits from soil structure improvement are listed below:

- Reduced topsoil loss
- Reduced nutrient loss (especially P) from overland flow
- Improved crop yields
- Reduced N loss via denitrification (N₂O and N₂) associated with waterlogging
- Reduced risk of local flooding
- Improved water quality

Maintaining and improving soil structure can improve soil productivity at a given level of nutrient inputs, or at reduced nutrient input levels, thereby improving the overall efficiency of the farm system and reducing lifecycle burdens of produce. Quantifying these effects precisely is difficult, but benefits could be of a similar magnitude to those reported for soil drainage (Section 4.4).

Specific measures

Newell-Price et al. (2011) list a number of measures relevant for maintaining and improving soil structure, and specific environmental effects attributable to each of them (Table 4.16).

Table 4.16. Changes in emissions to air and water for the relevant measures recommended in Newell-Price et al. (2011)

	Nitrate	Nitrite	Ammonium	Particulates	Solubles	Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Establish cover crops in the autumn	↓↓	↓	↓	↓↓	↓	↓↓	~	~	~	↓	~	↑
Early harvesting and	↓	~	~	↓↓	↓	↓↓	~	~	~	↓	~	~

	Nitrate	Nitrite	Ammonium	Particulates	Solubles	Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
establishment of crops in the autumn												
Cultivate land for crops in spring rather than autumn	↓↓	↓	↓	↓↓	↓	↓↓	~	~	~	↓	~	~
Adopt reduced cultivation systems	↓	↓	↓	↓↓	(↓)	↓↓	~	~	~	(↑)	~	↓
Cultivate compacted tillage soils	~	~	~	↓↓	↓	↓↓	~	~	~	(↓)	~	(↑)
Cultivate and drill across the slope	~	~	~	↓↓	↓	↓↓	~	~	~	~	~	~
Leave autumn seedbeds rough	~	~	~	↓	~	↓	~	~	~	~	~	↓
Manage over-winter tramlines	~	~	~	↓↓	↓	↓↓	~	~	~	~	~	↑
Loosen compacted soil layers in grassland fields	~	~	~	↓↓	~	↓↓	↓	↓	↓	↓	~	↑

Source: Newell-Price et al. (2011).

Appropriate environmental performance indicators

Indicators of soil quality and erosion (risk)

- Soil bulk density g/cm³
- Soil structure definition determined by profile analysis
- Soil aggregate form
- Soil colour (brown and orange colours indicate good drainage in most soils)
- Rooting depth – pasture >15 cm deep
- Erosion losses (tonnes soil/ha/y)
- Erosion degree (visual inspection)
- Emission factors related to SOM oxidation (CO₂, NO₃ and N₂O losses)
- % land bare over winter
- % arable land with cover crops
- Existence of earthworms (Y/N)

Management indicators

- Produce an erosion risk plan
- Crop rotation plans
- Practice timely and appropriate tillage operations to avoid erosion
- Create roughened seedbed for water infiltration
- Apply low-impact aeration techniques to alleviate compaction in permanent pasture
- Use low ground pressure tyres on machinery to reduce impact
- Match land use to erosion risk

Cross media effects

Establishing cover crops in autumn should be done only in dry soil conditions to avoid soil structural damage and hence increased potential for nitrate leaching.

Operational data

Soil erosion risk mapping

DEFRA (2005) sets out a system of risk assessment which ranks crops susceptibility to erosion and anti-erosion measures. Key criteria to assessing erosion risk are rainfall, slope of land (best obtained using a clinometer) and soil texture. Low soil organic matter will exacerbate erosion problems (Table 4.17). Additionally Panagos et al., (2014) published a soil erodibility map (Figure 4.16) for the EU member states based on a cubist regression model²⁶ that was used to correlate spatial data e.g. latitude, longitude, remotely sensed and terrain features calculations (based on the literature i.e. Wischmeier and Smith, 1978).

Table 4.17. Criteria used for preparing a field erosion risk plan

Soil texture	Steep slopes >12% >7°	Moderate slopes 5–12% 3°–7°	Gentle slopes 3.5–5% 2°–3°	Level ground <3.5% <2°
Sand and light silty soils	Very high	High	Moderate	Lower
Medium and calcareous soils	High	Moderate	Lower	Lower
Heavy soils	Lower	Lower	Lower	Lower

Source: DEFRA (2005)

To Map the risk of soil erosion for a farm, estimate the annual rainfall at the farm and the slope of individual fields. Combine this information with an assessment of soil condition (see Section 4.1) to identify areas of high, medium and low erosion risk (Figure 4.16). Visual field indicators of erosion include (Boardman et al., 2009):

- rilling
- gullying
- slumping
- waterlogging
- sediment deposits
- poaching
- mud on roads by gateways

²⁶ The mean K-factor for Europe was estimated at $0.032 \text{ t ha h}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ with a standard deviation of $0.009 \text{ t ha h}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$. The technical documentation for the K factor estimation is listed below: i. the yielded soil erodibility dataset compared well with the published local and regional soil erodibility data, ii. the incorporation of the protective effect of surface stone cover, which is usually not considered for the soil erodibility calculations, resulted in an average 15% decrease of the K-factor, iii. the exclusion of this effect in K-factor calculations is likely to result in an overestimation of soil erosion, particularly for the Mediterranean (Panagos et al., 2014).



Figure 4.16. Soil rilling after intensive rain with redeposited soil visible downslope (EC, 2012, image attributed to P.N. Owens)

Land uses that are highly susceptible to erosion risk are: Late sown winter cereals, Potatoes, Sugar beet, Field vegetables, Outdoor pigs, Grass re-seeds, Forage maize, Out-wintering stock, Grazing forage crops in autumn or winter.

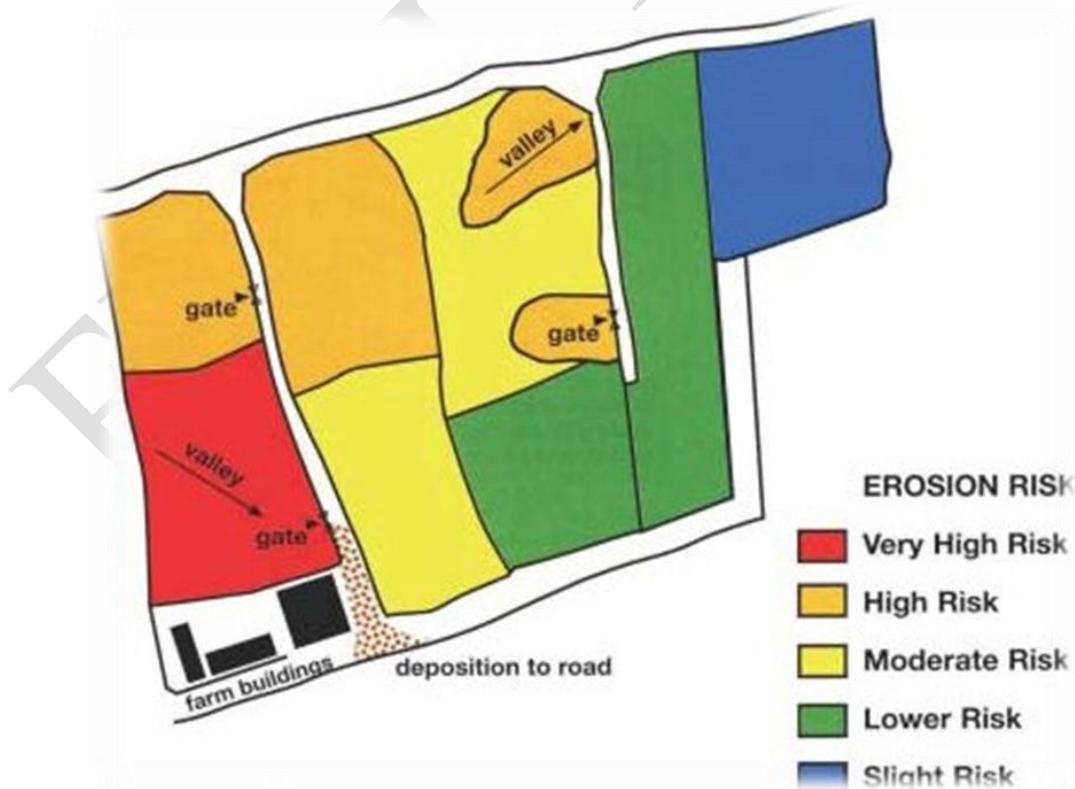


Figure 4.17. An example erosion risk plan (MAFF, 2009)

Soil Erosion can be minimised by:

1. Adapting the layout of a farm to:

- Match land use to erosion risk, e.g. avoid late sown winter cereals, potatoes and maize on high risk areas such as long steep slopes, particularly those leading down to watercourses (those with a break of slope-convexity in them);
- Protect soils using best farming practices such as crop cover, vegetation and crop establishment techniques;
- Carry out sub-soiling in compacted areas or soil slitting in grassland and other soil amelioration techniques.
- Maximise the natural drainage by managing carefully the soil structure (e.g. proper maintenance of the existing drains, installation of new drains where appropriate on mineral soils
- Minimise drainage of peat soils and soils where there is a high risk of increased nutrient transfer to water via drainage
- Maximise the area and time period of bare soil e.g. by increasing the plant cover

2. Managing crop and stock operations:

- Grow winter cover crop,
- retain cereal stubble with chopped straw over winter,
- sow grass leys at the bottom of field slopes and along contours on a sloping arable crop
- create a roughened seedbed that increases surface area for water infiltration,
- maintain and increase field hedges downslope,
- remove animal traffic from susceptible field gateways.

3. Managing tillage operations by:

- Using appropriate cultivations working along contours when safe to do so and avoid machinery trafficking wet soil.
- Practising spring ploughing is appropriate where a compacted layer is sub-surface, otherwise use no- or low- tillage for arable crops.
- Sward lifters or soil aerators are effective in alleviating compaction and therefore potential runoff erosion from compacted grassland
- Apply organic matter
- Using low ground pressure tyres during cultivation.

Avoid soil damage through timely cultivations by:

- Establishing cover crops in autumn
- Cultivating land for crop establishment in spring
- Adopting minimal cultivations
- Avoiding tramlines over winter
- Leaving autumn seedbeds rough.

Chapter 6 contains technical related information for this particular aspect.

In-field soil textural analysis

To work out the texture class of soils on-farm, moisten a dessertspoon of soil, knead it thoroughly between finger and thumb, and follow Figure 4.18.

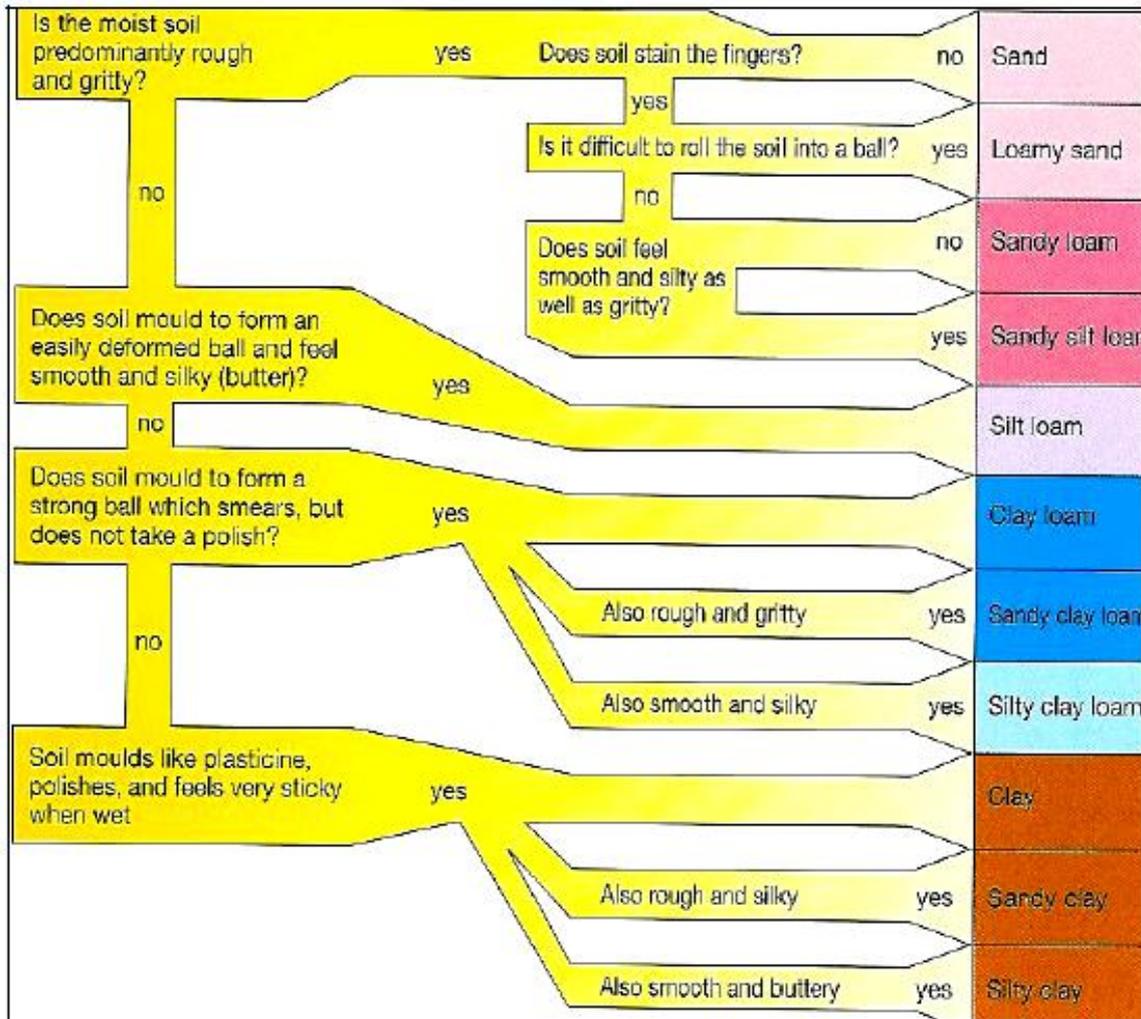


Figure 4.18. On-farm assessment of soil texture (WRT sheet 17)

Figure 4.19 and Figure 4.20 show how soils may be tested for erodibility by farmers.



Figure 4.19. On-farm slaking test to indicate erodibility. The right-hand image is a soil with the greater aggregate stability and hence less susceptible to erosion (DSV).



Figure 4.20. On-farm run through test of soil erodibility; the soil on the right drains more rapidly and much soil is lost in the drainage water due to less soil aggregate cohesion and stability than the soil on the left (DSV).

Sub-soiling and sward lifting

Sub-soiling for drainage is described in section 4.4, whilst an example of chisel ploughing and aeration on grassland fields is described in the subsequent case study. Figure 4.21 shows a sward lifter in action, raising the sward level to improve soil structure and drainage, countering compaction.



Figure 4.21. Sward lifter leads with a cutting disc that opens up the turf allowing the subsoil leg to travel through the sward without soil bursting onto the surface. Spring-loaded rollers at the rear close up the turf, leaving a level surface (OPICO, 2014)

Applicability

Erosion control is applicable to all farm types and most locations. In general, water erosion is potential problem all over Europe), whilst wind erosion is more of a problem in the drier south and east of Europe (Figure 4.22).

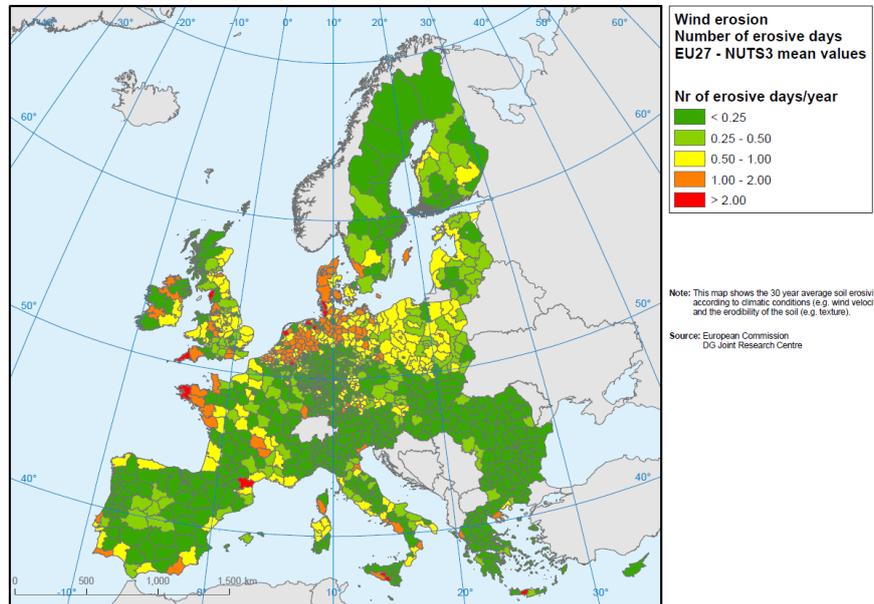


Figure 4.22. Wind erosion and number of erosive days in EU 27 (EC, 2009)

Economics

A full detailed example of erosion control measures to be implemented on a steeply sloping field with sandy loam soil is presented in Table 4.18. The main characteristics of this example are listed in the bullet points below:

- Cost of sub-soiling 47 €/ha (EA, 2008b)
- Cost of soil aerator was 7,000 € with a life expectancy of longer of 20 years. Wearing parts on the aerator are replaced every 3-4 years at a cost of 180 €/set.
- 4 ha covered in 3 hours.

Table 4.18. Case study example of economics of erosion control measures on a steeply sloping field with sandy loam soil.

Reduced soil erosion

Soils on a 10 ha field with a steep slope were classed as being sandy loam and assessed as having a risk of capping and erosion.

The soil was ploughed, pressed and drilled with winter wheat that resulted in a weatherproof coarse seedbed. No rolling was carried out.

The costs were:

Plough and press @ £50 per ha	= £500
Spring tine harrow @£25 per ha	= £250
Drill @ £30 per ha	= £300
Total cost	= £1050

The savings included:

Reduced loss of yield @ £8 per ha	= £80
Less additional field operations	= £110
Less highway clearance	= £105
Reduced need for ditch clearing	= £35
Annual saving	= £330

Additional uncosted benefits include:

- Reduced risk of pollution and associated prosecution and civil damages
- Reduced loss of nutrients
- Reduction in loss of topsoil
- Reduced risk of local flooding
- Less impact on wildlife.

Source: WRT sheet no.18, accessed Sept 2013.

Driving forces for implementation

The main driving forces for soil improvement are:

- Maintaining and improving yields (economics)
- Maintaining and improving soil workability
- Water Framework Directive
- River Basin Management Plans
- CAP (GAEC)

Reference organisations

- Morfa Cwbyr Farm, Wales

Reference literature

- Boardman, J., Shephard, M.L., Walker, E., Foster, I.D., 2009. Soil erosion and risk-assessment for on- and off-farm impacts: A test case using the Midhurst area, West Sussex, UK. *J. Env. Manag.* 90, 2578–2588.
- DEFRA, 2005. Controlling soil erosion. Incorporating former advisory leaflets on grazing livestock, wind, outdoor pigs and the uplands Defra Publications, London
- DEFRA, 2009. *Protecting our Water, Soil and Air. A Code of Good Agricultural Practice for farmers, growers and land managers.* Publ. TSO, Norwich, England.
- DSV, Germany. Website accessed Nov 2013: www.dsv-saaten.de/export/sites/dsv-saaten.de/extras/dokumente/Innovation-ab-1-12/3-13-boden_erosionsstabil.pdf.
- EBLEX, 2010. *Improving Soils for Better Returns.* Beef and Sheep BRP Manual 3. AHDB, Warwickshire, U.K.
- EC, 2008. *Threats to Soil Quality in Europe.* Tóth, G., Montanarella, L. and Ezio Rusco, E. (Eds.) Luxembourg: Office for Official Publications of the European Communities. 162 pp.
- EC, 2009. Addressing soil degradation in EU agriculture: relevant processes, practices and policies, report on the project Sustainable Agriculture and Soil Conservation (SoCo), joint Research Centre, ISBN: 978-92-79-11358-1.
- EC, 2012. *The Implementation of the Soil Thematic Strategy and Ongoing Activities.* European Commission, Brussels. 15pp.
- EC, 2012. *The State of Soil in Europe.* JRC Reference Reports SOER 2010. Publ. European Union, Luxembourg. Environment Agency (EA), 2008a. *Think Soils.* Publ. Environment Agency, Bristol, U.K.
- Environment Agency (EA), 2008b. *Best Farming Practice.* Publ. Environment Agency, Bristol, U.K.
- European Environment Agency (EEA), 2000. *Down to earth: Soil degradation and sustainable development in Europe. A challenge for the 21st century.* Environmental issue series No 16, European Environment Agency, Copenhagen. http://reports.eea.eu.int/Environmental_issue_series_16/en/envissue16.pdf
- MAFF, 1999. *Controlling soil erosion. Controlling Soil Erosion: A Field Guide for an Erosion Risk Assessment for Farmers and Consultants* (1999, PB4092). Publ. MAFF, London.
- OPICO, 2014. Website accessed Feb 2014: <http://www.opico.co.uk/opico-machines/grassland-subsoiler/grassland-subsoiler.php>
- Panagos P., Meusburger K., Ballabio C., Borrelli P., Alewell C. 2014. Soil erodibility in Europe: A high-resolution dataset based on LUCAS, *Science of the Total Environment* 479–480, 189–200.
- Wischmeier W, Smith D. 1978. Predicting rainfall erosion losses: a guide to conservation planning. Agricultural Handbook No. 537. Washington DC, USA: U.S. Department of Agriculture.

- WRT-Westcountry Rivers Trust., *Pinpoint Best Practice Information sheet no. 17, Checking soil condition*. Publ. Association of Rivers Trust, England. Accessed Sep 2013: www.therivertrust.org/pinpoint/info_sheets/Pinpoint%20-%202017.0%20Soil%20Management%20-%20Checking%20Soil%20Condition.pdf
- WRT-Westcountry Rivers Trust., *Pinpoint Best Practice Information sheet no. 18, Recognising soil loss and damage*. Publ. Association of Rivers Trust, England. Accessed Sep 2013: www.therivertrust.org/pinpoint/info_sheets/Pinpoint%20-%202018.0%20Soil%20Management%20-%20Recognising%20soil%20loss%20and%20damage.pdf

FINAL DRAFT

4.3.1 Soil aeration case study

Soil aeration techniques on arable land, Morfa Cwbyr Farm, Wales.

The 194 ha mixed dairy and beef farm lies in an area with predominantly heavy clay soils in close proximity to the main holding with outlying land variable in texture from light sandy soils to a mixed loam. The aerator is used predominantly on arable land where maize, barley and wheat are grown with the implement used at a depth of 12 inches or 0.3 m, some 3- 4 inches or 0.07-0.1 m below plough share depth. In the past, it was noted that yields tended to reduce on the heavier land as the plough pan made it difficult for crops to access moisture with the heavier land cracking during periods of dry weather. As a result, a soil aeration management programme has been ongoing for some 20 years with the initial activity being based round a straight-legged chisel plough type implement to the present aerator/soil lifter implement purchased around 4 years ago (Figure 4.23).



Figure 4.23. Soil aerator features tines which lift and fracture tough compacted soil shown here with added ballast useful for stony soils (EA, 2008a)

Breaking up of the plough pan and aerating the soil has helped increase and maintain crop yields and improve soil drainage characteristics, particularly on the level land adjacent to the main holding where the soil type is predominantly heavy clay. All arable ground receives aeration post ploughing with the current regime Plough-Aerate/Flat lift-Harrow-Seed/Harrow-Roll maintained.

Where possible, manure is spread on the arable land and slurry to the grassland therefore the higher organic matter manure in conjunction with the aeration programme has made the land easier to work, has improved the drainage characteristics and help to improve and consequently maintain yields of some 8 t/ha for Winter Wheat and 5.5 t/ha for spring sown barley. The improved soil structure has assisted root formation, reduced lodging that had been a common occurrence pre-aeration activities and also reduced waterlogging to some extent. Increased fertiliser take up efficiency has resulted in more accurate crop forecasts and more efficient use of nutrients.

Grain yields have been improved and levels maintained since the introduction of the management programme to ensure that the farm is self-sufficient in feed grain and without the need to increase arable crop area. Without this regime, additional land would need to be turned over to arable cropping to compensate for the lower yields. Farmer estimate is that of up to a 15% increase in yields when compared to 15-20 years ago.

Tractor used for aerator is a 130 hp model with some 10 acres (4 ha) covered in 3 hours. Cost of implement was £6000 (7,600 €) incl. V.A.T. @20% with a life expectancy of longer than 20 years. Wearing parts on the aerator are replaced every 3 -4 years at a cost of £150/set. Fuel costs have not been identified as yet for operations.

Use of this particular aerator is not being considered for the grassland on the farm on a routine basis as it is considered that there are other implements more suited to this activity however, where re-seed of pasture is being planned, this aerator/lifter is used post ploughing. This is the case where grass leys have been down for some time and compaction of the upper layers is a potential threat to the establishment of new leys.

In the event of catastrophic failure of the implement, purchase of another can be easily and speedily arranged without affecting the seedbed preparation programme. The particular implement in use on the farm was selected with robustness in mind, shear pins should prevent any major distortion/damage and these are checked regularly for wear.

More case studies regarding soil conservation can be found at the Joint Research Centre, Institute for Prospective Technological Studies website²⁷. The main carried out case studies are listed below:

- West-Flanders; Flanders (Belgium)
- Belozem; Rakovski (Bulgaria)
- Svratka river basin; South Moravia & Vysocina-Highlands (Czech Republic)
- Bjerringbro/Hvorslev; Viborg (Denmark);
- Midi-Pyrénées (France)
- Uckermark; Brandenburg (Germany);
- Rodopi; Anatoliki Makedonia, Thraki (Greece);
- Marche region (Italy)
- Guadalentín Basin; Murcia (Spain);
- Axe & Parrett catchments; Somerset / Devon (UK).

²⁷ http://agrilife.jrc.ec.europa.eu/rural_soco.htm

4.4 Soil drainage management

Description

In general drainage water management influences the amount of soil movement, which occurs during rain. The sustainable measures that have to be taken should ensure that all the soil nutrients loss and soil biology because of the soil movement are minimised. The main measures as well as the main aspects of this BEMP are listed below (partly based on Franklin Sustainability project, undated):

- Minimise soil movement within the paddock (e.g. introduction of paddock catchment areas (where possible) with their own treatment measures and silt trap)
- Installing drains on grassland and arable soils and mapping
- Peat soils – special case e.g. Ysbyty Ifan village in Wales, United Kingdom
- Promote natural drainage (e.g. tree planting to reduce overland flow Pont Bren case study or plant cover crops)
- Maintaining drains (e.g. Morley Farm case study)
- Manage water movement across cropping areas
- Minimise soil compaction and ensure adequate infiltration of water

Increasing the speed of soil infiltration changes the soil hydrology from one dominated by overland flow to one dominated by subsurface lateral flow through the soil. This will result in reduced overland flow to rivers and lakes. Good management of field drainage can improve crop growth, reduce nutrient losses and pollution risk, increase workability, lengthen the grazing period, improve animal welfare and reduce the chance of soil damage due to agricultural operations. It may not be cost effective to drain new areas or maintain existing field drainage.

However, poorly drained soils may be better suited to wetland or buffer zone creation to provide light summer grazing and reduce the risk of pollution. Fenton (2013) stated that several researchers have been working on the area of the soluble and gaseous losses caused by land drainage (e.g. Skaggs et al., 2005; Ibrahim et al., 2013).

Drainage systems can be classified as surface drainage or subsurface drainage systems (NCSU, 2013). It is best practice to engineer surface drainage systems that are environmentally sensitive and to build-in features such as non-uniform cross-sectional profiles, meanders, riffles and pools, and natural vegetation increase the heterogeneity of depths and velocities and thus create variable habitats for the flora and fauna (Figure 4.24).

Types of subsurface drainage techniques include:

- Field drains (tile)
- French drains (permeable fill)
- Moling (open channel or gravel filled versions)

Secondary techniques for improving the internal drainage of low permeability soils include the following measures. There is usually no water quality hazards associated with these supplemental drainage practices:

- subsoiling
- deep tillage
- mole drainage
- cropping with deep rooted legumes (e.g. alfalfa)
- crop rotations
- deep rooted trees are used to lower the water table.



Figure 4.24. Build in natural heterogeneous features such as meanders into surface drains to promote biodiversity and water quality (Aalto University, Finland)

Table 4.19 summarises the main steps to develop an action plan for improvements to field drainage systems.

Table 4.19. Best practice is to develop an action plan for improvements to field drainage system based on the following steps (SWARM, 2013)

Steps	Details
1	Map drains in each field
2	Review field drainage system to identify and prioritise improvement on a field-by-field basis using the farm map
3	Plan new field drainage, e.g. where drainage is inadequate but is required for timely and productive crop growth, or to reduce the potential for soil damage by livestock poaching
4	Promote natural drainage wherever possible e.g. using trees, deep-rooted crops, crop rotation
5	Maintain existing field drainage, e.g. where drainage is adequate and necessary. Maintain land drain outfalls regularly.
6	Make sure field drains stop short of watercourses to buffer them from soil and nutrient inputs
7	Create small ponds and wetland areas at ditch junctions or by drainage outlets to help manage runoff and increase biodiversity
8	Sacrifice field drainage in areas where the benefits of improvements are outweighed by the costs e.g. riparian zones, natural wetlands and ribbon areas at the base of steep slopes. These can be managed as buffer zones, wetlands and to provide light summer grazing
9	Avoid nutrient losses and the risk of watercourse pollution. Do not spread fertilisers, manures, slurries and dirty water and liquid wastes such as dilute pesticides onto land that is well drained or has shallow drains in wet conditions

It is worth to mention the operation of the controlled drainage systems. In particular, with this system the level of the water table can be raised or lowered by adding or subtracting gates (Figure 4.25). In this system there is a water control structure with data transmission, which eventually set the number of the gates inside the underground vertical square duct (Figure 4.26). This system is solar powered by a PV solar panel, which is placed on the ground next to the drainage system.



Figure 4.25. Controlled drainage system; the gates are also presented inside the underground vertical square duct (Reetz, 2011)

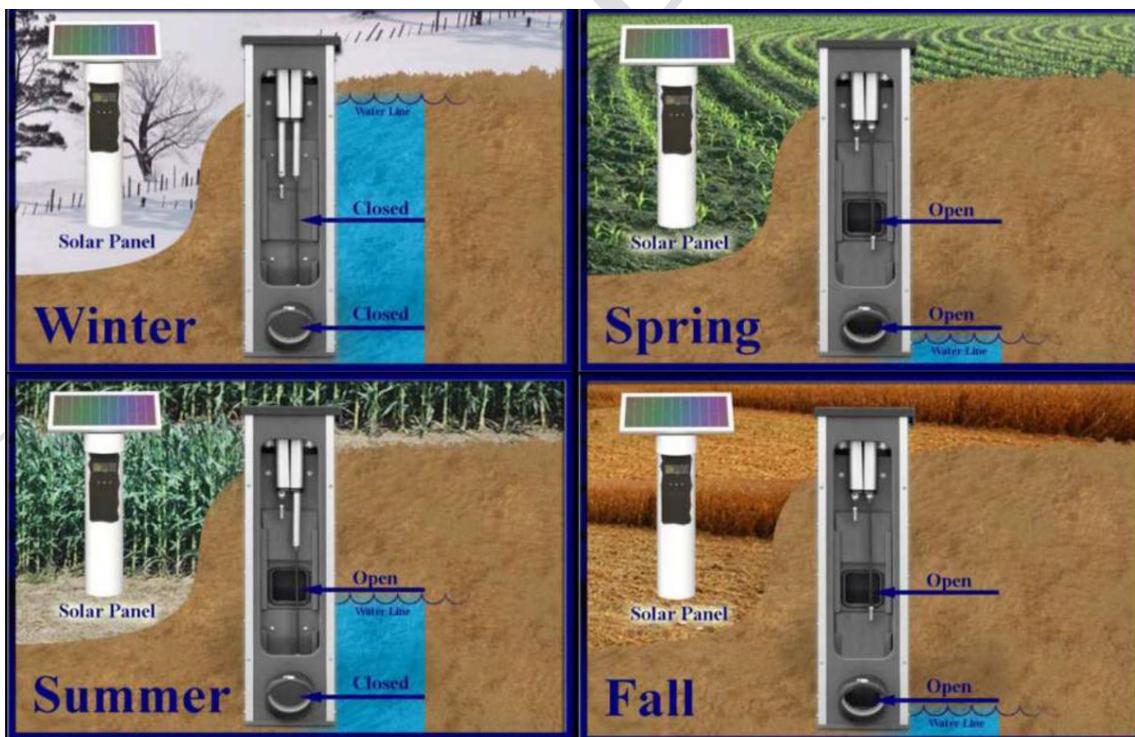


Figure 4.26. Operation of the controlled drainage system over a whole year; the water line is illustrated in each season as well as the number of the gates and the equipment on the ground (Reetz, 2011)

Whenever is possible, the paddock should be cut into smaller catchments with their own treatment measures and silt trap as well. Moreover, the run off should be treated from a catchment only once, and further to be discharged it from the paddock into a drain. The size of the silt traps depends on the amount of soil movement that could occur. In particular, the soil movement depends on the:

- slope angle and length
- size of area draining into the catchment area
- soil type and soil aggregate size
- severity of significant rainfall events

Catchment area is the land that drains into a given silt trap. When cut-off drains are not used to direct water from above the cropping area away from the crop, this area must be included as part of the catchment area. Therefore, the catchment area is precisely determined (Franklin Sustainability project, undated).

Furthermore, the paddock drainage should achieve the two following objectives:

- prevent surface water from entering the paddock
- direct water that falls on the cropping area away through a silt trap

It is feasible to prevent waters entering the cropping areas by using interception drains to divert water from the catchment area above the cropping block. Afterwards, this water has to be kept separately from in-paddock sediment control measures, and eventually has to be discharged into the water-table in small volumes at regular intervals (Franklin Sustainable Project, undated).

Achieved environmental benefits

All farm types

Higher yields on drained soils can lead to a multitude of direct and indirect resource efficiency and environmental benefits, including improved nutrient use efficiency, reduced soil nutrient surplus, avoided fertiliser requirements, land sparing. Some key benefits are described below:

- Reduced loss of N and P from overland flow
- Reduced soil erosion and compaction
- Improved animal health (lower risk of liver fluke, etc., where soils are drier)
- Reduction of seed rot/population losses
- Encourage early deep root development
- Improved crop and animal productivity
- Increased days for grazing and cultivations
- Lower prevalence of conditions leading to N₂O emissions.
- Potentially contribution to reduction of flooding downstream

The lifecycle environmental burdens of farm produce can be significantly reduced where drainage leads to yield improvements from the same level of fertiliser and energy inputs. In addition, the percentage of nutrients applied lost to water and air can be reduced through improved drainage.

Grassland farm benefits

The production benefits of improved drainage to grassland farmers are listed by Tuohy et al. (2013) and SWARM (2013):

- Yield advantages of 10-25% compared with un-drained soils
- An extended grazing season
- Reduced surface damage by livestock
- Improved trafficability/accessibility for machinery
- Reduced reliance on supplementary feedstuffs
- Reduced disease risk to livestock
- Better availability of N in soil (increase de-nitrification N₂)

- Increased soil temperature
- Improved utilisation and sward composition (decrease in rushes and bare areas)

Specific measures

Newell-Price et al. (2011) list two key measures relevant for soil drainage control (Table 4.20).

Table 4.20. Changes in emissions to air and water for the relevant measures recommended in Newell-Price et al. (2011)

	Nitrate	Nitrite	Ammonium	Particulates	Solubles	Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Maintain/improve field drainage systems	↑↑	(↑)	(↑)	(↑)	~	(↑)	(~)	(~)	~	↓	~	↑
Ditch management	↑	↑	↑	↑	~	↑	~	~	~	↓	~	↑

Appropriate environmental performance indicators

Management indicators

Managing soil drainage is a key to avoiding compaction and break down in soil structure. This in turn can positively impact on length of time animals can graze over winter and the overall soil health and productivity.

- Install drains on grassland and arable land and produce field drain maps
- Regulate water level on peat soils
- Promote natural drainage wherever practical
- Regularly monitor and maintain drains

Soil drainage indicators

- Soil moisture status (% water holding capacity, g water/100 g dry soil per season of the measurement)
- Visual inspections for defining ponding (intervals to be defined by local parameters)
- Percentage field areas drained
- Soil colour – grey and orange mottling is indicative of water movement in a soil; grey mottled = poor drainage, brown = good drainage
- Rooting depth – pasture >15 cm deep
- Aggregate form
- Surface ponding

Cross-media effects

According to Fenton (2013) and Reetz (2011):

- Land drainage may change the forms of N and P that leave agricultural lands in overland flow and subsurface flow. For example more ammonium can leave in overland flow, with more nitrate being lost in subsurface pathways.
- The channelling of water in drainage networks increases the speed of water delivery to rivers and by passes the soil's ability to remove nutrients such as nitrate, phosphorus, and also pathogens, sediment and pesticides from the drainage water. Drainage also by-passes potential methods to mitigate diffuse pollution such as riparian zones beside rivers. Other losses that may occur in drainage water include pharmaceuticals.
- Land drainage is likely to increase the emission of greenhouse gases, particularly in the first couple of years after drainage. When wet soils are drained oxygen introduced in to these soils leads to a substantial release of carbon and nitrogen that was locked up in the soil organic matter.

- The increased availability of nitrogen in drained soils can increase crop growth but where this exceeds crop demands there is potential to increase nitrous oxide and nitrate leaching losses to the environment.
- There is potential for increased nitrate leaching following deep cultivation.
- Occasionally over-drained soils during dry part of growing season
- Fewer temporary wetlands

Operational data

Field level drainage planning

There is no one size fits all drainage design. Every plot or field will need a retro fitted drainage design depending on soil and rainfall characteristics. Preparing a soil management plan will help to manage and protect soils on a field-by-field basis which is mandatory on farms receiving Single Farm Payment and referred to as a Soil Protection Review.

Yield mapping helps identify lower-yielding areas, especially in wet years (Figure 4.27), and repair work will be carried out either in whole or part fields, depending on the level of damage.



Figure 4.27. Example of poor drainage affecting growth in Wexford, Ireland (Fenton, 2013)

Peat soils

Peat soils that have not been drained and improved for agriculture are rare and increasingly important habitats for bio-diversity and have a part to play in flood control. All peat soils hold large reserves of carbon and should be managed to minimise losses:

- All un-drained land with peat or peaty soils should be left as natural or semi-natural areas, or as traditionally managed pasture.
- When managing land adjacent to such sites, protect the peat habitat by not lowering the water-table, by preventing spray drift, and by preventing nutrient and sediment rich run-off entering the site.
- On upland sites, protect the peat from erosion. If there are signs of erosion, take measures to stabilise the surface.
- Large areas of lowland peat have been improved for agriculture. Minimise the oxidation (shrinkage) of the peat by keeping the water-table as close to the surface for as long as possible

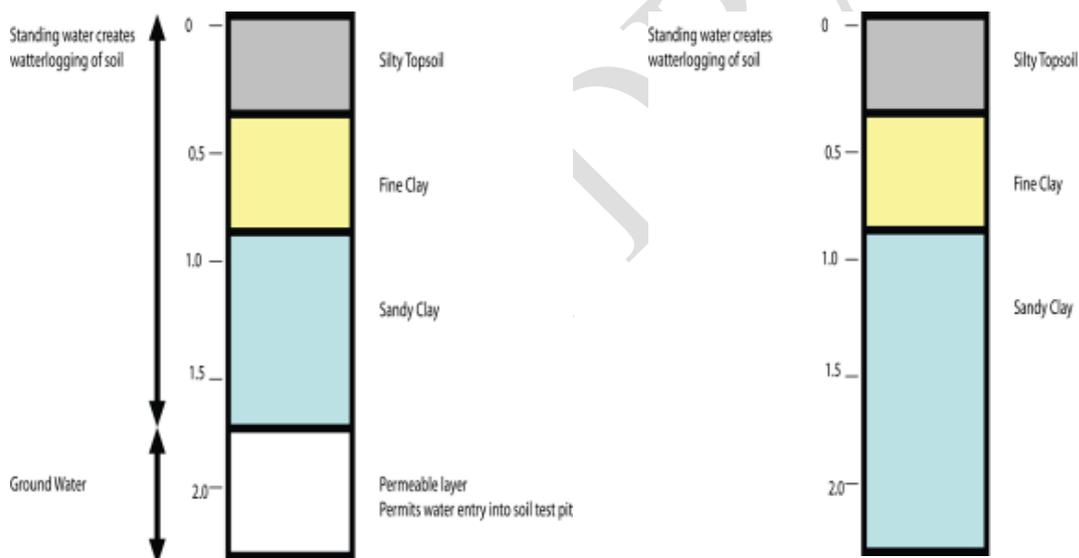
consistent with the need to manage such land for food production (as practiced on European polders) and practise minimum tillage.

Lifespan of installed drains

If installed correctly, groundwater drainage systems generally have a working life of anything between 20-40 years. Drainage performance may be enhanced through regular mole drainage or sub soiling every 5-10 years. Refer to RSPB (2010) for more operational information on drain systems and cultivation measures. Mole drains may only have a life of a few years. Most land drainage systems are poorly maintained. Open drains should be clean and as deep as possible and field drains feeding into them should be regularly rodded or jetted (Fenton and Tuohy 2013).

Identifying appropriate drain types

The hydrology of the soil determines the type of drainage system required (Figure 4.287 and Figure 4.29). There are two types of field drainage systems: shallow or groundwater systems. Distinguishing between the two types of drainage systems essentially comes down to whether or not a permeable layer is present (at a workable depth) that will allow the flow of water with relative ease. If such a layer is evident, a piped drain system at that depth is likely to be effective. If no such layer is found during soil test pit investigations, it will be necessary to improve the drainage capacity of the soil. This involves a disruption technique such as moling, gravel moling or sub-soiling in tandem with collector drains. Outfall level must not dictate the drainage system depth. If a free draining layer is present, it should be utilised.



(a) Groundwater drainage system: a network of piped drains exploiting permeable layers.

(b) Shallow drainage system: where the permeability of soil is low at all depths and needs to be improved.

Figure 4.28. Field drainage systems in (a) the presence and (b) absence of a permeable layer (Tuohy et al., 2013).



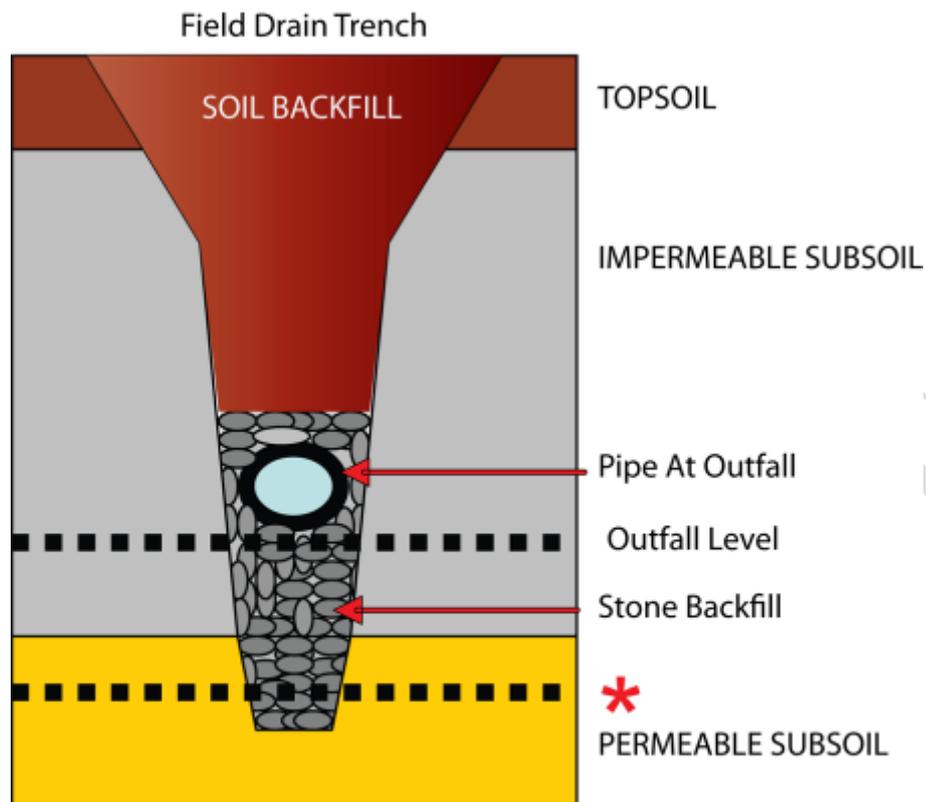
Depth (cm)	Description
0-20	Top soil layer (silt and clay)
20-35	Gravel & stones
35-70	Heavy layer
70-140	Heavy layer with orange and grey colours
140-280	Seepage of water
280	Rock

Figure 4.29. An example of where water ingresses showing the division between permeable and impermeable layers (Fenton, 2013)

Drains are not effective unless they are placed in a free draining soil layer or complimentary measures (mole drainage, sub-soiling) are used to improve soil drainage capacity. If water isn't moving through the soil in one or other of these two ways, the water table will not be lowered (Fenton, 2013).

The main drainage system receives water from the field drainage system. Main drains will receive water from the field drainage systems in place as well as surface runoff and groundwater in their immediate vicinity. Field drainage, such as mole channels, should be installed above and perpendicular to drainage channels to ensure the field area is hydrologically connected to the main drainage channels (Figure 4.30).

Drain pipes should always be used for drains longer than 30 m. If these get blocked it is a drainage stone and not a drainage pipe issue. Drainage stone should not be filled to the top of the field trench except for very limited conditions (the bottom of an obvious hollow). Otherwise it is an extremely expensive way of collecting little water. Most of the stone being used for land drainage today is too big. Clean aggregate in the 10–40 mm grading band should be used (Fenton, 2013).



* Stone in permeable layer allows water to boil up to the pipe

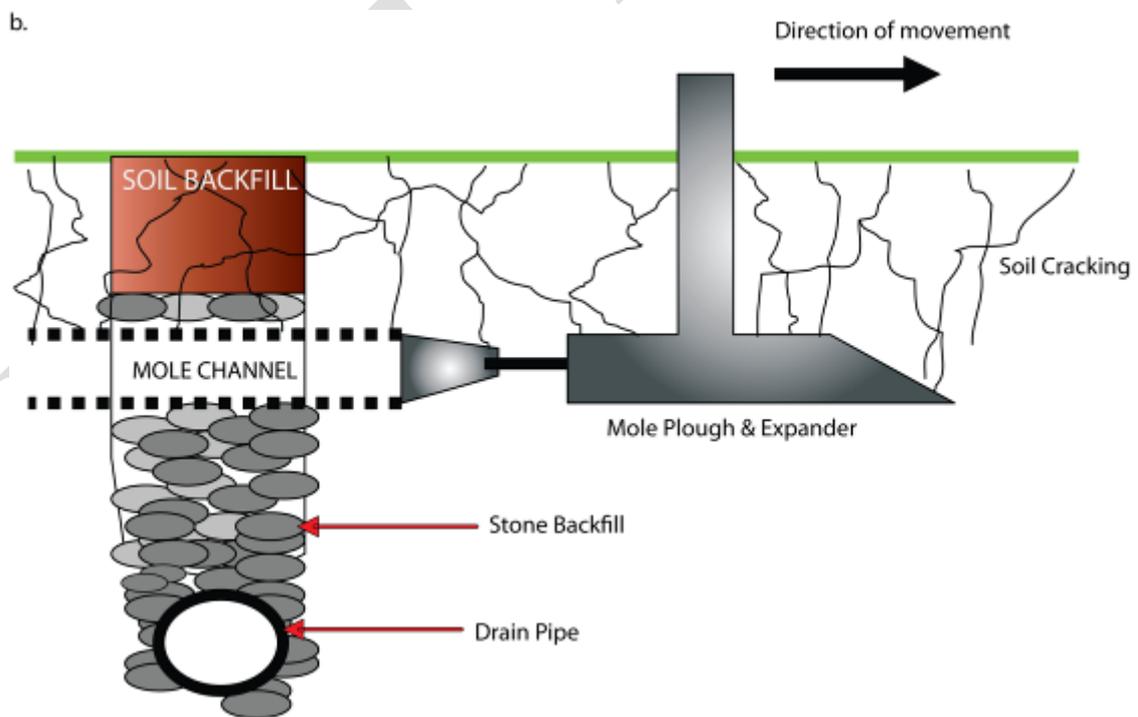


Figure 4.30. Diagram of a field drain trench (above), and a mole plough used to create mole channels the complement such drainage systems (below) (Fenton, 2013)

Sub-soiling is not effective unless a shallow impermeable layer is being broken or field drains have been installed prior to the operation. Otherwise it will not have any long-term effect and may do more harm than good.

In parallel, the snorkel or drainage pipe drains the silt trap between rainfall events. In particular, those pipes are installed at the lowest point of the silt trap and should discharge to an erosion-proof outfall. The pipes should be solid PVC and non-perforated (the entire construction is illustrated in Figure 4.31). The pipes diameter depends on the size of the catchment area (Table 4.21) (Franklin Sustainable project, undated).

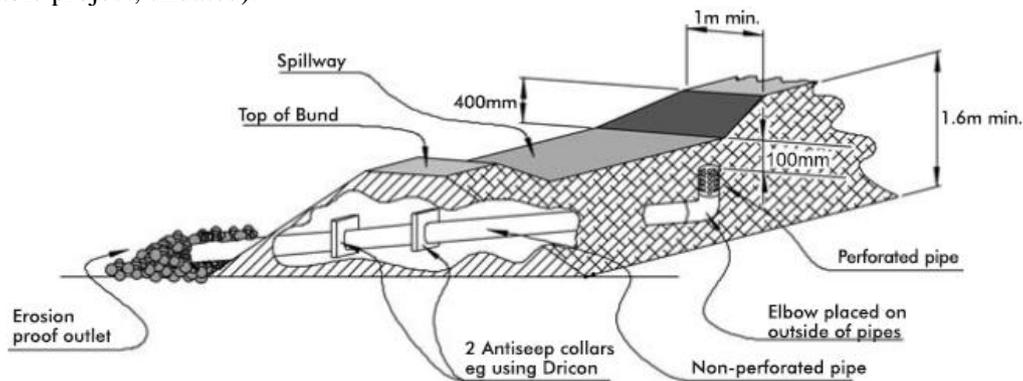


Figure 4.31. Snorkel/discharge piping system (Franklin Sustainable project, undated)

Table 4.21. Pipes diameter according to the size of the catchment area

Pipe diameters (mm)	Catchment area (ha)
100	< 1
150	1-2
225	> 2

Regarding the paddock drainage, whenever possible:

1. Break the paddock into smaller catchments with their own treatment measures and silt trap.
2. Treat runoff from a catchment only once, and discharge it from the paddock into a drain.

Table 4.22 illustrates the drainage specifications for drains diverting water from cropping areas and permanent drains.

Table 4.22. Technical specifications regarding catchment area, water flow and depth of drain (Franklin Sustainable project, undated)

Catchment area (ha)	Water flow (m ³ /s)	Depth of drain (m)	Best shape
1	0.21	0.2	best shape to minimise channel erosion  longitudinal gradient < 5%
2	0.42	0.3	
4	0.84	0.45	
5	1.05	0.5	
10	2.1	0.8	

Note: these figures have been determined for a grassed drain with a 2% longitudinal slope, 1 m wide at the base and have a ratio of 1:1 shaped slides. The water flow rates are for permanent drains with the ability to carry the 100-year storm. When the abovementioned data changed then the calculations should be done again.

Concluding, the following key points should be installed to deal with the paddock drainage:

1. Apply cut-off drains to prevent water entering into the cropping area; discharge this amount of water into the water table.
2. Drain size depends on water-flows in the drain.

3. Discharge water from paddock control systems into the water-table in small volumes and at regular intervals.
4. Access-ways should be adequately raised and located away from the lowest point in the paddock.
5. Recommended maximum paddock length is 200 m when slopes are greater than two percent.

Minimising negative environmental effects

Drainage design is now taking environmental concerns into account (Fenton 2013). Water table control (with and without pumping) is now evident in parts of Europe and the US, which allow for the manipulation of the water table depth at different times of the year. This helps to minimise nitrous oxide emissions. Also in parts of Scandinavia two stage ditches are now being implemented to decrease the environmental impact of drainage systems. Also end of pipe solutions and consideration of pollution swapping in engineered structures will all help to decrease the environmental footprint of such systems (Fenton et al., 2014; Healy et al., 2012).

Figure 4.32 presents a side profile view of an integrated smart drainage system where all the important components are shown as well as the water table and the number of the gates in the vertical duct (Reetz 2001).

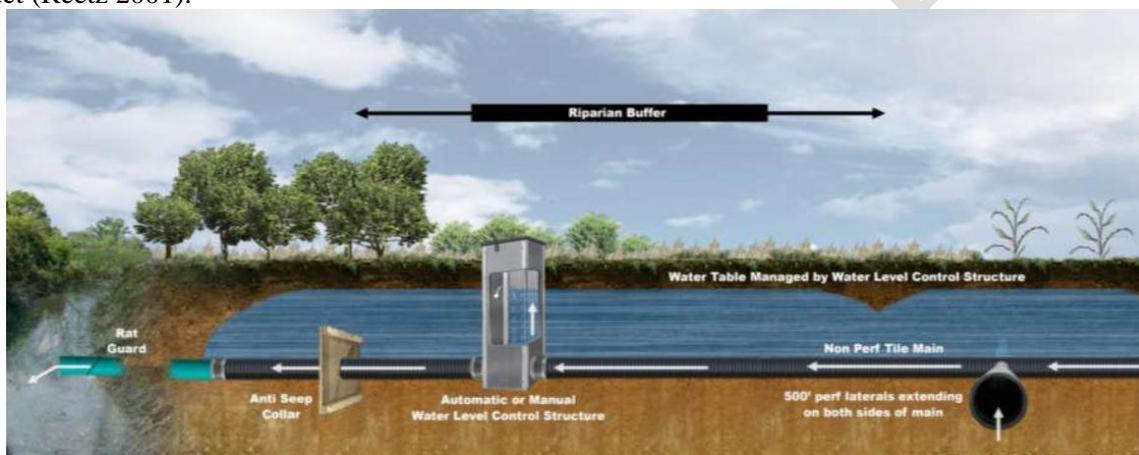


Figure 4.32. Side profile view of an integrated smart drainage system (Reetz, 2001)

Applicability

The number of listed measures within this BEMP is strongly influenced by local factors like the block topography, the cropping system and resource availability (Franklin Sustainability project, undated).

- Improved drainage is applicable to most non-sandy and non-organic arable and grassland soils.
- Drainage should be avoided or minimised on peat soils and wetlands.

Economics

Field drainage carried out by a professional contractor is typically around 2,000 to 2,600 €/ha to drain on a comprehensive basis (20 m spacing) (Farmers Weekly, 2012).

The following data are relevant for individual operations on farms:

- Cost of subsoiling 47 €/ha (EA, 2008 b)
- Cost of soil aerator: 7,000 € with a life expectancy longer of 20 years. Wearing parts on the aerator are replaced every 3 -4 years at a cost of 180 €/set.
- 4 ha covered in 3 hours.

These costs must be balanced against productivity gains that can be achieved via drainage. According to Tuohy et al. (2013), revenue increases from productivity benefits could be in the region of 20% (Table 4.23).

Table 4.23. Approximate costing of drainage systems (Fenton 2013; Tuohy et al., 2013)

Drainage System	Drain Spacing (m)	Depth (m)	Cost/m (€)	Cost/Acre (€)	Cost/ha (€)
<i>Piped drainage system</i>					
Conventional system - (costly and ineffective)	8	0.8-1.5	5-7	2,500-3,500	6,200-8,600
Ground water drainage	15-50	1.0-2.5	8-11	1,500-2,500	3,700-6,200
<i>Shallow drainage system</i>					
Mole drainage	1-1.5	0.45-0.6	-	50	125
Gravel mole drainage	1-1.5	0.35-0.5	-	600	1,480
Collector drains	20	0.75-1.0	5-7	1,000-1,400	2,500-3,500
Collector drains	40	0.75-1.0	5-7	500-700	1,200-1,700
Collector drains	60	0.75-1.0	5-7	350-450	800-1,150

Fencing off un-drained areas

WRT provides a case study of a cost benefit analysis for not draining wet ground in order to create a biodiversity habitat. A farmer was considering whether to drain an area of low-lying wet ground and decided on an alternative. He made an application for Higher Level Stewardship. Fencing on 500 m of ditches and streams to exclude dairy cows and other livestock from the boggy area, although access was retained for controlled grazing.

The fencing reduced lameness, injury, infection and loss/wandering of stock. The fencing, using farm labour, cost some 4.70 €/m. Reduced lameness/injury costs of 4.70 € per dairy animal in a herd of 100 saved 470 €/year. Payback was less than five years even without the un-costed benefits of cleaner animals, easier stock control, improved wildlife habitat and the Stewardship grant.

Driving forces for implementation

- Yield improvements (economics)
- It is part of cross compliance (GAEC) to produce a soil protection review which includes drainage and soil structure measures.
- Water Framework Directive
- Habitats Directive (peat)

Reference literature

- Aalto University, Finland. http://civil.aalto.fi/en/research/water_and_environment/water_resources/environmental_hydraulics. Website accessed Feb 2014.
- DEFRA, 2009. *Protecting our Water, Soil and Air. A Code of Good Agricultural Practice for farmers, growers and land managers*. Publ. TSO, Norwich, England.
- EBLEX, 2010. *Improving Soils for Better Returns. Beef and Sheep*. BRP Manual 3. AHDB, Warwickshire, U.K.
- Environment Agency, 2008a. *Best Farming Practices*. Publ. Environment Agency, Bristol, UK.
- Environment Agency, 2008b. *Think Soils*. Publ. Environment Agency, Bristol, UK.
- Farmers Weekly, 2012. <http://www.fwi.co.uk/articles/13/01/2012/130966/extreme-weather-means-good-land-drainage-is-vital.htm> accessed Nov 2013.
- Fenton, O., 2013. Personal communication November 2013.

- Fenton, O and Tuohy, P. 2013. Personal communication November 2013.
- Fenton, O., Richards, K.G., Thornton, S., Brennan, F., Healy, M.G., Jahangir, M.M. R., Ibrahim, T.G. 2014. Permeable reactive interceptors – blocking diffuse nutrient and greenhouse gas losses in key areas of the farming landscape. *Journal of Agricultural Science*, in press.
- Franklin Sustainability project, undated. Soil and drainage management guide, available online: <http://www.aucklandcouncil.govt.nz/EN/environmentwaste/sustainabilityconservation/landandsoilconservation/Documents/franklinsustainabilityprojectguide.pdf>, accessed January 2015.
- Healy, M.G., Ibrahim, T.G., Lanigan, G.J., Serrenho, A.J., Fenton, O. 2012. Nitrate removal rate, efficiency and pollution swapping potential of different organic media in laboratory denitrification bioreactors. *Ecological Engineering*, 40: 198-209
- Ibrahim, T.G., Fenton, O., Richards, K.G., Fealy, R.M., Healy, M.G. 2013. Loads and forms of nitrogen and phosphorus in overland flow and subsurface drainage on a marginal land site in south east Ireland. *Biology and Environment. Proceedings of the Royal Irish Academy*. DOI:10-3318/BIOE.2013.13
- National Trust, 2009. *Soil handbook*. Publ. National Trust, England.
- NCSU, 2013. *Drainage water management online advisory*. Webpage last accessed December 2013: www.bae.ncsu.edu/topic/drainageadvisory/background.php
- Newell Price, J.P., Harris, D., Chadwick, D.R, Misselbrook, T.H, Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., and Chambers, B.J., 2011. *Mitigation methods – user guide. An inventory of mitigation methods and guide to their effects on diffuse water pollution, greenhouse gas emissions and ammonia emissions from agriculture*. Prepared as part of DEFRA Project WQ0106, 158 pp.
- Reetz H.F. 2011. Drainage water management to enhance crop production systems, Reetz Agronomics, Monticello, Indiana CCA Conference.
- RSPB, 2010. *Lowland Agricultural Land Drainage Systems: Function and modification for wetland conservation*. Ver. 1, June 2010. Accessed Sep 2013: www.rspb.org.uk/images/land_drainage_systems_tcm9-254843.pdf
- SWARM, 2013. South West Agricultural Resource Management Hub. Website accessed Sept 2013: <http://www.swarmhub.co.uk/>
- Tuohy, P., Fenton, O., O'Loughlin, J. Humphreys, J., 2013. *Land Drainage – a farmer's practical guide to draining grassland in Ireland*. Moorepark Dairy Levy Research Update Series 20. Teagasc – Agricultural & Food Development Authority, July 2013.
- Woodland Trust, 2013. *Planting trees to protect water The role of trees and woods on farms in managing water quality and quantity*. Report downloaded February 2014 from: <http://www.woodlandtrust.org.uk/mediafile/100083903/Planting-trees-to-protect-water-RBC-Bluewater-farming-report-evidence.pdf>

4.4.1 Soil drainage case studies

Management of blanket bog habitat, Ysbyty Ifan, Wales

Much of this SSSI-designated upland blanket bog and heather moorland was drained by surface grips in the 1950s and provided summer grazing for sheep on a common grazing rights basis for local shepherds. The land is owned by the UK's National Trust and in recent years the organisation has implemented the blocking of grips to reinstate water levels on the bog, following consultation with its tenant farmers (Figure 4.33). The primary objective was to avoid the peatland from drying out and avoiding further mineralisation of the peat and the resulting high emissions of CO₂.



Figure 4.33. Heather moorland on the National Trust Ysbyty Ifan Estate, North Wales, where grip blocking of previously drained peat bog has been undertaken to improve water retention and reduce peat oxidation. The blocked grip is evidenced here by prolific growth of sphagnum moss.

The area is still grazed by sheep in the summer but numbers have declined, largely reflecting falling prices for lamb and wool products. The flocks are no longer hefted to this area and this has led to a reduction in labour costs as animals are now dipped prior to going on the moor for summer grazing; this avoids having to round up the animals and dip on the moor which was the old practice when flocks were hefted on the moors and went up to graze in early summer.

There is anecdotal evidence from the farmers in the valley of the catchment that their fields do not flood as often as before the grip blocking started and are getting more grazing days from these fields. If proven, this reflects the extra water-holding capacity the peatland has now regained through grip blocking.

Routine maintenance of drains, Morley farms, England.

Drainage can often be improved through simple maintenance measures. E.g. a large pond formed in one field where tile drains were installed every 40 m. After exploring the adjacent drainage ditch,

David found a clay pipe a few inches in diameter and pushed rods up it. A clump of matted roots came out, followed by a flow of water that drained the field in a few days. Most drainage installed in 1970s and 1980s with grants. Increasingly becoming blocked, and requires simple maintenance, such as a day with a rake clearing under-road pipes etc. in drainage ditches.

Tree planting in pastures to improve soil drainage, Pontbren project, Wales.

A farmer-led initiative outside of any agri-environmental scheme, with Millennium Grant money, to undertake tree-planting and other initiatives to reduce environmental pollution and also to improve eco-efficiency.

Land hydrology vastly improved with tree roots reducing runoff carrying soil, nutrients and chemicals by up to 40% and improved biodiversity. Trees planted at 90 degrees to field slope maximised intercept of overland flow (Figure 4.34). Tree root channels opened up soil structure to improve water and oxygen infiltration through the soil profile (Woodland Trust, 2013).



Figure 4.34. Trees planted to intercept of overland flow also improved drainage by opening up soil structure.

5 NUTRIENT MANAGEMENT

Introduction

This section is relevant to all farm types and covers four BEMPs, namely:

- Field nutrient budgeting;
- Crop rotation for efficient nutrient cycling (legumes);
- Synchronise nutrient supply with plant demand;
- Precise application of nutrients;
- Select lower impact fertilisers

According to Crosson, (2012) the nitrogen application and production accounts for approximately 15 – 20% of total systems emissions per unit output. However, the above-mentioned figure differs among different production systems²⁸. In addition to induced soil emissions of N₂O, a potent GHG with a GWP 298 times that of CO₂, NPK fertiliser manufacture accounts for 0.6 – 1.2% of global GHG emissions (IFA, 2010). In addition, nutrient losses from soils contribute to eutrophication, ammonia emissions from volatilisation of manure and fertiliser N contribute to acidification and eutrophication.

Figure 5.1 displays total N application to agricultural land across EU member states, indicating high average values (>150 kg N/ha) for Ireland, Luxembourg, the Netherlands, Slovenia and the UK. A similar though less pronounced pattern is shown for average P₂O₅ application (Figure 5.2). These patterns may reflect the high proportion of pasture-based livestock agriculture in these countries, resulting in high rates of organic N, and to a lesser extent P, additions.

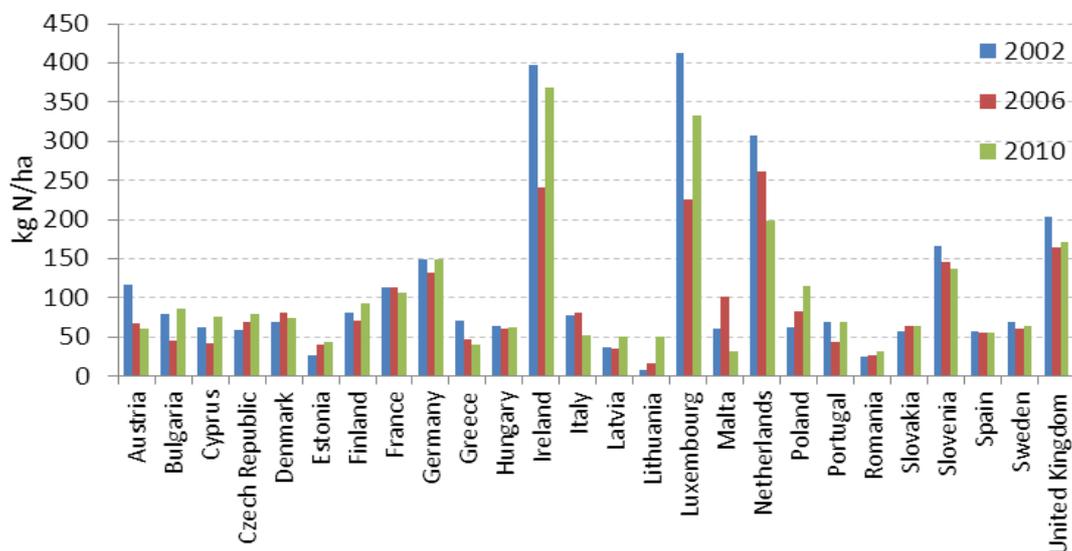


Figure 5.1. Total N applied to agricultural land in 2002, 2006 and 2010 across EU member states (FAOStat, 2013)

²⁸ The above figures are about animal production systems (livestock sector).

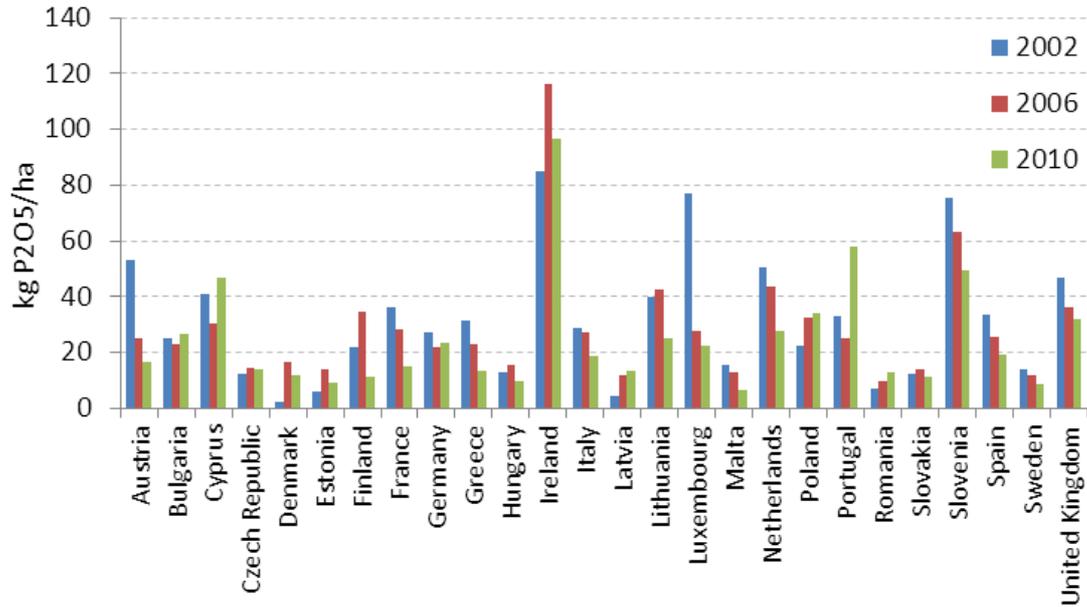


Figure 5.2. Phosphorus (P₂O₅) applied to agricultural land in 2002, 2006 and 2010 across EU member states (FAOStat, 2013)

Figure 5.3 shows how the proportion of N lost to the environment increases strongly with increasing N inputs on livestock farms (Figure 5.4, Figure 5.5).

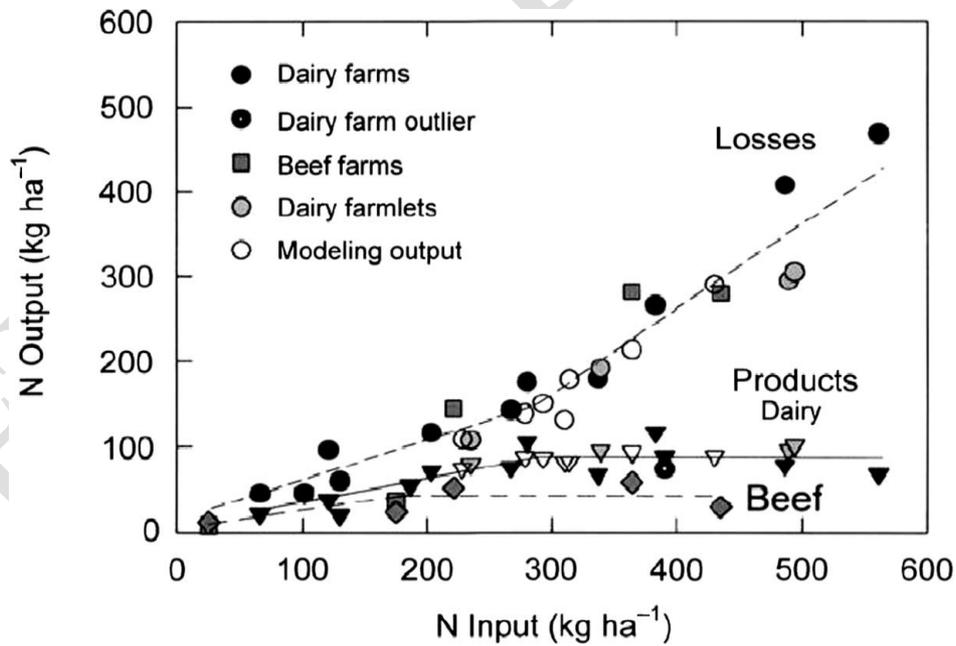


Figure 5.3. Nitrogen output in products and as losses to the environment with increasing N input across livestock farms (ENA 2011; Rotz et al., 2005)

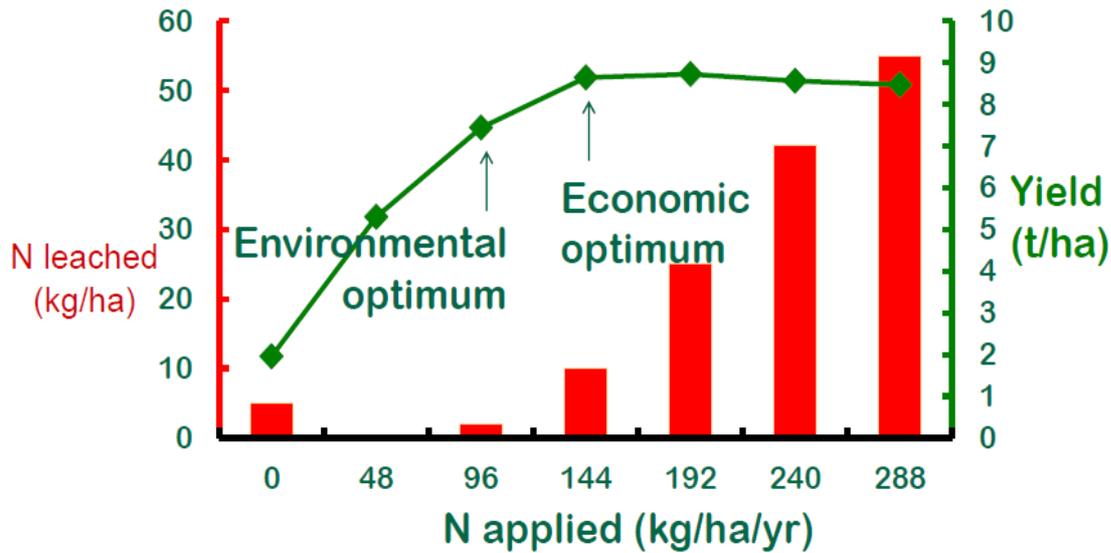


Figure 5.4. Shows how the linear relation between N applied and N leached and the difference in N loading between environmental and economic optima in terms of yield for arable and horticultural crops (Withers, 2014)

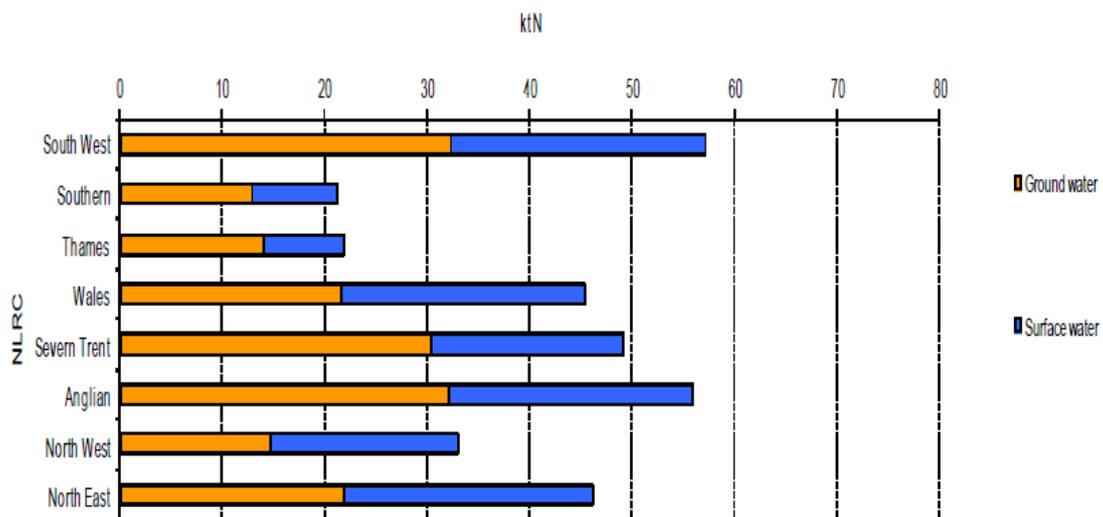


Figure 5.5. N loading (ktN) in England and Wales to groundwater (orange) and surface water (blue) as a result of agriculture (61%), sewage treatment (32%) and other (7%) sources Withers (2014)

A Nutrient Management Plan (NMP) is a key strategy in running a farm to optimise yield and ensure that maximum benefit is obtained from the organic manures and fertiliser applied. The cost for a farmer to establish a N balance is in the range of 200-500 € per farm per year (Bittman et al., 2014).

Point source and diffuse pollution from farms is an important environmental issue across Europe. Member State implementation of the Nitrates Directive through Nitrates Actions Programmes and the Water Framework Directive has had an important effect in reducing such pollution. The Nitrates Directive is at the heart of the cross-compliance mechanism of CAP support and remains so in the current reform proposals for 2014-20. An increasing share of agricultural land designated within NVZ is leading to greater restrictions on permitted N application rates, capped at 170 kg N/ha/y in such zones. The Commission has proposed that the WFD become part of cross-compliance as soon as implemented by all MS and obligations on farmers are identified (Hammell, 2012)

In addition, increasing fertiliser costs have driven improvements in nutrient management planning (NMP) over the past ten years. However, it is expected that best practice in NMP will take at least a further 15 years to become the norm across farms (Hamell, pers. comm. 2013). An interesting example of significantly improved NUE at a national level is provided by Germany, where considerable reductions in N and P nutrient surpluses have occurred since the mid-1980s, reflecting both structural changes associated with reunification in 1989 and a more judicious use of mineral fertiliser attributable to more rigorous NMP (Figure 5.6).

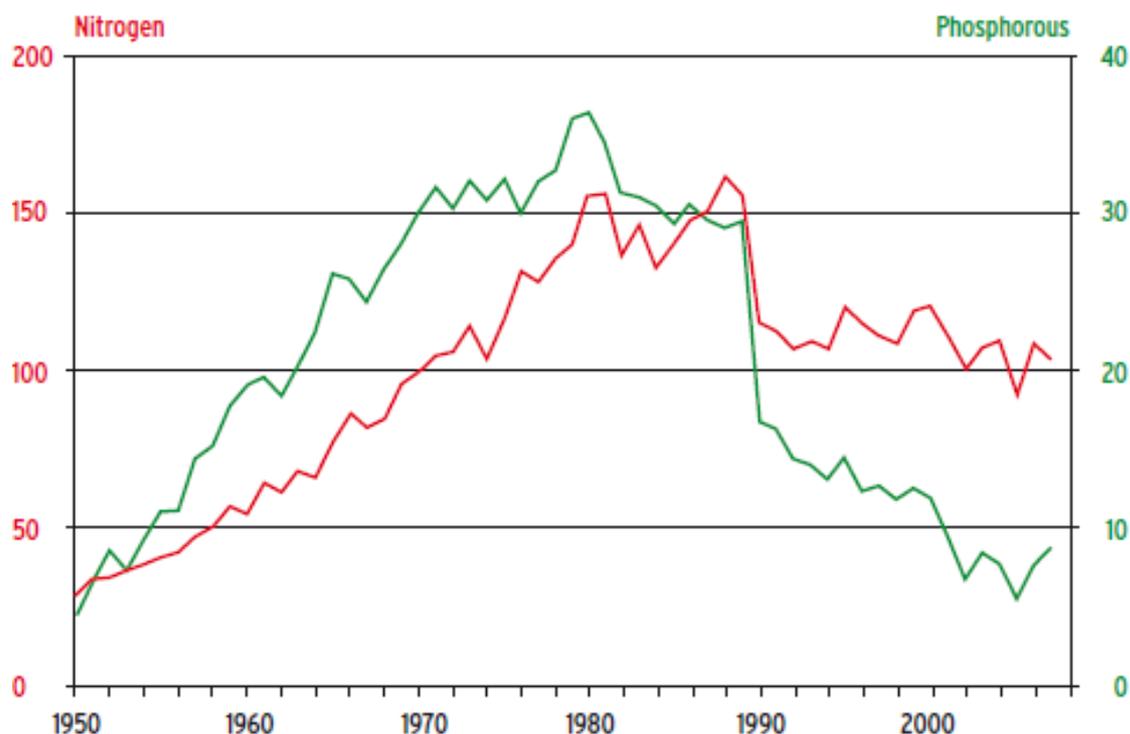


Figure 5.6. Nitrogen and phosphorus surpluses calculated at the national level for Germany between 1950 and 2008 (UBA, 2010)

Nonetheless, set against an increasing demand for agricultural production of food, fibre and fuel, there is an urgent need to develop joined-up approaches to optimize the planet’s nutrient cycles for delivery of our food and energy needs, while reducing threats to climate, ecosystem services and human health. Such inter-connections require an international approach that takes account of local and regional conditions and focuses on a shared aim to improve nutrient use efficiency (NUE) (Sutton et al., 2013).

There are large potentials for GHG-emission reductions via optimised manure and fertiliser handling (e.g. slurry systems with coverage of stores, cooling, and acidification), cattle feeding practices (e.g. optimised fat and roughage rations), and changed land use (e.g. restoration of cultivated wetland soils, and more cover crops).

The UK CCC report on GHG abatement options for agriculture emphasised the high potential for optimised fertiliser and manure management to reduce GHG emissions and generate economic savings within the agricultural sector (CCC, 2008).

Figure 5.7 displays some of the important factors determining nutrient flows on the farm scale, highlighting the large number of processes that must be accounted for to undertake accurate nutrient budgeting.

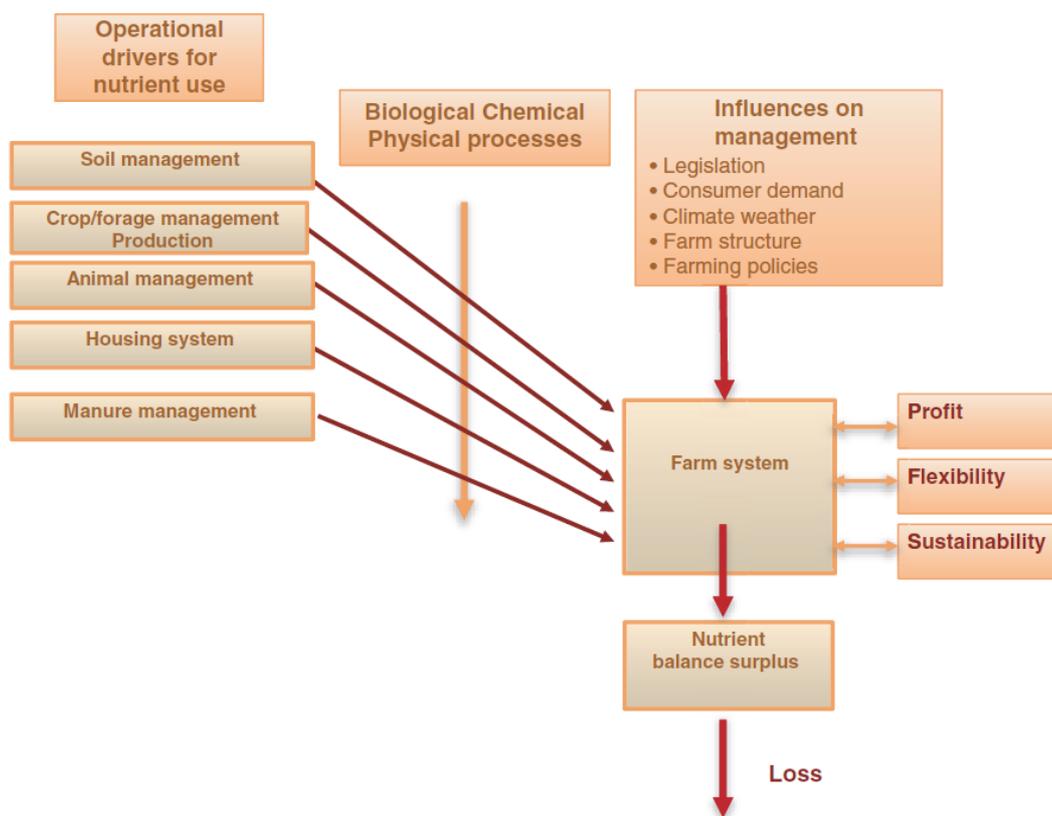


Figure 5.7. Key factors for farm level nutrient flows and budgeting (Sutton et al., 2011)

Reference literature

- Bittman, S., Dedina, M., Howard C.M., Oenema, O., Sutton, M.A., (eds), 2014. Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen, Centre for Ecology and Hydrology, Edinburgh, UK
- CCC, 2008. Building a low-carbon economy – Britain’s contribution to tackling climate change. TSO, London.
- Crosson, P. 2012. Mitigating greenhouse gas emissions from Irish beef cattle systems – the Carbon Navigator. In: *Teagasc, Agri Environment Conference 2012 'Sustainable Pathways to Food Harvest 2020'*, December 2012, Farmleigh, Dublin, Ireland, available online: http://www.teagasc.ie/publications/2012/1637/Paul_Crossan_Teagasc.pdf, last accessed May 2015.
- ENA, 2011. *The European Nitrogen Assessment*, ed. Mark A. Sutton, Clare M. Howard, Jan Willem Erisman, Gilles Billen, Albert Bleeker, Pering Grennfelt, Hans van Grinsven and Bruna Grizzetti. Pub.Cambridge University Press.
- FAOStat, 2013. Agricultural statistics gateway page, accessed August 2013: http://faostat3.fao.org/faostat-gateway/go/to/download/Q/*E
- Hamell, M., 2012. Challenges in the agri-environment relationship in the period to 2030. In: *Teagasc, Agri Environment Conference 2012 'Sustainable Pathways to Food Harvest 2020'*, December 2012, Farmleigh, Dublin, Ireland.
- Hamell, M. (European Commission DG Environment), personal communication March 2013.

- IFA (International Fertiliser Association Industry), 2010. Greenhouse gas budgets of crop production – current and likely future trends. Helen C. Flynn and Pete Smith. Publ. IFA, Paris.
- Sutton M.A., Bleeker A., Howard C.M., Bekunda M., Grizzetti B., de Vries W., van Grinsven H.J.M., Abrol Y.P., Adhya T.K., Billen G., Davidson E.A., Datta A., Diaz R., Erisman J.W., Liu X.J., Oenema O., Palm C., Raghuram N., Reis S., Scholz R.W., Sims T., Westhoek H. & Zhang F.S., with contributions from Ayyappan S., Bouwman A.F., Bustamante M., Fowler D., Galloway J.N., Gavito M.E., Garnier J., Greenwood S., Hellums D.T., Holland M., Hoysall C., Jaramillo V.J., Klimont Z., Ometto J.P., Pathak H., Plocq Fichelet V., Powlson D., Ramakrishna K., Roy A., Sanders K., Sharma C., Singh B., Singh U., Yan X.Y. & Zhang Y., 2013. *Our Nutrient World: The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management*. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.
- UBA, 2010. Water Protection in Cooperation with Agriculture. Umwelt Bundes Amt, Berlin.
- Withers, 2014. *Advanced Training Partnership material*. ATP, Bangor University.

FINAL DRAFT

5.1 Field nutrient budgeting

Description

Within this BEMP, the following measures are discussed:

- Producing a nutrient management plan
- Accounting for organic nutrients accurately (using relevant software tools and nutrient composition data for organic matter)
- Accounting for crop requirements and nutrient off take
- Nitrogen Use Efficiency (NUE) for field crops
- Improving the soil fertility

Sound nutrient management minimises fertiliser inputs allowing the farmer to maximise economic returns and safeguard the environment. It is necessary to calculate the nutrient requirement of a crop and then deduct the nutrients supplied by the soil, organic materials and alternative nutrient sources to budget the need for inorganic fertiliser.

Accurate soil nutrient management is one of the most important measures a farmer can take to optimise the efficiency of farm production. In addition, it is widely acknowledged that nutrient budgeting is a powerful tool for raising awareness and stimulating improvement action. Nutrient planning at the farm system level requires detailed accounting of the nutrient budgets at the farm and field level, and is closely related with other BEMP such as the type of manure spreading technique (Section 9.6 and 9.7), organic matter inputs (Section 4.2), manure storage type and capacity (Chapter 9) and timing of manure application (Section 5.3). Reflecting the importance of NMP, and the multiple components of NMP for livestock and arable farms, it is broken down into three main components that are addressed in relevant chapters of this report (Table 5.1).

Table 5.1. Major NMP components addressed in chapters of this report

NMP component	Aspects addressed	Chapter
Soil fertility management	Soil nutrient testing Soil pH testing Calculating crop nutrient requirements Calculating inputs from soil amendments	5
Nutrient budgeting fundamentals	Farm nutrient budgeting overview	5
Livestock farm nutrient budgets	Livestock feed inputs NUE and N surplus for livestock and mixed farms Benchmarks	8
Livestock feed	Dietary N optimisation	8
Precision application	GPS application control Timing and type of fertiliser Efficient slurry application	5 and 9
Arable farm nutrient budgets	Crop nutrient requirements NUE and N surplus for crops and mixed farms	5

Leaky nutrient cycles account for a large portion of the agricultural sector's environmental footprint. Taking the UK as an example, nutrient use in agriculture is currently responsible for:

- 50-60% of nitrate and 26% of phosphate in surface waters. These nutrient losses contribute to eutrophication of rivers, lakes and coastal waters.

- The loss of 250,000 tonnes each year of ammonia (90% of total ammonia emissions), which can affect respiratory health in humans and impact on the quality of terrestrial and aquatic ecosystems.
- Around 9% of UK greenhouse gas emissions, 50% of which are from soil nutrient management. 78% of UK nitrous oxide emissions come from farming (DEFRA, 2013).

Table 5.2 expands on some of the above measures and relates them to farm level nutrient budgeting.

Table 5.2. A breakdown of the main measures involved in sound NMP

Stage	Measure	Description
Maintain soil pH, P, K, Mg	Systematic periodic soil testing to maintain optimum pH range and appropriate nutrient levels.	Test soils regularly: at least every three or five years for permanent pasture and every three years for crops and leys.
Soil nutrient budgeting	Optimise fertiliser application rates.	Account for all nutrient inputs to soils, and apply nutrients in correct amounts for optimum yield response. Take into account the amount and plant availability of nutrients added as organic matter (e.g. manures). Refer to the most relevant nationally available published guideline values.
Farm nutrient balance calculation	Calculate N (or P) imports minus N (or P) exports of a specified land unit (e.g. ha, farm, country).	An established OECD agri-environmental indicator. The higher the nutrient surplus, the greater the potential for offsite pollution whilst the greater the deficit, the more likelihood of soil becoming impoverished. For details on how this is implemented across major farm types, see Section 8.2 for livestock farms and this section for arable farms.
Farm nutrient use efficiency calculation	Calculate the ratio of fertiliser N (or P) harvested or exported in livestock products to nutrient inputs as fertiliser N (or P) and feed.	Use relevant farm records to calculate all nutrient inputs and outputs in order to draw up a nutrient budget related to production for the entire farm. For details on how this is implemented across major farm types, see Section 8.2 for livestock farms and this section for arable farms.

A simple and basic way to assess a farm's nutrient balance is to carry out the so-called 'farm-gate NPK balance'. This adds up all nitrogen (N), phosphorus (P) and potassium (K) coming onto the farm (inputs) and compares it to that leaving the farm (outputs) in a given period. A balance can be carried out for the whole farm over a 12 month period or on individual fields over a whole rotation. A 'whole farm' approach identifies the nutrient status over the whole farm system where as a 'rotation' calculation focuses the exercise on individual fields which can be more useful in targeting production and managing production.

Figure 5.8 shows a typical crop-yield response curve to nutrient supply (DEFRA, 2010). Fertiliser use is necessary to optimise production and without applied fertiliser (organic or mineral), yield is low (A). Yield increases almost linearly with fertiliser up to B (the on-farm economic optimum fertiliser rate) after which the 'law of diminishing returns' applies where further fertiliser addition results in small crop yield gain and it is not economic to apply more fertiliser. At nitrogen rates above the on-farm economic optimum, there will be a surplus of residual nutrient in soil after harvest. Surpluses can lead to nutrient transfer by leaching and run-off to surface and groundwater bodies, causing eutrophication. A surplus in N can also lead to increased risk of gaseous losses in the form of the GHG N₂O.

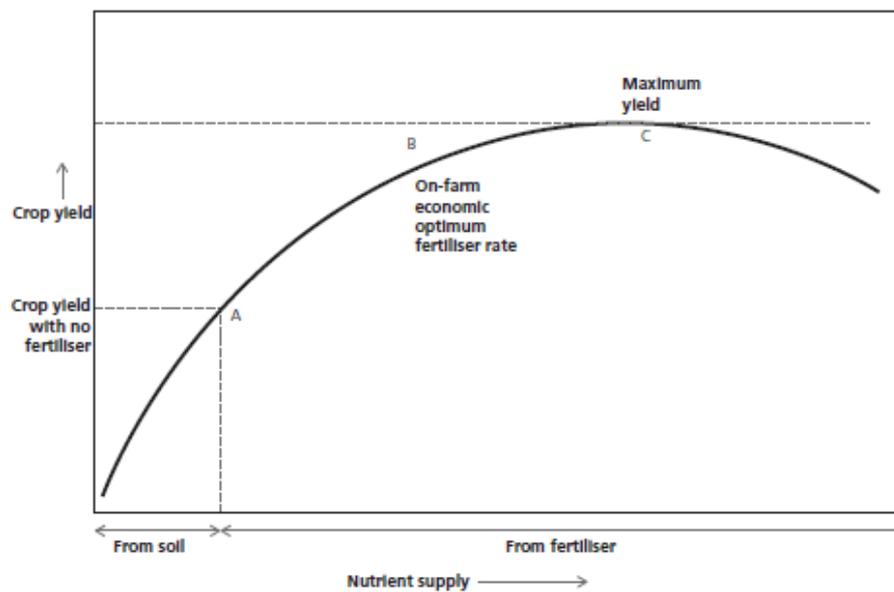


Figure 5.8. Typical crop yield response curve to nutrient supply (DEFRA, 2010)

Best practice measures for soil fertility

The UK fertiliser manual (DEFRA, 2010) provides the following list of best practice measures:

- Regular soil analysis every 3-5 years for P, S, K and Mg Index and pH.
- Identification of the Soil Nitrogen Supply (SNS) Index system every spring before applying nitrogen fertiliser.
- Estimation or measurement of the nutrient contents of any organic manure applied.
- Taking account of all other sources of nutrients before deciding on fertiliser application rates.
- Where appropriate, soil or plant tissue analysis to help with decisions on application of sulphur or micronutrients.
- Use of a recognised nutrient recommendation system.
- Regular calibration and tray testing of fertiliser spreaders and calibration of manure spreaders.
- Rapid incorporation of organic manures after application to tillage land or use of trailing hose, trailing shoe or injection equipment for slurry.

Accounting for soil nutrient status

Soil N supply can range from < 60 to 160 kg N (which can be higher for different soil types e.g. peat soils) per hectare depending on the previous crop, on the soil type and hydrological regime/soil treatment. Accurately accounting for this N ensures optimum crop response to any fertiliser-N applied, maximising NUE and minimising environmental impacts of:

- fertiliser-N manufacture (including GHG emissions up to 6 kg CO₂e/kg N)
- fertiliser-N application (including GHG emissions of c.5 kg CO₂e/kg N).

Estimating and measuring dry matter yields

The estimation of pasture production helps the farmer taking grazing management decisions. The main target is the estimation of the forage availability and the balance of the forage supply with animal requirements. In particular the estimation of the forage production is useful for allocating paddock area and/or projecting the carrying capacity, especially moving into the non-growing season. Likewise, another important element is the monitoring of the pasture condition. The pasture quality

vary greatly from one area to another but the trend over the time should show the direction in which pasture condition is moving. In particular, the best time to monitor the pasture condition is 15 days after a grazing period (Shewmaker et al., 2010).

Several researchers have concluded that there is a high correlation between forage height and dry matter yield. This correlation is improved when bulk height is determined by depressing the forage with a weighted plate. This weighted plate referred to as a weighted disk meter, appears to improve the estimated pasture yield. The different designs of weighted disk meters are usually called rising plate meters depending on the how the measurements are taken (Earle and McGowan, 1979; Michell and Large, 1983). This method combines the height of the plant(s), structure and density into one measurement referred to as bulk density or compressed sward height (Shewmaker et al., 2010). In the operational data section, the ways of using it are presented.

Achieved Environmental Benefits

Qualitative Overview

Nutrient budget data are not currently collected at farm level across Europe (Kremer, 2013) and therefore environmental benefits, indicators and benchmarks are not directly accessible (Table 5.3).

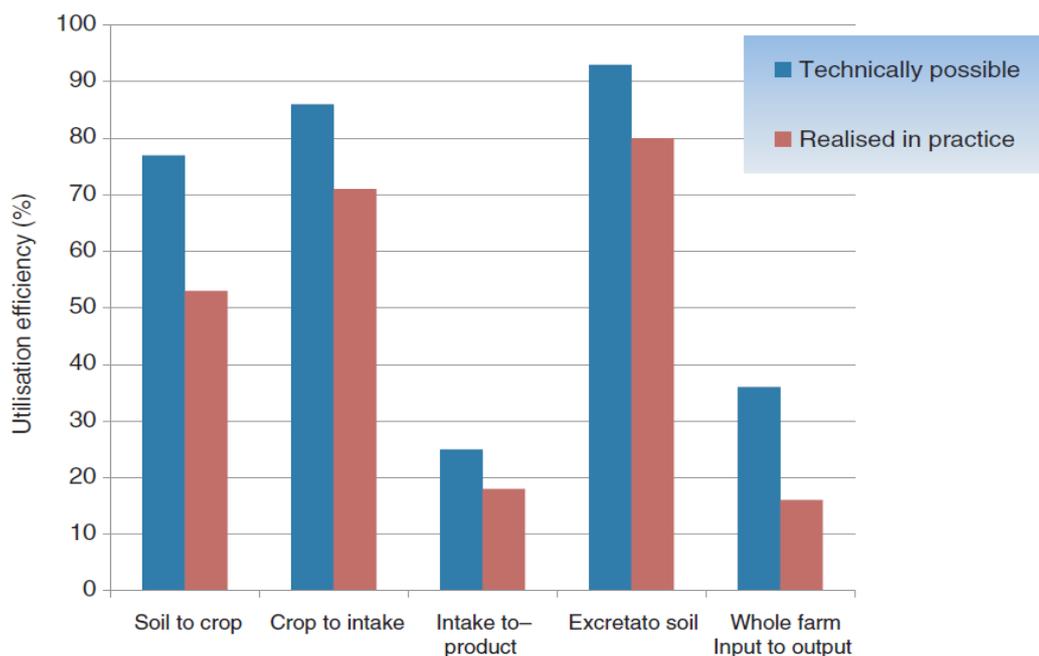
Table 5.3. Environmental benefits associated with the measures listed above

Measure	Environmental benefit
Optimise fertiliser application	Avoids over-application of fertiliser and associated upstream, downstream pollution and groundwater.
Nutrient balance and NUE	Both provide indicators of nutrient input and output through a system and indicate relative risk of diffuse pollution. Nutrient balance raises farmer awareness about N wastage and can be used to derive NUE. NUE enables farm systems to be compared and promoted in terms of their overall efficiency of production.

Achievable improvements in nitrogen use efficiency

Bassanino et al. (2011) state that the adoption of best practices for fertiliser management via nutrient surplus calculations could significantly reduce environmental pressures and help reach the 2020 goals to reduce the N, P, and K surpluses by 25%, 70%, and 57%, respectively.

Figure 5.9 shows the gap between technically possible and current best practice NUE through farm stages, indicating a particularly large gap (improvement potential) for soil-to-crop NUE. The gap between poor- or average- performers and best performer would relate more directly to improvement potential associated with BEMP, but this is not displayed in Figure 5.9. However, it has been observed for several years that the N utilisation efficiency value in DeMarke farm (intensive production farm) in Netherlands is higher than 40% (Verloop, 2015).



Source: Sutton et al. (2011)

Figure 5.9. Technically achievable and front-runner farmer achieved N use efficiency

Calculating emissions reductions

There is considerable variation in the proportion of applied nutrients, in the form of either organic or mineral fertiliser, lost to the environment – depending on the application timing, technology and conditions, soil characteristics and crop type, amongst other factors. Values provided in the table below for mineral nitrogen reflect default factors used for GHG emission calculations in IPCC (2006) methodology (Table 5.4). These factors may be multiplied by the amount of N application avoided through NMP in order to estimate the environmental benefit associated with that NMP. However, these generic default values may be substituted with more location- or technique- specific values where available, especially those provided by nutrient budgeting tools such as MANNER-NPK in the UK. Misselbrook et al. (2012) report an NH₃-N volatilisation factor of just 0.018 for non-urea fertilisers.

Table 5.4. Nitrogen loss fractions for fertiliser additions used in IPCC reporting

Lost N fraction	Ammonium nitrate fertilisers	Urea fertilisers	Organic fertilisers
	kg N per kg N applied		
N ₂ O-N	0.01	0.01	0.01
NH ₃ -N	0.10	0.30	0.20
NO ₃ -N	0.30	0.30	0.30

Source: IPCC (2006)

Manufacture of mineral N requires large quantities of energy and gives rise to considerable GHG emissions, depending on the type of fertiliser and the efficiency of the manufacturing plants. The upstream GHG emissions avoided through NMP may be calculated through multiplication of avoided N by emission factors listed in Section 5.4. Note that whilst urea has considerably lower upstream emissions from manufacture than ammonium nitrate, approximately 30% of applied urea-N volatilises (compared with c.10% for ammonium nitrate), leading to lower N availability, higher NH₃ emissions

and higher indirect N₂O following deposition of NH₃, so that the overall environmental performance of urea is not necessarily better than ammonium nitrate.

With regard to P loss, a major driver of freshwater eutrophication, the fraction lost to water via dissolution and erosion is highly dependent on vegetation cover, soil type, soil P status, climate and other factors including tillage management, etc. An approximate loss rate value of 3% P for pasture land and 1% P for arable land of applied P may be used to estimate the benefit of avoided P application (Withers, 2014, Johnes et al., 1996). In addition, avoided P application automatically translates into a direct benefit in terms of reduced depletion of this finite resource.

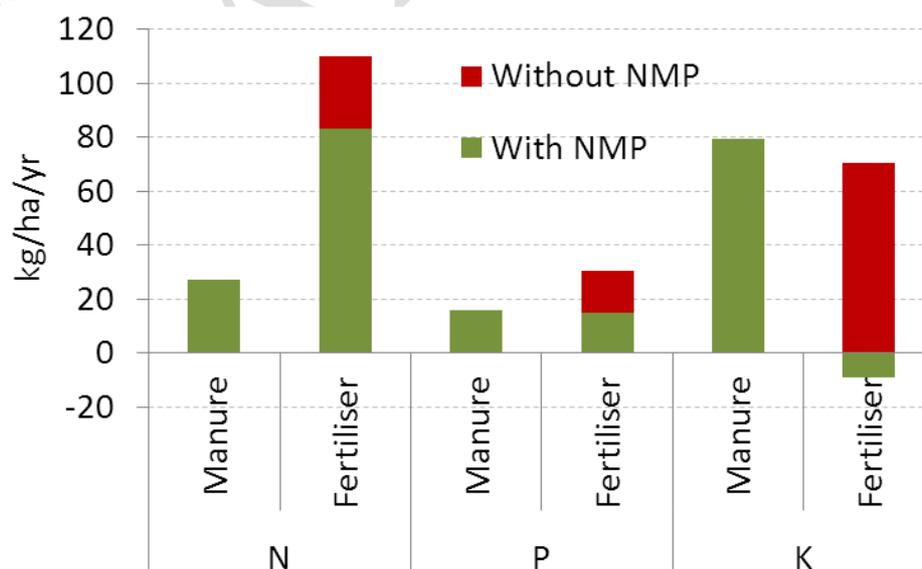
Improved environmental condition

Rough estimations show that it takes approximately 10 years for minerals to migrate 2 m through the soil profile, leading to delayed response of groundwater quality to reduce nutrient applications, although significant improvements in groundwater quality within 2 m of surface observed in Denmark (Hamell, 2013). On the other hand, for deep draining sandy soils, which are extremely fast, the N applied in the year X will affect groundwater in the following year (X+1). Also, the mobility of P is much lower than of N (Verloop, 2015).

The Denmark Agreement (Danish Green Growth, 2009) set targets for environmental improvement from better management practices in agriculture. The ecological quality of the Danish lakes is controlled by nutrients. A significant decrease in the load of nutrients has been observed since the 1990s. The average level of phosphorus and nitrogen in Danish lakes has decreased by 26 % and 18 % respectively from 2000 to 2008, associated with reduced water turbidity and better conditions for the bottom vegetation.

Accounting for Organic amendments example

A farmer applies cattle slurry (6% dry matter) to a field of spring barley (for animal feed), at a rate of 30 m³ /ha, but does not take this into account and also applies the full mineral fertiliser requirement for the crop: 110 kg/ha N, 70 kg/ha P₂O₅ and 280 kg/ha K₂O (DEFRA, 2010). The slurry application supplies 78 kg total N (of which 27 kg available), 36 kg P₂O₅, 96 kg K₂ O (DEFRA, 2010). Manure and fertiliser application rates with and without NMP are displayed in Figure 5.10 as a worst and best case example.



NB: Available N following Spring application with splash-plate (DEFRA, 2010). Available K from manure in excess of crop demand can be carried over to the next crop (negative fertiliser application rate in year of application)

Figure 5.10. Manure and fertiliser application rates for spring barley with and without NMP (i.e. no or full accounting of nutrients available from manure application) (DEFRA, 2010)

In the worst case example, if the farmer completely fails to account for the available nutrient content of manures, an additional 27 kg N, 16 kg P and 80 kg K are applied per hectare, leading to the following conservative estimates of additional losses in Table 5.5 (based on average default loss coefficients for fertilisers: in fact, loss coefficients are likely to be higher for application rates above the optimum). These additional losses are avoidable through accurate NMP and, for N₂O, NH₃ and NO₃, are also translated into GHG emission savings (Table 5.5). Avoided fertiliser manufacture also translates into large potential GHG savings realisable through full NMP of manure nutrient content. Total avoidable GHG emissions are 420 kg CO₂e/ha/y in this case, and the potential economic saving through full NMP is over EUR 130/ha relative to a worst-case failure to account for any manure nutrients and neglecting any crop yield response above recommended (ca. optimum) application rates (based on MANNER-NPK fertiliser prices listed under “Economics”, below).

Table 5.5. Additional (avoidable) emissions arising from failure to account for nutrient availability from manure application

	Avoidable losses through NMP (kg/ha)	
	Substance	CO ₂ e
Avoidable N₂O (air)	0.4	126
Avoidable NH₃ (air)	3.3	13
Avoidable NO₃ (water)	35.9	28
Avoidable PO₄ (water)	0.5	
Avoidable fertiliser manufacture (air)		253
Total avoidable GHG		420

NB: Based on IPCC (2006) default loss factors for N; Johnes et al. (1996) loss factors for P on arable soils and fertiliser manufacture CO₂e emissions from the Cool Farm Tool and Lal (2004). Assumes ammonium-nitrate application, wet climate and no carry-over of manure N to subsequent crops.

The amount of N available to the crop following spreading is strongly influenced by the type of spreading method (Section 9.6 and 9.7). In this case, high loss rates from splash-spreading mean less N is available. The potential over-application of fertiliser that can be avoided through NMP would be greater than indicated here if more efficient spreading methods, such as injection or trailing hose, were applied.

Appropriate environmental performance indicators

Management indicators of NMP centre on the judicious use of nutrients to produce sustainable crops and livestock. It is about applying the environmental optimum amount of nutrients as opposed to the economic optimum.

- Regular soil fertility testing; practically, it can be expressed as annual testing of chemical composition of slurry (N, P contents)
- Produce a nutrient management plan
- Use recognised nutrient accounting tool
- Account for organic nutrient inputs, crop residues, SNS and crop requirements
- Optimise crop rotation for nutrient and organic input (BEMPs 4.2, 5.2, 6.4)
- Avoided fertiliser application from organic nutrient accounting (kg nutrients)

Nutrient indicators

- Nutrient surplus kg/ha
- N balance (kg N/ha)
- Nitrogen use efficiency (%)
- Nutrient use efficiency (kg/unit input related to the input of fertiliser)

- Crop nutrient offtake (kg/ha/y) and NUE for field crops

Nutrient surplus and use efficiency indicators

Gross nitrogen or phosphorus balance is calculated as the potential surplus of nitrogen or phosphorus on agricultural land (kg/ha/year). Nitrogen use efficiency is the amount of n imported to the farm system (fertilisers, feed and bedding materials: see section 6.4) that is exported from the farm in products (e.g. cereal grain, straw, animal live weight, milk).

A recent report on NUE at the global scale (Sutton et al., 2013) highlights the importance monitoring NUEs, not only in agriculture but to work towards a “full-chain NUE” on a regional or national basis, and promotes the use of NUE as an indicator to quantify and report on the impacts of practices to improve nutrient consumption on a global scale. For mixed crop-animal farm systems, the N surplus and NUE are calculated as follows (TFRN, 2011):

SurplusN = [FertN + ManureN + CompostN + BNF + Atm.N + SeedN] – [CropN]
NUEcrop = [CropN] / [FertN + ManureN + CompostN + BNF + Atm.N + SeedN]
SurplusN = N Surplus at farm level, kg/ha
NUEcrop = N use efficiency at farm level, mass/mass ratio (dimensionless)
FertN = Amount of fertilizer N fertilizer imported to the farm, kg/ha
ManureN = Amount of manure N imported to the farm, kg/ha
CompostN = Amount of compost N imported to the farm, kg/ha
BNF= Amount of biologically fixed N ₂ by leguminous crops, kg/ha
Atm.N = Amount of N from atmospheric deposition, kg/ha.
SeedN = Amount of N imported via seed and plants, kg/ha.
CropN = Net amount of N in harvested crop exported from the farm, including residues, kg/ha
Source: TFRN (2011)

OECD (2013) uses surplus of phosphorus on agricultural land (kg P/ha/year) per country or region as a primary risk factor for phosphorus pollution of waters.

In France, the national average P surplus declined over 16 years (1990-2006) from 17.5 to 4.4 kg P/ha/y, mostly because of a significant decrease in mineral fertiliser application (CEEP, Scope 93, May 2013).

Table 5.6 displays representative values for surpluses of the major nutrients across UK farm types.

Table 5.6. Calculated nitrogen, phosphate (P₂O₅) and potash (K₂O) surpluses (kg/ha) on ten representative “standard” farms

	Dairy	Beef suckler cows	Pig breeder/finisher	Pig importer/finisher	Poultry layers	Poultry broilers	Combina-ble crops	Combina-ble crops + manures	Root crops	Root crops + manures
N	255	167	496	459	350	245	62	99	39	87
P ₂ O ₅	74	24	161	136	94	133	-14	26	8	45
K ₂ O	113	59	194	184	107	124	8	29	5	38

Source: DEFRA, (2005)

Table 5.7 contains criteria from the Swedish Climate Label for Food that could be regarded as benchmarks for NMP management. Some of these benchmarks are also relevant for farm nutrient budgeting described in Sections 8.2 and 9.2.

Table 5.7. Relevant criteria contained in the Swedish Climate Label for Food that could adopted for use as indicators of best practice (Klimatmärkning för mät, 2010)

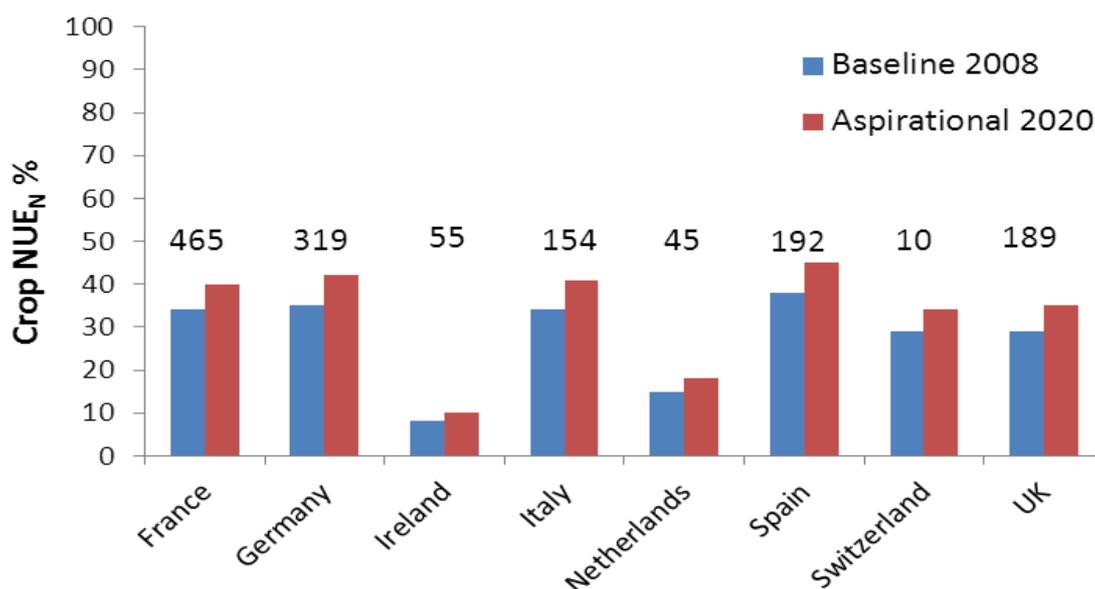
Aspect	Criteria
Farm nutrient budgeting	A nitrogen balance at farm level is drawn up annually. Key data on nitrogen utilisation on the entire farm are produced and are monitored over a five-year period.
Field nutrient budgeting	An annual fertilisation plan is prepared for each field on the basis of expected yields that lie within the range of those obtained on the farm during a five-year period. Account is taken of the total nutrient content of farmyard manure, pre-crop effects and green manure/ley in the crop rotation. All manures are analysed for nitrogen content, every year for three years, then, if stable values, after any significant changes in animal diet or management system (exception for farmyard manure and deep litter manure). The nitrogen use efficiency is documented annually at field or crop level, with suggested measures to increase the degree of use efficiency viewed over a three-year perspective.
Continuous improvement	Key data must be reviewed and a plan must be provided for improving the use efficiency of new N per tonne of harvested product and for decreasing the amount of excess new nitrogen in the production enterprise A review must be carried out at least every five years.

National NUE:

National NUE, as calculated by Sutton et al. (2013) may provide a useful benchmarking indicator for policy-makers and farm advisory services, in addition to providing guidance on achievable targets for mixed farm systems (although values are highly dependent on the mix of crops and livestock systems included).

Crop NUE_N is defined as the nitrogen in harvested crops in a country as a % of the total nitrogen input to that country (sum of mineral fertiliser N input plus crop biological nitrogen fixation) whereas a full-chain NUE_N is here defined as the nitrogen in food available for human consumption in a country as a % of the total nitrogen input to that country (sum of fertiliser inputs, biological nitrogen fixation in crops and grass, import in fertiliser, feed and food), (Sutton et al., 2013). Table 5.8 presents indicative ranges for target $N_{surplus}$ and NUE for different farming systems and crop species across EU based on literature data (Bittman et al., 2014).

Figure 5.11 displays estimated Crop NUE_N per region for 2008 (baseline) as compared with an aspirational target for 2020, based on a 20% relative improvement from the 2008 values. The figures above the bars give the equivalent total savings per region (ktonne N/year) achieved by the aspirational goals (Adapted from Sutton et al., 2013).



N.B.: Numbers above bars are potential annual reductions in N applications, kt per year.

Figure 5.11. Average national values for crop NUE in 2008, and aspirational 2020 targets, calculated from national statistics on nutrient use and yields (Adapted from Sutton et al., 2013)

Table 5.8. A compilation of N surplus and NUE data from literature on European farms

Farm type	N surplus (kg/ha/year)	NUE _N	Source/Comment
Dairy commercial (UK)	255		Defra, 2005
Dairy commercial (NL 2010)	195	34% (farm basis)	Oenema et al., 2012 Dairyman project
Dairy 'Pioneers' (NL 2010)	141		Dairyman project
Upland organic farm (UK)	18		Goulding et al., 2008
Lowland dairy (UK)	120		Goulding et al., 2008
Stockless arable	96		Goulding et al., 2008
Maize (grain) (IT)	103-175		Bassinino et al., 2011
Maize (silage) (IT)	27-98		Bassinino et al., 2011
Leys/meadows (IT)	-40-4		Bassinino et al., 2011
Winter wheat (IT)	10-148		Bassinino et al., 2011
Wide dairy farm (EU level)		25-30%	Goulding et al., 2008
Specialised cropping system ^a			
Arable crops	0-50	0.6-0.9 kg/kg	Bittman et al., (2014)
Vegetables	50-100	0.4-0.8 kg/kg	
Fruits	0-50	0.6-0.9 kg/kg	

^a Cereals have high NUE, Root crops have low NUE, Leafy vegetables have low NUE

Table 5.9. Nitrogen balances (kg/ha) on 171 commercial farms assessed in a UK benchmarking study (DEFRA, 2005)

	Arable only	Arable + imported OMs	Mixed arable & beef/sheep	Mixed arable & dairy	Arable & mixed livestock	Mixed arable pigs/poultry	Organic
Number of farms	2	6	15	28	6	6	9
Mean	66	95	76	152	136	278	140
Median	-	86	81	148	141	260	148
Min	37	20	34	62	45	102	53

Max	94	198	133	272	215	483	229
Std dev	-	62	32	54	59	141	56
Top ¹ 10%	i.d	i.d	i.d	95	i.d	i.d	i.d
Top ¹ 25%	i.d	i.d	44	105	i.d	i.d	107

i.d = insufficient data to compile a robust benchmark

¹ Top = percentage of farms with a nitrogen balance below the specified kg/ha value.

Table 5.10. Phosphate (P₂O₅) balances (kg/ha) on 171 commercial farms assessed in a UK benchmarking study (DEFRA, 2005)

	Arable only	Arable + imported OMs	Mixed arable & beef/ sheep	Mixed arable & dairy	Arable & mixed livestock	Mixed arable pigs/ poultry	Organic
Number of farms	2	6	15	28	6	6	9
Mean	8	27	8	32	16	65	8
Median	-	24	0.4	30	23	57	6
Min	-5	-9	-31	9	-10	8	-13
Max	20	85	71	117	37	136	26
Std dev	-	35	29	23	21	50	14
Top ¹ 10%	i.d	i.d	i.d	11	i.d	i.d	i.d
Top ¹ 25%	i.d	i.d	-10	17	i.d	i.d	0

i.d = insufficient data to compile a robust benchmark

¹ Top = percentage of farms with a nitrogen balance below the specified kg/ha value.

Indicators of soil fertility status

- Olsen P (or Resin P, Morgan's P) (mg/kg)
- Soil N supply (kg/ha)
- Cation Exchange Capacity (cmol+/kg dry soil)
- Soil K, Mg, and trace element concentrations (mg/kg)
- Soil pH
- Soil organic C and N(%) for organic matter content

Fertiliser application should not exceed off-take of nutrients in cropping to maintain optimum soil nutrient status. For northern Europe, maintenance level (i.e. the level at which a soil mineral nutrient concentration should be maintained after a season's cropping) may be regarded as an appropriate benchmark. DEFRA (2010) recommend the following maintenance levels for UK cropland:

- P₂O₅: 16-25 mg/l (Olsen P) or 31-49 (Resin P)
- K₂O: 121-180 mg/l (ammonium nitrate extract)
- MgO: 51-100 mg/l (ammonium nitrate extract).
- Grassland soil pH optimum: pH 6.0
- Arable soil pH optimum: pH 6.5.

Cross-media effects

Accurate NMP is not associated with significant cross-media effects. When implemented successfully, it maximises farm output for a given level of fertiliser input and all the environmental burdens associated with that fertiliser input.

Testing soil fertility is not associated with significant cross-media effects and when implemented, it allows for precise nutrient management planning. However, according to IPCC (2006) each tonne of

lime applied results in the emission of approximately 500 kg CO₂e. These emissions need to be balanced against the nutrient availability (yield response) benefits of maintaining higher soil pH over time: i.e. the application of lime every e.g. five years needs to be balanced against crop-yield benefits or reduced nutrient application benefits over those five years.

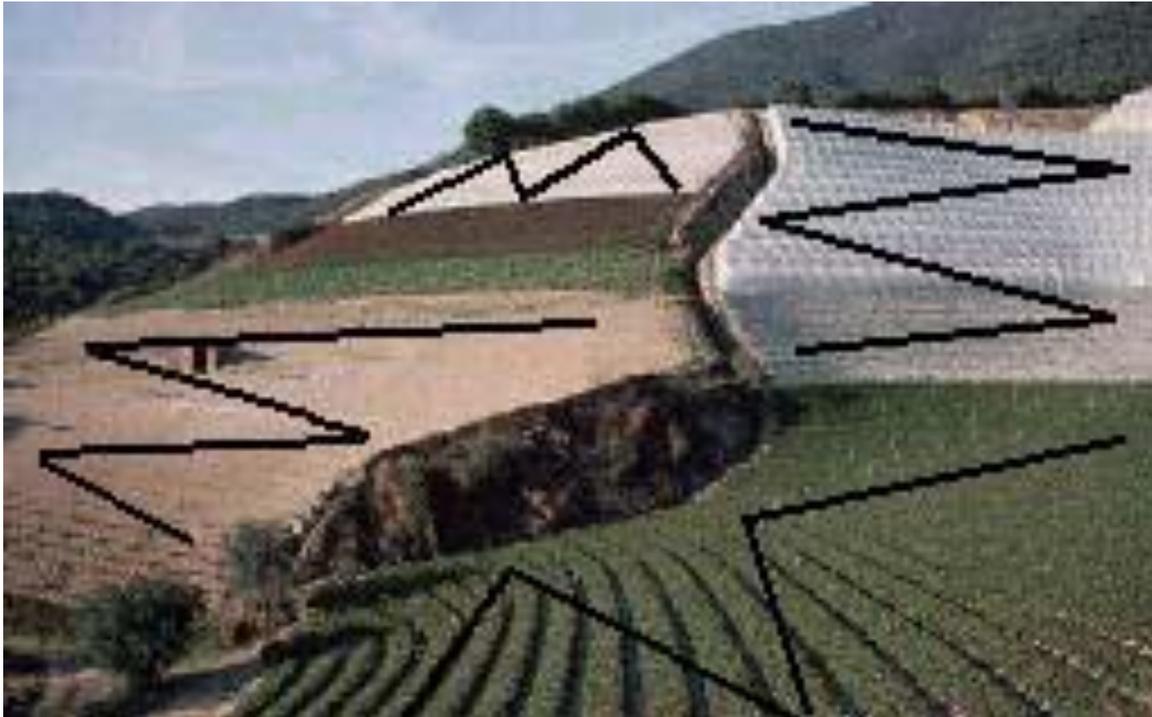
Operational data

Testing for soil fertility

Routine management of soil nutrient status is an important component of good crop / plant production management. It allows fertiliser and manures to be targeted as required—ensuring economic efficiency and reducing the risk of environmental impact. Stepwise instructions are provided below based on NRM Laboratories²⁹ (2014):

- Carry out soil testing of fields, in rotation, every four years (six years for permanent pasture).
- Routine analyses include pH, available phosphorus (P), potassium (K) and magnesium (Mg).
- The best time to sample is November – February; avoid sampling for up to 6 months after applications of fertiliser, manure or lime.
- You will need a soil auger, plastic bucket and clean bags/boxes to send soils off to the lab (a spade can be substituted for an auger but it takes much longer and needlessly large quantities of soil are collected).
- For arable and cultivated soils sample to a depth of 0-15 cm (0-6”) which is related to cultivation depth. For permanent grassland, sample to a depth of 0-7.5 cm (0-3”) which is related to the rate of soil formation and animal hoof penetration.
- Sample each field in a W pattern consisting of 20 – 25 cores (Figure 5.12); avoid unusual patches such as gateways, headlands and near trees. Mix the soil cores in the bucket very thoroughly, and then take out a representative sample for sending away for analysis. The accuracy of your results will only be as good as the thoroughness of mixing. More details about this technique can be found later on the rising plate description (Figure 5.15).

²⁹ There are several labs that offer soil analytical services along with fertiliser recommendations, if requested. Results for P, K and Mg are usually given as indices and most farmers know what indices their crops require. Detailed information about this can be found in DEFRA (2010) and there are very easy-to-use online fertiliser calculators e.g. www.fertiliser-recommendations.co.uk/



Source: Reproduced from NRM Laboratories, 2014: www.nrm.uk.com/

Figure 5.12. Field in a W pattern consisting of 20 – 25 cores; unusual patches such as gateways, headlands and near trees are also illustrated

Accounting for nutrient content of manures

The nutrient content of manures tend to be variable (even within a farm and specific type of manure) and whilst using published tables of standard values can provide an approximation to content, best practice is to send manure samples away for laboratory analysis. This should be repeated every three years if no system changes are made before then.

Tools to assist NMP

Various “rules of thumb” can be used to assist NMP. In Italy, manure N efficiency in derogation farms (where max permissible manure N application is 250 kg/ha/year) must be at least 0.66 for slurry and 0.50 for FYM (Mantovi, 2010). This means that a farmer calculates the N requirement of his crop and then applies 1.5 times as much slurry N as the crop requires or 2.0 times as much FYM, these values reflecting the %N that is plant-available in the first year of fertilisation. Mineral fertiliser N efficiency is set at 1. However, various tools are available to enable more precise NMP.

In the UK, the PLANET fertiliser recommendation software input/output model (ADAS, 2013), can be used to produce balances and NUE, allowing farm standards or benchmarks to be produced. Commercial farms are then scored at 25%, 20%, 15% or 10% above or below the benchmark value for a specific farm system. Benchmarks are expressed as kg nutrient/ha or per livestock unit.

The MINAS (Mineral Accounting System) balance approach was used in the Netherlands as a regulatory tool up to 2006 (e.g. Oenema et al., 2012) before being replaced with a limitation on fertiliser application rate. Many experts regard nutrient balance or NUE as best practice although it is generally considered by regulatory bodies as too complex to administer as an instrument. EU agricultural best practice projects e.g. Cows & Opportunites, DairyMan, GreenDairy use such indicators in their commercial farm regimes.

The MANNER-NPK tool, developed by ADAS in the UK, provides estimates of NH₃ and NO₃ losses, and calculates the amount of applied organic-N that remains available to plants, according to application method and timing and organic composition (e.g. slurry type, or specified chemical

composition). This model may be used not only to more accurately estimate NH₃ and NO₃ losses from organic N applications, but to calculate the reduction in mineral-N fertiliser achievable through accurate accounting of organic nutrient inputs.

Typical nutrient application rates in organic amendments are listed in Table 5.11.

Table 5.11. Nutrient provision from commonly applied organic amendments and application rates (based on data from DEFRA, 2010)

Manure type	Total N	Total P ₂ O ₅	Total K ₂ O
	kg		
Cattle slurry at 30 m ³ /ha	78	36	96
Pig FYM at 35 t/ha	245	210	280
Green waste compost at 30 t/ha	225	210	165
Layer manure at 12 t/ha	228	168	114

Berry et al. (2010) has estimated that there is scope to reduce GHG emissions associated with the English agriculture GHG inventory by almost 4% by using N fertiliser more efficiently. This would represent more than one third of the targeted reduction. Table 5.12 shows possible reduction in GHG as a result of better N fertiliser timing management. Refer to Section 5.5 for practical details on timing of applications.

Table 5.12. Summary of how changes in N fertiliser timing management may reduce GHG emissions for crops grown in England (kt CO₂e per annum) (Adapted from Berry et al., 2010)

Change in N management		Winter wheat	OSR	Winter barley	Spring barley
Changing N timing to reduce N rate or increase yield	Potential	-	47 (0.16)	47 (0.16)	-
	Realistic	-	24 (0.08)	35 (0.12)	-
Avoid autumn N	Potential	-	33 (0.11)	-	-
	Realistic	-	16 (0.06)	-	-
Reduce N ₂ O by altering N timing	Potential	165 (0.55)	4 (0.01)	7 (0.02)	11 (0.04)
	Realistic	124 (0.42)	3 (0.01)	5 (0.02)	8 (0.03)

Calculations include only N₂O emissions and direct fuel use, for comparison with GHG inventory figures (total agricultural emissions in 2007 of 29.6 Mt CO₂e in England and 47.9 Mt CO₂e in the UK). Figures in parentheses are % reduction from the English Agriculture GHG inventory (GHG savings from fertiliser manufacture not included in data, as per GHG inventory accounting for agriculture).

The nutrient uptake of the crop is estimated according to field experiments and approved recommendations, which take account of crop variety, expected yield and nutrient supplies, as well as local soil and weather conditions. A crop's nutrient uptake can be calculated by multiplying its yield by its nutrient content per tonne (Table 5.13)

Table 5.13. Nutrient requirements of crops vary considerably and nutrient supply has to be carefully adapted to the needs of the plant. Average nutrient content in kg/t DM harvested (EFMA, no date).

	% dry matter	N nitrogen	P ₂ O ₅ phosphate	K ₂ O potash	MgO magnesium	CaO calcium	SO ₃ sulfate
Wheat							
<i>grain</i>	86	20	8.5	6	2	1	5.5
<i>straw</i>	86	5	3	17.5	2	4.5	4.2
Maize							
<i>grain</i>	86	14	8.5	5	2.5	2.5	-
<i>straw</i>	86	7	6	20	3	6	-
Oilseed Rape							

	% dry matter	N nitrogen	P ₂ O ₅ phosphate	K ₂ O potash	MgO magnesium	CaO calcium	SO ₃ sulfate
<i>grain</i>	91	33	18	10	5	-	8.7
<i>straw</i>	86	7	3	25	2.5	-	3.0
Sugar beet							
<i>beet</i>	23	1.7	9.5	2.5	0.8	4	8.0
<i>leaf</i>	16	2.9	9.5	5.5	0.8	1.2	8.0
Potato							
<i>tuber</i>	22	3.5	1.4	6	0.6	0.3	0.5
<i>leaf</i>	25	4	1.5	6	2	-	1.0

Crops also vary in their efficiency of uptake of nutrients (Figure 5.13 and Table 5.14).

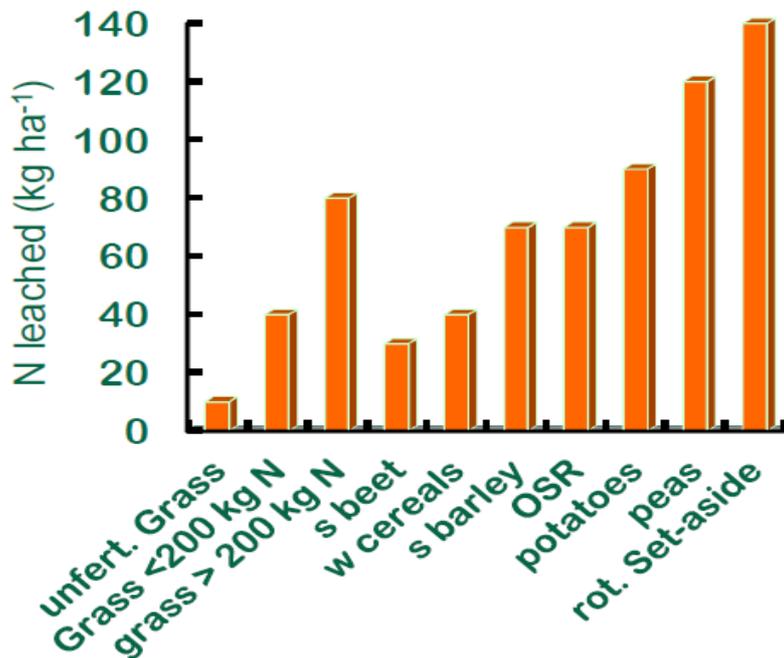


Figure 5.13. Crop inefficiency in utilising N applied at economic optimum (Withers, 2014).

Table 5.14. Typical NUE and N-surplus of specialised cropping systems (UNECE, 2014).

Farm system	Crop	NUE kg/kg	N surplus kg/ha/y	Comment
Specialised cropping systems	Arable crops	0.6-0.9	0-50	Cereals have high, root crops low NUE
	vegetables	0.4-0.8	50-100	Leafy veg have low NUE
	Fruits	0.6-0.9	0-50	

Crop residue N returned to soil can also be estimated. For every tonne dry matter crop residue remaining above ground, the N return can be calculated from the above: below ground biomass ratio and the respective N-contents of each fraction, using IPCC (2006) in Table 5.15.

Table 5.15. Data for estimation of N added to soils from crop residues

Crop	N-content of above-ground residues, kg N/kg DM	Ratio of below-ground to above-ground biomass	N content of below-ground residues, kg N/kg DM
Grains	0.006	0.22	0.009
Beans and pulses	0.008	0.19	0.008
Potato	0.019	0.20	0.014

Crop	N-content of above-ground residues, kg N/kg DM	Ratio of below-ground to above-ground biomass	N content of below-ground residues, kg N/kg DM
N-fixing forages	0.027	0.40	0.022
Non N-fixing forages	0.015	0.54	0.012
Perennial grasses	0.015	0.80	0.012
Grass-clover ley	0.025	0.80	0.016

Example calculation: four tonne DM wheat stubble, from a 12 tonne DM total crop biomass yield, being ploughed in to one hectare of soil will contain:

$(4000 \times 0.006) + (12\ 000 \times 0.22 \times 0.009) = 24 + 23.76 = 47.76 \text{ kg N/ha}$

Case study: Morley Farms, Norfolk UK – taking account of nutrients applied in organic amendments. Soils are tested every three years on this arable cropping farm in Norfolk, UK, and lower P and K index soils targeted for manure application with manures imported from neighbouring livestock farms. Turkey manure is typically applied prior to oil seed rape establishment, and cattle and pig manure prior to sugar beet. Phosphorus and K supplements are applied for sugar beet, but not during remainder of the three year rotation. The farm manager follows RB209 (DEFRA, 2010) guidelines using his own spreadsheets to calculate manure and fertiliser application rates (note that this farmer replicates calculations undertaken by the freely-available online PLANET and MANNER-NPK tools: ADAS, 2013). Turkey manure is periodically tested by the supplier, and has a relatively stable composition. Manure storage is important because the turkey farm produces a continuous supply, whilst demand on Morley Farms is concentrated in spring and autumn. Some manure is stored in piles on fields, subject to leaching and volatilisation losses, and some stored on the turkey farm over summer (subject to volatilisation losses). Avoiding emissions associated with storage is a challenge, and it can be difficult for turkey and pig farms in this NVZ area to dispose of their manures over winter (anaerobic digestion is one possible solution: see Section 9.2).

KNS – Kultururbegleitende N_{min} Sollwert System

The KNS tool was developed in Germany aiming to provide support to the farmers regarding the split application of nitrogen fertiliser. According to the N-expert system, in order to meet the optimum N supply level, soil N_{min} residue in root depth, N released from soil organic matter, crop residue, organic manure through mineralisation should be considered before the calculation of chemical N fertiliser requirement. The equation (1) describes the function of the KNS tool (Leibig et al., 2013):

$$N_{fert_rate} = \frac{(N_{uptake_target} + N_{min_buffer} + N_{loss_necessary}) - (N_{min_res_root\ zone} + N_{mineral_organic\ matter} + N_{mineral_crop\ residues})}{1}$$

- N_{fert_rate} = N fertilization rate
- N_{uptake_target} = Target N uptake
- N_{min_buffer} = N_{min} buffer
- $N_{loss_necessary}$ = necessary N loss
- $N_{min_res_root\ zone}$ = N_{min} residues in root zone
- $N_{mineral_organic\ matter}$ = N mineralization from soil organic matter
- $N_{mineral_crop\ residues}$ = N mineralization from crop residues

The KNS tool is based on target values for nitrogen and the N-content in the soil, according to the root depth. The main elements of this tool are listed below (De Nies, 2014):

- Soil samples at planting
- Long growing period; after 5-8 weeks additional samples
- Avoiding unpredicted climate conditions i.e. rain
- Incorporate mineralisation by measuring more frequently i.e. soil mineralisation, crop residues, green manure

- Preventing leaching out

The KNS tool was developed in 80's in Germany and was further developed, digitalised and renamed as N-expert system. This tool uses appropriate N-uptake curves for all relevant crops allowing calculating the expected N-uptake between the current stage of the crop and the harvest time. Therefore soil sampling during the growing period allow correcting the mineral nitrogen level in the soil. Additionally, the occurred mineralisation during the growing period is possible to be monitored before sampling (van de Sande et al, 2013).

The KNS tool considers root zone mineral N at planting and also during the crop. Soil mineral N is determined twice (minimum) for each crop. According to this tool, there is a buffer value for root zone soil mineral N below which production is N limited. In particular, the buffer zone, which is expressed as kg N/ha is added to the anticipated N uptake for a given period in order to calculate the N_{min} target value for that period. Therefore that value, N_{min} target value, is the amount of mineral N that should be available to the crop and in parallel will guarantee the optimal production for the same examined period. Moreover the amount of N applied as mineral fertiliser is the difference between N_{min} target value for the examined period and the amount of mineral N fertiliser in the root zone. In case where measured soil mineral N is greater than the N_{min} target value then no N fertiliser is further needed (Thompson et al., 2013).

Flemish research centres applied the KNS tool principles in different crops in order to provide advice to farmers. According to van de Sande et al., (2013) in almost all of the examined cases farmers were giving higher amounts of organic fertiliser. In particular, the share of the applied organic fertiliser was 1/3 pig slurry, 1/3 did not apply any organic manure and the rest 1/3 applied soil manure or compost. On the other hand, the research centres did not apply any organic fertiliser in half of the cases, while in the rest half compost was applied. Figure 5.14 illustrates a cumulative distribution of all measured (layer between 0 cm and 90 cm) residual nitrate contents in both fields fertilized by the farmer and fields fertilized following advice (van de Sande et al., 2013).

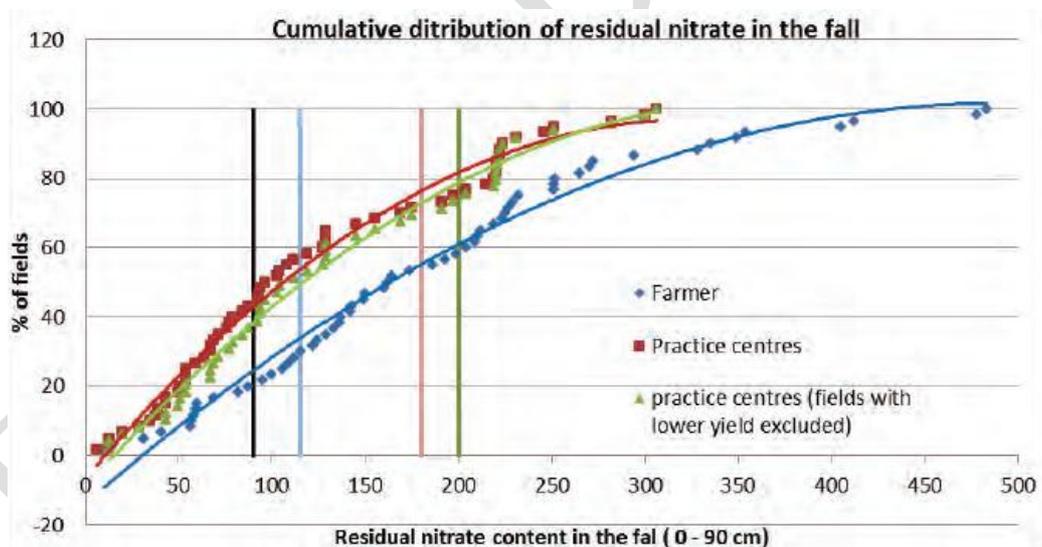


Figure 5.14. A cumulative distribution of all measured (layer between 0 cm and 90 cm) residual nitrate contents in both fields fertilized by the farmer and fields fertilized following advice (van de Sande et al., 2013).

Figure 5.14 demonstrates the different fertilisation approach between the farmers and the advice coming from the Flemish research centres. Analysing the results, only 24% of the fields fertilized according to farmer's principles and experience attained successfully the legally obliged maximum residual NO₃-content in the 0- 90 cm soil layer. On the other hand, the percentage of the fields that are fertilized by the KNS tool principles was 43% instead. Additionally it should be mentioned that a significant number of fields has very high residual NO₃--nitrate contents exceeding the amount of 300

kg NO₃-N/ha where most of those fields received high amount of organic fertilizers (van de Sande et al., 2013).

Micronutrient limitations

Good NMP includes periodic testing for soil micronutrients that can be deficient and reduce crop yields and quality (and thus reduce farm efficiency). A few major micro-nutrient considerations are listed in Table 5.16. Copper, cobalt and selenium deficiency is not usually noticeable in pasture but can affect grazing animals which are best treated directly with a corrective bolus.

Table 5.16. Some risk factors for micro-nutrient deficiency in field crops (DEFRA, 2010)

Micro nutrient	Risk factors
Boron	Die-back, heart rot affects brassicas, sugar beet, carrot.
Copper	Leaf yellowing and distortion in cereals.
Iron	Yellowing leaf tips and green veins in fruit trees
Manganese	Pale green and limp foliage in cereal. Interveinal mottling and leaf curl in sugar beet.
Molybdenum	Whiptail in cauliflower
Zinc	Rarely deficient in field crops

Soil Nitrogen Supply

DEFRA (2010) fertiliser manual states that: “The Soil Nitrogen Supply (SNS) is the amount of nitrogen (kg N/ha) in the soil (apart from that applied for the crop in manufactured fertilisers and manures) that is available for uptake by the crop throughout its entire life, taking account of nitrogen losses.”

Soil N Supply = Soil Mineral N (NO₃- + NH₄-N) + estimate of N already in the crop + estimate of mineralizable soil N

Soil N supply in any given field/year is dependent on factors including soil type, weather (climate dependent) and the previous crop. Some estimated SNS values under different conditions, and a classification index, are provided in UK fertiliser guidelines (DEFRA, 2010) and recreated in Table 5.17 and Table 5.18. It is apparent that SNS can provide a large share of crop N requirements although the supply may be rate limited during peak growth times (see Section 5.3 regarding fertiliser application timing).

For grass, UK fertiliser recommendations classify SNS into high, medium or low, with high and low classifications requiring 30 kg N/ha/y lower or higher, respectively, N additions relative to optimum quantities reported for medium SNS soils.

Table 5.17. Soil Nitrogen Supply indices for low rainfall areas (500-600 mm annual rainfall, up to 150 mm excess winter rainfall) based on the last crop grown (DEFRA, 2010)

SNS Index	0	1	2	3	4	5	6
SNS (kg/ha/yr.)	<60	61-80	81-100	101-120	121-160	161-240	>240
Soil type							
Light sands or shallow soils over sandstone	Cereals, Low N vegetables, Forage crops (cut)	Sugar beet, Oilseed rape, Potatoes, Peas, Beans, Medium N vegetables,	High N vegetables				

SNS Index	0	1	2	3	4	5	6
SNS (kg/ha/yr.)	<60	61-80	81-100	101-120	121-160	161-240	>240
		Uncropped land					
Medium soils or shallow soils not over sandstone		Cereals, Sugar beet, Low N vegetables, Forage crops (cut)	Oilseed rape, Potatoes, Peas, Beans, Uncropped land	Medium N vegetables	High N Vegetables		
Deep clayey soils			Cereals, Sugar beet, Low N vegetables, Forage crops (cut)	Oilseed rape, Potatoes, Peas, Beans, Medium N vegetables, Uncropped land	High N Vegetables		
Deep silty soils			Cereals, Sugar beet, Low N vegetables, Forage crops (cut)	Oilseed rape, Potatoes, Peas, Beans, Medium N vegetables, Uncropped land	High N Vegetables		

Table 5.18. Soil Nitrogen Supply indices for high rainfall areas (over 700 mm annual rainfall, or over 250 mm excess winter rainfall) based on the last crop grown (DEFRA, 2010)

SNS Index	0	1	2	3	4	5	6
SNS (kg/ha/yr.)	<60	61-80	81-100	101-120	121-160	161-240	>240
Soil type							
Light sands or shallow soils over sandstone	Cereals, Oilseed rape, Potatoes, Sugar beet, Peas, Beans, Low/medium vegetables, Forage crops (cut), Uncropped land	High N vegetables					
Medium soils or shallow soils not over sandstone		Cereals, Oilseed rape, Potatoes, Peas, Beans, Sugar beet, Low and medium N vegetables, Forage crops (cut),	High N vegetables				

SNS Index	0	1	2	3	4	5	6
SNS (kg/ha/yr.)	<60	61-80	81-100	101-120	121-160	161-240	>240
		Uncropped land					
Deep clayey soils		Cereals, Sugar beet, Oilseed rape, Potatoes, Low and medium N vegetables, Forage crops (cut), Uncropped land	Peas, Beans, High N vegetables				
Deep silty soils		Cereals, Sugar beet, Low N vegetables, Forage crops (cut)	Medium N vegetables, Oilseed rape, Potatoes, Peas, Beans, Uncropped land	High N vegetables			

Rising plate

Michell and Large (2006) (who performed a comparative evaluation of a rising-plate meter and a single-probe capacitance meter calibrated at and above ground level), concluded that the herbage mass below 18 mm is greater on summer period than spring swards when compared with a ground level cut.

As it was previously mentioned (Description section) the pasture condition plays a key role in the forage production. In particular, Shewmaker et al., (2010) developed a suitable matrix that can be used by farmers where they can score the pasture condition taking into account parameters like natural rainfall or irrigated pastures. It can be easily used by farmers in order to rate pastures 10 to 15 days after grazing at about the same time each year (Table 5.19).

Table 5.19. Pasture condition and trend score sheet (Shewmaker et al., 2010)

Category	Criteria	Score	Field identification	Pasture condition scores:
Plant population	Desirable	4		1-8: very poor 9-16: poor 25-32: good 33-40: very good
	Intermediate	2		
	Undesirable	0		
Plant diversity	Broad: > 7-9 species	4		
	Medium: 4-6 species	2		
	Narrow: < 3 species	0		
Plant density	Dense: > 90%	4		
	Medium: 60-70%	2		
	Sparse: < 40%	0		
Plant vigor	Strong	4		
	Medium	2		
	Weak	0		
Legumes in	40-60%	4		

Category	Criteria	Score	Field identification	Pasture condition scores:
stand	20-30% or > 70%	2		
	< 10% or > 90%	0		
Severity of use	Uniform	4		
	Appropriate	2		
	Light	0		
Uniformity of use	Uniform	4		
	Intermediate	2		
	Spotty	0		
Soil resources	< 5%	4		
	10-15%	2		
	> 25%	0		
Undesirable canopy	< 10%	4		
	20%	2		
	> 30%	0		
Plant residue	Excessive	4		
	Appropriate	2		
	Deficient	0		
Total score				

The rising plate meter method relies on both plant height and density, which are eventually combined into one measurement referred to as bulk density. In order to estimate yield it is necessary to follow a specific procedure (similar to pasture ruler). Initially the sample counter should be set to zero and then the user has to follow a 'W' pattern in the pasture to estimate the average plate meter (Figure 5.15). At every 25 footsteps the user (farmer) pushes the pasture meter vertically into the sward in order to take a measure. Each measurement has to be taken under the same pace for consistency reasons. Finally the final plate number should be recorded and then the average plate meter is calculated by subtracting the initial value from the final value and then dividing by the number on the sample counter (number of the sward sampling). This average plate meter is correlated with forage bulk density and then converted to yield using a calibration equation (Hall, 2007; Shewmaker et al., 2010).

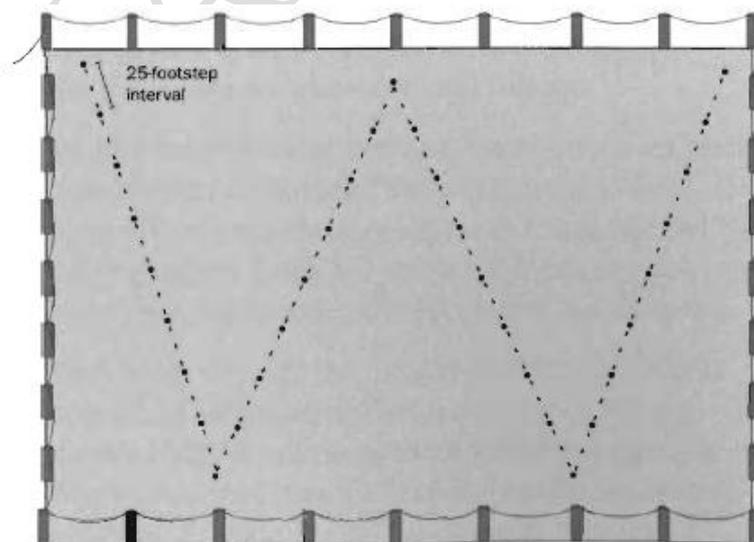


Figure 5.15. A 'W' pattern for sampling pastures (Shewmaker et al., 2010)

Nakagami and Itano (2013) developed a new calibration method that combines usability and accuracy for estimating herbage mass from rising-plate meter readings. The developed methods differ in the

way their parameters are related to sampling date (seasonal variations) and compared their estimation accuracies using cross-validation. In particular, farmers can apply this method, which provides more accurate and reliable results.

Applicability

NMP is a key BEMP for all farms.

Economics

Fertiliser and lime prices have increased considerably over the past decade. For example, one tonne of CAN fertiliser has increased from approximately EUR 150 to EUR 350 over the past ten years. In Spring 2013, one tonne of 20:10:10 N:P:K compound fertiliser costs EUR 353/t, similar to CAN.

The MANNER-NPK tool (ADAS, 2013) provides estimates of economic savings arising from the net fertiliser replacement value of applied organic amendments, based on nutrient availability in relation to method and timing of application, type of organic amendment, soil type, crop cover, and weather conditions, etc. Default fertiliser costs used in MANNER-NPK are (converted into EUR at 0.85 EUR/GBP):

- EUR 1.06 per kg N
- EUR 0.94 per kg P₂O₅
- EUR 0.71 per kg K₂O

Some EU agricultural support payments that encourage efficient NMP include the agri environmental scheme higher stewardship level payment and CAP Pillar 2 RDP funds.

Using a fertiliser recommendation tool will be a management cost, costed at £2/ha (EUR 2.35/ha) in 2007, but there may be savings in fertiliser, which would produce a net benefit (Cuttle et al., 2007).

According to UNECE (2014) and Bittman et al., (2014), the estimated indicative costs of structuring a N input-output balance ranged from €200 to €500 per farm annually, depending on the installed/existing farming system and on the assistance of accountancy and/or advisory provided services. It should be mentioned that the aforementioned estimations do not include education, promotion and start-up costs. Those costs may vary across EU member states, while those tend to decrease over time because of the already acquired know-how (learning effect). The net cost of improving N management and increasing thus NUE and decreasing N_{surplus} are in the range of -€1 to €1 per kg N. The net costs are the result of gains through fertilizer savings and increased production performance, and gross cost related to sampling and analyses, training and advisory costs (UNECE, 2014).

Similarly, TFRN (2011) demonstrated that the costs of establishing a nitrogen balance are in the same range as UNECE (2014) and Bittman et al., (2014), such as 200-500 € per farm per year. This translates from €1 to €10 per ha per year, depending on farm size and efficiency increase. The costs of establishing a nitrogen budget at national level are in the range of €1,000 to €10,000 per year. The cost of increasing nitrogen use efficiency through improving management are in the range of €-1.0 to €2.0 per kg N saved. The possible savings are related to less cost for fertilizer and increased crop quality. The possible costs are related to increased cost for advisory services and soil, crop and manure analyses. The economic cost of possible investments in techniques are not include here, but discussed with other provisions (TFRN, 2011).

Integrating fertiliser and manure nutrient supply will save money in artificial fertiliser nutrients not applied and upstream emissions from production. Table 5.20 shows the savings associated with

slurry/manure from winter storage, which can be spread evenly, but savings from dung and urine deposited during grazing have not been included (Cuttle et al., 2007).

Table 5.20. Savings associated with slurry/manure from winter storage, which can be spread evenly; savings from dung and urine deposited during grazing have not been considered (Cuttle et al., 2007)

Annual farm system costs	Arable, 60 ha treated	Dairy, 33 ha treated	Beef, 18 ha treated	Broilers	Pigs (indoor)
Savings €/ha	7	14	7	38	27

Case Study: Savings arising from NMP, Rhual Farm, Wales

Where Nutrient Management Planning occurs, significant reductions in bought in fertiliser costs can occur. Targeting manure applications to those fields where P & K indices are lower can lead to improvements in soil fertility and structure and assist towards an additional Soil Management Planning strategy for the farm which can often form part of a Farm Assurance scheme requirement.

An example of good Nutrient Planning was demonstrated at Rhual Farm, where fertiliser usage in 2010 of 124.1 tonnes was reduced to 84.6 tonnes resulting to a reduction of 39.5 tonnes. the related cost savings as compared with the 2010 data are presented below:

$-39.5 * \text{£}310$ (2012 price/tonne 34.5%N) = $\text{£}11,850$ (€13,950).

- Worked Example 1 (Source: WRT, Pinpoint 33):

Soil testing of 10 ha of grass silage land, which is manured each year, showed a phosphate and potash index of over three.

Using existing soil reserves for two cuts of silage saved 75 kg of P/ha and 175 kg K/ha.

Soil testing on 10 ha for P, K and pH on a 4-5 year rotational basis costs $\text{£}75/\text{y}$ (€88/y), provided by the farmer who collects the samples.

This gives fertiliser savings of approximately $\text{£}85/\text{ha}$ (€100/ha), a total saving of $\text{£}850$ (€1,000).

The payback period is less than one year.

- Worked Example 2 (Source: WRT, Pinpoint 33):

As a rule of thumb, aim to supply up to 50-60% of your crop's expected N requirement for optimum yield from organic manure, and only use inorganic fertiliser N to top up crop needs. For example, if winter wheat responds to an optimum rate of 200 kg/ha N, supply half of the crop needs from manure and half from inorganic fertiliser N. This would minimise the potential impacts of variations in manure N supply as crop N requirements will be at the top of the yield response curve. However, the Dutch legislative framework for dairy farms, 250 kg organic N is permitted to be applied whereas the allowed use of fertiliser N is about 120-150 kg in many cases (Schröder et al., 2005).

For best practice, obtain lab analysis of manures.

The effect of application method and timing on the Nitrogen Fertilizer Replacement Value (NFRV) and economic value of cattle slurry applied to grass silage is displayed in Table 5.21 (Schröder et al., 2005; Schröder et al., 2007; Lalor and Schulte, 2008a; Lalor and Schulte, 2008b; Schröder et al., 2010).

Table 5.21. Effect of application method and timing on Nitrogen Fertilizer Replacement Value and the economic value of cattle slurry applied to grass silage (Teagasc, 2008)

Application timing	NFRV %		kg N/m ³ slurry		Value of N (€/m ³ slurry)	
	Splash plate	Trailing Shoe	Splash plate	Trailing Shoe	Splash plate	Trailing shoe
April	29%	39%	1.05	1.40	1.26	1.68
June	10%	21%	0.36	0.75	0.43	0.90

Soil nutrient management benefits

Benefits from soil nutrient management planning (Section 5.1), informed by soil testing, can be realised immediately. The following example was provided by the Westcountry Rivers Trust (no date is mentioned):

Regular testing of soils (and manures) helps to reduce fertiliser costs. In this worked example, soil testing of 10 ha of grass silage land, which is manured each year, showed a phosphate and potash index over three. Using existing soil reserves for two cuts of silage saved 75 kg of P/ha and 175 kg of K/ha. The soil testing of 10 ha for P, K, and pH (on a 4-5 year rotational basis) cost €88/year assuming the farmer who collects the samples. Lower mineral fertiliser costs (P 75 kg/ha x €0.47/kg and K 175 kg/ha x €0.42/kg) saved €109/ha. On 10 ha, the saving was €1,090 a year, resulting in a payback of less than one year.

Additionally, the ammonia emission reduction techniques result in significant savings. In particular, Table 5.22 lists the potential economic benefits expressed in euros per kg NH₃-N saved including benefits related to decreased fertilizer costs, decreased application costs in a combined seeding and fertilizing system and decreased biodiversity loss. However, it should be mentioned that the range of costs are linked to the farm size (economics of scale), local soil conditions and climate (UNECE, 2014).

Table 5.22. Ammonia emission reduction techniques for application of fertilizers and associated costs (UNECE, 2014)

Fertilizer type	Application techniques	Cost (€/kg NH ₃ -N saved)
Urea	Injection	-0.5-1
	Urease inhibitors	-0.5-2
	Incorporation following surface application	-0.5-2
	Surface spreading with irrigation	-0.5-1
Ammonium carbonate	Ban	-1-2
Ammonium based fertilizers	Injection	0-4
	Incorporation following surface application	0-4
	Surface spreading with irrigation	0-4

Driving forces for implementation

- Economic savings of reduced fertiliser inputs.
- Nitrates Directive, Water Framework Directive (especially restrictions on N application rates in NVZs).
- Agri environmental higher level stewardship payments.
- Improved image of the industry and public perception.
- Reduction in N and P movement offsite to receiving waters – improved water quality and reduced potable water treatment costs.
- Reduction in GHG both from improved fertiliser efficiency but also reduced upstream emissions from fertiliser production.
- Reduction in NH₃ emissions so less impact on sensitive oligotrophic habitats from feed production and use.
- Reduced use of finite reserves of minerals e.g. rock P.

Reference literature

- ADAS, 2013. Planet nutrient management planning webpage, accessed August 2013: <http://www.planet4farmers.co.uk/Content.aspx?name=Home>

- Bassanino, M., Sacco, D., Zavattaro, L., and Grignani, C., 2011. "Nutrient Balance as a Sustainability Indicator of Different Agro-environments in Italy", *Ecological Indicators*, Vol. 11, No. 2, pp. 715-723.
- Berry, P.M., Wiltshire, J.J.J., Roques, S., Clarke, S., Thorman, R., Jones, G., Simpson, D., 2010. Scoping the potential to reduce greenhouse gas emissions associated with N fertiliser applied to arable crops. Defra Project No AC0221, 34pp.
- Bittman, S., Dedina, M., Howard C.M., Oenema, O., Sutton, M.A., (eds), 2014, *Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen*, Centre for Ecology and Hydrology, Edinburgh, UK
- CEEP, 2013. Scope Newsletter 93. Publ. European Commission. May 2013 http://www.crugroup.com/content/events/44598/76458/85877/ScopeNewsletter93_-_Phosphates_2013_coverage_May_13.pdf
- CFT, 2012. Cool Farm Tool webpage. Tool downloaded August 2012: <http://www.coolfarmtool.org/>
- Cuttle, S. P. et al., 2007. An Inventory of Methods to Control Diffuse Water Pollution from Agriculture (DWPA). User Manual. Prepared as part of Defra Project ES0203.
- Danish Green Growth, 2009. Agreement on Green Growth. Webpage accessed November 2013: http://www.mst.dk/NR/rdonlyres/56A2C35F-2A22-4AF5-A9DE-5AC1101B5E3D/0/DanishAgreementonGreenGrowth_300909.pdf
- De Nies J. 2014. Nitrogen advice in Flanders, Congres "Chou-fleur": Les enjeux de la production européen, St Pol de leon, France, 10 Decembre.
- DEFRA, 2005. Farm Nutrient Auditing: Support to PLANET (Benchmarking). DEFRA funded project ES0124. Prepared by ADAS, IGER, Rothamsted and FWAG. DEFRA, London.
- DEFRA, 2010. Fertiliser Manual RB209. UK: TSO. Retrievable at <http://www.defra.gov.uk/publications/2011/03/25/fertiliser-manual-rb209/>
- DEFRA, 2013. Nutrient management webpage, accessible at: <http://www.defra.gov.uk/food-farm/land-manage/nutrients/>
- Earle D.F., McGowan A.A.1979. Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry*, 19, 337-343.
- Michell P., Large R.V.1983, The estimation of herbage mass of perennial ryegrass swards: a comparative evaluation of a rising-plate meter and a single-probe capacitance calibrated at and above ground level. *Grass and Forage Science*, 38, 295-299.
- EBLEX, 2013. Silage decisions factsheet: soil pH. Accessed August 2013 from: <http://www.silagedecisions.co.uk/pdfs/Soil%20pH%20factsheet%202.pdf>
- Extension.org, 2013. Soil pH webpage, accessed may 2013: <http://www.extension.org/pages/13064/soil-ph-modification>
- FAO, 2013. Sustainable Agriculture Platform: webpage on nutrient management, accessible at: <http://www.fao.org/tc/exact/sustainable-agriculture-platform-pilot-website/nutrients-and-soil-fertility-management/en/>
- Goulding, K., Jarvis, S., Whitmore, A., 2008. Optimising nutrient management for farm systems. *Phil. Trans. R. Soc. B.* 363, 667-680.
- Hall M. 2007, Determining pasture yield, Publications Distributions Centre, The Pennsylvania State university, code UC197.
- Hamell, M. (DG ENV), 2013. Personal communication 15.03.2013.
- HGCA, 2013. Nutrient management homepage, accessible at: <http://www.hgca.com/content.output/5652/5652/Crop%20Management/Crop%20Management/Nutrient%20management.msp>
- IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Retrieved from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>
- Johnes, P., Moss, B., Phillips, J., 1996. The determination of total nitrogen and total phosphorus concentrations in freshwaters from land use, stock headage and population data: testing of a model for use in conservation and water quality management. *Freshwater Biology* 36: 451-473.

- Klimatmärkning för mät, 2010. Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010. Sweden: Klimatmärkning för mät.
- Kremer, A.M. (Eurostat, European Commission), pers. comm. 2013.
- Lal, R., 2004. Carbon emission from farm operations. *Environment International* 30: 981– 990.
- Lalor, S. and Schulte, R.P.O., 2008a. Nitrogen fertilizer replacement value of cattle slurry applied to grassland. Teagasc, Johnstown Castle, Booklet of 'Slurry and Nutrient Efficiency Display', 1 May 2008.
- Lalor, S.T.J. and Schulte, R.P.O., 2008b. Slurry application using trailing shoe - potential benefits come at a price. *TResearch*, pp. 35-37.
- Liebig H.P., Chen Q., Horlacher D., Li X., Li H., Zhang H., Tang L., Zhang X., Ren Z. 2003. Development of environmental friendly vegetable production systems with reduced pollution in densely populated areas in the North China Plain (1998.10-2002.12). A3 subproject, available online: https://www.uni-hohenheim.de/chinaproject/publ/A3_Report_final/A3_Final_Reports_2003-01-21.pdf, accessed November 2014.
- Mantovi, P., 2010. Nitrate Directive: how to manage nitrogen in intensive dairy farming. EDF Congress 2010 – Dairy Farming under Mediterranean Conditions, Saluzzo (CN), 23 - 25 June 2010.
- Misselbrook, T.H., Gilhespy, S.L., Cardenas, L.M. (Eds.), 2012. Inventory of Ammonia Emissions from UK Agriculture 2011. DEFRA, London.
- Nakagami K., Itano S. 2013, Improving pooled calibration of a rising-plate meter for estimating herbage mass over a season in cool-season grass pasture, *Grass and forage science*, 69(4), 717-723.
- NRM, 2013. Website accessed June 2013: www.nrm.uk.com/
- Nutrient tools across Europe (Dairyman project page): <http://www.interregdairyman.eu/tools/fertilisation/>
- OECD, 2013. OECD Compendium of Agri-environmental Indicators. OECD. ISBN 978-92-64-18621-7.
- Oenema, J, van Ittersum, M., van Keulen, H., 2012. Improving nitrogen management on grassland on commercial pilot dairy farms in the Netherlands. *Agriculture, Ecosystems and Environment* 162, 116-126.
- Schröder J.J., Aarts H.F.M., van Middelkoop J.C., de Haan M.H.A., Schils R.L.M., Velthof G.L., Fraters B., Willems W.J. 2005, Limits to the use of manure and mineral fertilizer in grass and silage maize production in The Netherlands, with special reference to the EU Nitrates Directive, Plant Research International B.V., Wageningen, report 93.
- Schröder J.J., Uenk D., Hilhorst G.J. 2007, Long-term nitrogen fertilizer replacement value of cattle manures applied to cut grassland, *Plant Soil*, 299, 83-99.
- Schröder J.J., Assinck F.B.T., Uenk D., Velthof G.L. 2010, Nitrate leaching from cut grassland as affected by the substitution of slurry with nitrogen mineral fertilizer on two soil types, *Grass and Forage Science*, 65, 49-57.
- Shewmaker G., Gillaspay B. Fransen S., Griggs T., Hooper L. 2010, Estimating forage production, monitoring, and evaluating the grazing system, Moscow, Idaho : University of Idaho Extension, PNW; 614, 161-175.
- Sutton M.A., Bleeker A., Howard C.M., Bekunda M., Grizzetti B., de Vries W., van Grinsven H.J.M., Abrol Y.P., Adhya T.K., Billen G., Davidson E.A, Datta A., Diaz R., Erisman J.W., Liu X.J., Oenema O., Palm C., Raghuram N., Reis S., Scholz R.W., Sims T., Westhoek H. & Zhang F.S., with contributions from Ayyappan S., Bouwman A.F., Bustamante M., Fowler D., Galloway J.N., Gavito M.E., Garnier J., Greenwood S., Hellums D.T., Holland M., Hoysall C., Jaramillo V.J., Klimont Z., Ometto J.P., Pathak H., Ploq Fichelet V., Powlson D., Ramakrishna K., Roy A., Sanders K., Sharma C., Singh B., Singh U., Yan X.Y. & Zhang Y., 2013. Our Nutrient World: The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.

- Sutton, M.A. (Ed.), Clare M. Howard, Jan Willem Erisman, Gilles Billen, Albert Bleeker, Perine Grennfelt, Hans van Grinsven and Bruna Grizzetti (2011). The European Nitrogen Assessment. Cambridge University Press, Cambridge.
- Teagasc, 2009. Slurry application management for optimum fertilizer value. Downloaded May 2013. http://www.teagasc.ie/publications/2008/20081110/rep2008_paper08.asp
- TFRN, 2011. Draft Guidance Document for preventing and abating ammonia emissions from agricultural sources. Informal document no. 20. TFRN. Downloaded May 2013: <http://www.clrtap-tfrn.org/documents>
- Thompson R.B., Padilla F.M., Gallardo M., Peña-Fleitas M. T. 2013. Improved nitrogen management practices for vegetable production, conference proceedings of Nutrihort, Nutrient management innovative techniques, and nutrient legislation in intensive horticulture for an improved water quality, September 16-18, Ghent, Belgium.
- Van de Sande T., Callens D., Coopman F., De Nies J., De Rooster L., De Reyck L., Verhaeghe M. 2013. KNS – Based advisory system proves to be a useful tool in reducing residual nitrate content of horticultural soils in the fall, conference proceedings of Nutrihort, Nutrient management innovative techniques, and nutrient legislation in intensive horticulture for an improved water quality, September 16-18, Ghent, Belgium.
- Verloop K. 2015, personal communication, Wageningen university.
- Westcountry Rivers Trust, 2009. Best practice information sheet Pinpoint no.33. Nutrient budgeting. Publ. Association of Rivers Trust, England.
- Withers, P., (Professor in soil science, Bangor University), personal communication April 2013.
- UNECE 2014. Guidance document on preventing and abating ammonia emissions from agricultural sources, Economic Commission for Europe Executive Body for the Convention on Long-range Transboundary Air Pollution, Economic and Social Council, United Nations ECE/EB.AIR/120, Distr.: General 7 February 2014.

5.2 Crop rotation for efficient nutrient cycles

Description

Within this BEMP, the following measures are discussed:

- Optimise N cycling by incorporating legumes into crop rotation

Crop rotation is the succession of humus-increasing and humus-demanding crops on a field throughout a cycle of several years, whilst taking account of regulatory and edaphic constraints. Crop rotation affords a great number of benefits. Legumes, which are deep rooting, N-fixing, humus - and soil fertility - building crops, are grown in combination with a balanced proportion of N- and humus-demanding crops such as cereals and root crops (BIOIntelligence, 2010; Stein-Bachinger et al., 2013). On top of that, legumes are less susceptible to different diseases (pests) reducing significantly the amount of pesticides required and applied.

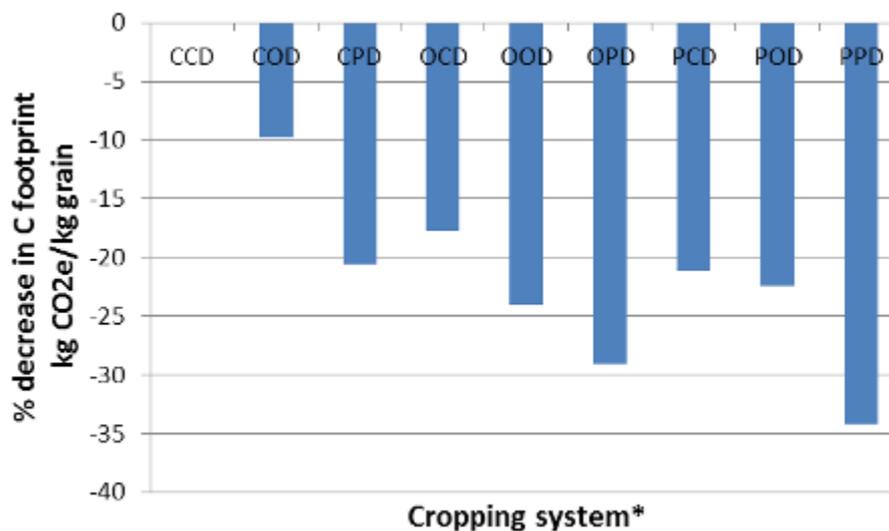


Figure 5.16. Reduction in C footprint achieved through use of crop rotation compared with a cereal-cereal-durum wheat baseline, where C is cereal, P is pulse, D is durum wheat, O is oilseed, averaged over three cycles (Gan et al., 2011).

Including biological N-fixers in a cereal cropping system with durum wheat lowered the carbon footprint of durum wheat by as much as 34% over monoculture wheat systems (Figure 5.16; Gan et al., 2011). The resultant reduction of N fertilization in the diversified cropping systems due to the use of biological N fixation contributed greatly to the lowered carbon footprint of durum grain.

- N offtake is the estimated quantity of nitrogen taken from soil reserves by the harvested crop.
- N transfer is the quantity of N left by the harvested crop which is available to the subsequent crop based on N residues in the soil after harvest, N mineralisation from crop residues and N losses by leaching and denitrification.
- Crop N need is calculated from N offtake of the planned crop minus N transfer from the previous crop, to give net N input needed from manure or fertiliser; ideally, high transfer crops are followed by high offtake crops.

A successful management of N supply through legume cultivation must:

- Optimise N-input via biological N fixation and

- Maximise N-transfer to subsequent crops with minimum N leaching losses.

A highly efficient recycling of N can be achieved by feeding home-grown grain legume to livestock then returning manure to fields where nutrients are most needed for the next crop.

To make the most from biological N-fixation, a cropping rotation should contain at least 30% legumes (BEMP 11.1). Legumes may be grown as a grass-clover ley, as a main crop e.g. grain or forage legume, or as a catch crop like field mustard (Table 5.23).

Table 5.23. Proportion (%) of legumes in rotations for differing farm types (Stein-Bachinger et al. 2013)

Farm type	Legumes	Cereals	Root crops	Catch crops
Dairy farm	30-50 ¹	30-50	5-15	20-50
Mixed farm (mainly ruminants)	30-40 ²	40-60	10-20	20-50
Mixed farm (pigs)	30-35 ³	40-60	15-25	40-60

NB: ¹) mainly forage legumes, ²) forage and grain legumes, ³) forage or grain legumes, for green manure, sale, clover seed production.

Appropriate crop rotation schemes are also applied for the energy crops (such as maize, cereals, sunflowers, grass etc.). The biomass from the energy crops can be treated in anaerobic digestion plants in order to produce biogas, which eventually can be used as a fuel or as an alternative to fuel. The key factors for a maximum biogas yield are the species used, time of harvesting and the nutrient composition of the treated biomass (or one step back the cultivated energy crop). This amount of biomass can be used in anaerobic digestion plants (BEMP 9.2) for ensuring the operational stability of the plant. When farmers cultivate energy crops they should take into account that in the initial crop rotation crops are used mainly for food production rather than energy generation. Also the cropping distributions should correspond to the region where the crops are cultivated. In the energy-based crop rotation system all crops must be designed properly for the biogas or ethanol generation. The following bullets show a balanced crop rotation scheme for energy crops over the years (Bauer et al., 2010):

- 1st year: Lucerne → utilisation: green manure
- 2nd year: Potato → utilisation: industry
- 3rd year: Summer barley → utilisation: food
- 4th year: Maize → utilisation: food
- 5th year: Sunflower → utilisation: food
- 6th year: Winter wheat → utilisation: food

Achieved environmental benefit

Legumes provide important benefits via:

- fixing atmospheric N which is readily available to the next crop
- providing high-protein fodder,
- mobilising P via symbiosis with mycorrhizae,
- reducing the intensity of tillage operations via extensive rooting systems.
- indirectly reducing N₂O by avoided use of manufactured fertilisers
- reducing pesticide use through improved plant health.

Appropriate environmental performance indicators

Management indicators

- Integrate legumes and break crops into rotation for N and C cycling
- Optimise crop rotation for nutrient and organic input (BEMPs 4.2, 5.2, 6.4)

Appropriate environmental indicators

- Number of break crops (ley, legume, oilseed in a rotation)
- Length of rotation /per years
- Home-grown forage and fodder utilised (%)
- Soil organic C (or %LOI) and total N, mineralisable N.
- Avoided fertiliser application (kg/ha)
- Field N balance (Table 5.24)
- 30-40% of clover on permanent grassland

Table 5.24. How field N balances (kg N/ha/year) are influenced by differing production scenarios (Stein-Bachinger et al., 2013)

Legume	With animals		Without animals	
	Red clover	Pea	Red clover	Pea
Kind of utilisation	fodder	grain fed	set-aside	grain sold
N-fix total plant	220	90	180	90
N in harvested products	-340	-140	0	-140
N-return with manure ¹	170	70	0	0
Gaseous N-losses from mulching	0	0	-35	0
N-balance	+ 50	+ 20	+ 145	-50

¹ estimated N-losses through animal refinement, storage and application: 50%
 N.B.1 Selling legume seed results in a loss of N from the system.
 N.B. 2 Forage legumes supply N to two or three subsequent crops whilst grain legume supply N for only 1 following crop.

Operational data

In order to calculate the percentage (%) legume in a rotation (Table 5.25), it is first necessary to estimate the (%) legume in the rotation (Table 5.26).

Table 5.25. How to calculate the percentage legume composition of differing crops over a six year rotation (Stein-Bachinger et al., 2013)

Crop mixture	% of the crop in the 6 years rotation	Legumes in the mixture (%)	Legumes in the rotation (%)
2 years clover-grass	33	30	10
2 years clover-grass	33	60	20
2 years clover-grass	33	80	25
1 year pea/oat intercropping	17	50	8
1 year grain legumes	17	100	17

Table 5.26. Estimating nutrients harvested and N fixed in grain and forage legumes (Stein-Bachinger et al., 2013)

Crop	Mean nutrient harvested, kg/ha			
	N	P	K	
Grain legume @ 1t/ha, 86% DM	35	4	8	
Forage legume @ 1 t/ha clover-grass, 100% DM	25-30	3.5	2.5	
Crop	N-fixation ready- reckoner			
Grain legume	kg N fixed = kg N grain harvested			
Forage legume	35 kg N fixed = 1 t (DM) legume yield			
Grassland	30 kg N = 1 t (DM) legume yield			
Forage catch crop	35 kg N fixed = 15 t fresh yield (German standard)			
Gross yield clover-grass ley (t DM/ha and year)	Fixed N kg/ha and year with a legume yield content of:			
	20%	50%	80%	
4	28	70	112	
8	56	140	224	
10	70	175	280	
Gross yield clover-grass grassland (t DM/ha and year)	Fixed N kg/ha and year with a legume yield content of:			
	10%	20%	30%	40%
4	12	24	36	48
8	24	48	72	96
10	30	60	90	120

There are also ready accountants for estimating the N-fixation capacity of a grass-legume ley or permanent pasture by visually assessing the percentage legume: e.g. DEFRA (2010) images and the ERA software tool (Legume Estimation Trainer www.beras.eu).

Once the proportion of legume in the forage is known and yield, it is possible to estimate the N-budget of a field using Table 5.20 or specialised calculators (e.g. ERA N Budget Calculator software tool www.beras.eu). The interpretation of N budget values is summarised in Table 5.27.

Table 5.27. Interpreting field N-budget (Stein-Bachinger et al., 2013)

N-budget (kg N/ha)	Interpretation
-10 and lower	N-output exceeds the input. N is used from soil reserves and no N is contributed to the system. This management is not sustainable, lead to a depletion of soil N and can result in lower yields in the future.
-10 to +10	Additional N-output equals the input. N fixed by the legumes is removed through the harvest and hardly any N remains in the system
+10 and higher	Additional N-input exceeds the output and lead to a net gain of N to the system which can be used by subsequent crops.

Applicability

Biological N fixation through legume crops is applicable to all farming systems apart from peaty soils that have a low pH value. It is fundamental to organic systems or low-fertiliser input farms and is also highly important to arable land where there is a shortage of organic nutrient supply.

Economics

The FRV of biologically fixed N – currently synthetic N fertiliser is approximately 1 €/kg. In the case of adding clover to grassland, nitrate (plus ammonium and nitrite) leaching losses would be reduced by up to 20% and an associated reduction in direct (up to 50%) and indirect (up to 20%) N₂O emissions and NH₃ emissions (c.50%) (Newell-Price et al., 2011).

Driving forces for implementation

- Nitrates Directive
- Water Framework Directive
- Organic certification
- Fertiliser prices

Reference literature

- Bauer A., Leonhartsberger C., Bosch P. Amon B., Friedl A., Amon T. (2010). Analysis of methane yields from energy crops and agricultural byproducts and estimation of energy potential from sustainable crop rotation systems in EU-27. *Clean Techn. Environ. Policy* 12, 153-161.
- BIOIntelligence (2010). Environmental impacts of different crop rotations in the European Union, European Commission (DG ENV), contract: No 07.0307/2009/SI2.541589/ETU/B1.
- Gan, Y., Liang, C., Wang, X., McConkey, B. (2011). Lowering carbon footprint of durum wheat by diversifying cropping systems. *Field Crops Research* 122, 199–206.
- Newell Price J.P, Harris D, Chadwick D.R, Misselbrook T.H, Taylor M, Williams J.R, Anthony S.G, Duethmann D, Gooday R.D, Lord E.I and Chambers B.J (2011). *Mitigation methods – user guide. An inventory of mitigation methods and guide to their effects on diffuse water pollution, greenhouse gas emissions and ammonia emissions from agriculture*. Prepared as part of Defra Project WQ0106, 158 pp.
- Stein-Bachinger, K., Reckling, M. & Granstedt, A., 2013. *Ecological Recycling Agriculture - Farming Guidelines, Vol. 1*. Järna, Sweden. ISBN 978-3-00-042440-3, www.beras.eu. 136 pp.

5.3 Precision nutrient application

Description

Within this BEMP, the following measures are discussed:

- Compound fertiliser application for balanced nutrient delivery that complement organic amendments
- Efficient manure and slurry nutrient delivery (cross-ref 9.5 - trailing shoe, injection, immediate incorporation) alongside with synthetic fertilisers (if needed)
- Timing of application (RB209) of manures and (synthetic) fertilisers to coincide with plant demand
- Split applications
- GPS systems for variable in-field application rates (Dutch precision ag calibrates application for small areas within fields)
- GPS for accurate placement (fertilisers, agro-chemicals) and keeping to tramlines
- Coated seeds and direct placement (e.g. fertigation)

Mineral fertilizers and manures should be applied in accordance with the basic principles of '4R Nutrient Stewardship' (Sutton et al., 2013):

- **Right fertiliser** (crop needs, that complements organic matter with nutrients)
- **Right time** (crop uptake, soil protection)
- **Right rate** (spreader calibration, crop needs, slurry analysis, field variability)
- **Right method** (N losses, grazing palatability).

Organic fertilisers should be analysed to determine plant available concentrations of N, P, and other nutrients, applied at the correct time, at rates that meet crop requirements for these nutrients, in a manner that minimizes losses from applied manures during and after application. However, manures can be over-applied, while it should be noted that the bio-availability of the synthetic fertilisers is initially much lower compared to manure.

Quantities and timing in relation to demand

Right fertiliser: recommendations for fertilizer use take account of the crop's needs. The nutrient uptake of a crop is calculated and the following is subtracted: SNS (soil nutrient supply) and the nutrient supply from farm manure. A crop's nutrient uptake can be calculated by multiplying its expected yield by its nutrient content per tonne.

According to DEFRA (2010), **the right rate:** i.e. accurate and even application of fertilisers, is very important in order to maximise the benefits from their use to improve crop yield and quality and profitability. Even where correct decisions have been made on the amount of fertiliser to apply, inaccurate application, uneven spreading or spreading into hedgerows or ditches can cause a range of potentially serious problems, including: uneven crops, lodging and disease, reduced yields and poor or uneven crop quality at harvest, more risk of the transfer of nutrients to watercourses at field margins causing nutrient pollution, more risk of causing botanical changes in hedgerows and field margins.

Spreading fertilisers and organic manures as uniformly and accurately as is practically possible to the cropped area is a requirement in Nitrate Vulnerable Zones (NVZs). Avoiding spreading into the edges of hedgerows and ditches is a requirement of Cross Compliance. Fertiliser spreaders and sprayers

should be regularly maintained and serviced, replacing worn out parts as necessary. Spreaders should be calibrated for rate of application every spring and whenever the fertiliser type is changed. To do this, follow the manufacturer's instructions. Furthermore when synthetic fertilisers and manures are both applied the application rates must be limited in order to ensure that N supply does not exceed the crop requirements. Therefore the application should be done at smaller quantities at regular intervals in order to match more closely the crop requirement for nutrients during the growing season. As it was previously mentioned above, special care should be paid to avoid a risk of run-off to surface waters. As far as the quantities are concerned, it should be mentioned that the bioavailability of synthetic fertilisers is initially much lower as compared with the manure (UNDP, 2004).

When necessary, fertiliser may need to be applied as several **split dressings**, especially for cereals, to maximize nutrient uptake and prevent losses. In irrigated systems, split dressings are applied after watering.

The **right time** to apply fertilizer is usually during, or just before, periods of fast growth, when the crop requires significant amounts of nutrient. Applications to waterlogged or frozen land should be avoided. Similarly, manures are best spread in spring than summer or autumn to achieve a better NUE (nutrient use efficiency). Good timing conserves N by reducing nitrate-N leaching losses and runoff and also by reducing N₂O emissions.

Choosing the **right method** for applying manures means using the technique that maximises N conservation by limiting ammonia-N losses. Slurry application by injection or trailing shoe optimises N delivery to pasture whilst injection or immediate incorporation techniques are best on arable land (refer to section 9.5).

Organic farms rely totally on organic matter additions, together with clover-rich swards to provide additional N, so it is particularly crucial to maximise nutrient efficiency by e.g. optimising spreading techniques. The following steps are recommended:

1. Know what nutrients you are applying (check nutrient content of manures etc.)
2. Know the quantity you are applying – application rate (check flow rate from spreader)
3. Know when it is optimum timing for spreading – to match crop requirement, when soil moisture allows access and when weather is appropriate (no heavy rain forecast nor onto frozen soil) usually in spring (Feb-Apr in N. Europe).
4. Know how to spread to gain maximum nutrient delivery and minimum nutrient loss to the environment via gaseous emissions or surface runoff (Ammonia is a key pollutant associated with spreading organic manures and the agricultural sector is responsible for 90% of ammonia emissions (Oenema et al., 2012)).
5. Know where not to spread manures.

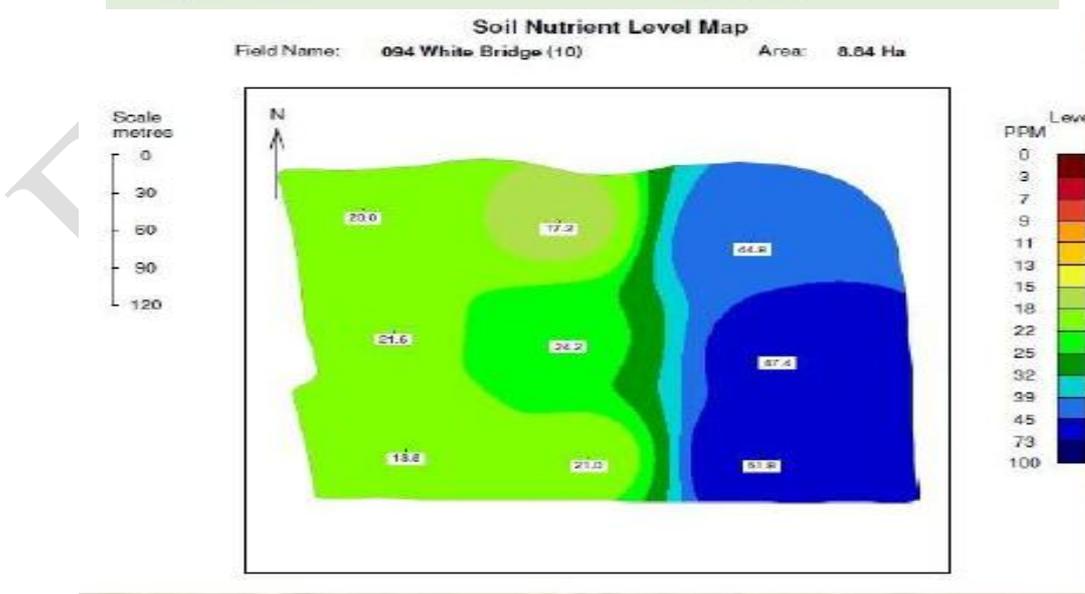
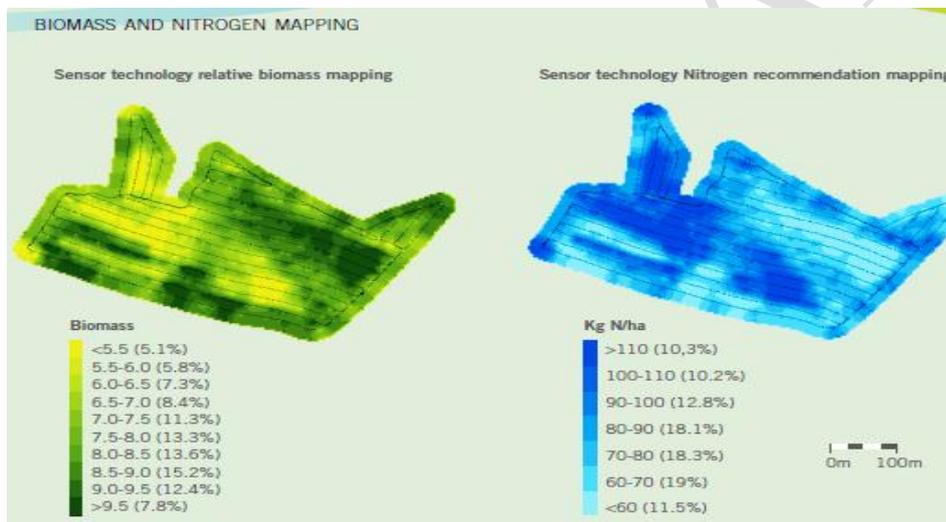
Precision delivery of nutrients using GPS technology

Further precision in the application of nutrients can be achieved by using GPS technology. Precision farming is the “management of farming practices that uses computers, satellite positioning systems, and remote sensing devices to provide information on which enhanced decisions can be made” (HGCA), whilst a broader definition would be to optimize field level management with regard to crop science, environmental protection and economics.

The application of GPS has two main applications:

- To inform variable nutrient applications within a field or in different parts of a field, where variation in crop canopy development can be identified, inspected and then managed using variable rate application, and
- To allow accurate locational placement of fertilisers, agro-chemicals and keep to tramlines.

The images below show a) in-cab monitor b) crop biomass and N sensor maps c) soil phosphate map.



Source: Dan fertilizers, citing www.agricon.de/en/products/sensors-agronomy (Top 2 images); Freestone, J. 2012 (bottom image)

It should be mentioned that precision application using GPS localisation contributes farmers to differentiate treatment in different parts of a field.

Soil amendments and precision farming:

The aim of precision farming is to manage crop variability by tailoring the organic matter inputs specifically to the growing crops needs, as opposed to having a set input used for all crops. This benefits the farmer economically, increasing yields without losing too much money on unnecessary inputs which also reduces the impact of inputs on the environment. This is achieved by measuring advancement of shoot growth and only applying in areas lacking in new shoot growth- digital photography. Most combine harvesters have yield mapping technology which can be used retrospectively to show areas of less fertility. Cereal yields can vary greatly in different areas of the same field. For example, one part may yield just 5 t/ha while others produce 10 t/ha or more (HGCA, 2013)

Direct placement of fertiliser to seed This technique involves the placement of granular fertiliser directly in or alongside the root zone ready for the growing crop, for example using a cartridge metering mechanism and distribution head to deliver fertiliser granules to outlets at the seeding units, where nutrients can be placed alongside or beneath the seed according to the agronomic needs. This technique is often applied in association with direct drilling of seed in particular, maize. Alternatively, liquid fertiliser can be employed in a similar way.

These so-called Starter fertilisers can offer many advantages one of which is the ability to target nutrition where it is needed: because they are applied with the seed only small quantities are required (10-40 kg/ha), typically only a tenth of what would be applied to the surface. More efficient use also benefits the environment through reduced leaching and reduces herbicide applications because the lack of fertiliser beyond the seedling reduces weed growth.

Fertigation involves the application of fertiliser with irrigation (refer to Chapter 10).

Achieved environmental benefits

- Reduced fertiliser application
- Improved and even crop yield
- Ammonia abatement from precise delivery techniques for manures (TFRN, 2011; Misselbrook et al. 2012) – see Table 5.28 below.
- In a six year trial using GPS to monitor crop canopy development, the SOYLSense project, UK, could more accurately time and dose N-fertiliser showed a yield benefit of between 3 and 8% as well as an overall reduction in N fertiliser (Freestone, 2012).
- Variable-applied N not only increased yield but reduced leachable N by up to one-third compared with standard fertiliser N application. (HGCA, 2010)
- Hultgreen and Leduc (2003) report that when urea was applied in a band below and to the side of the seed row, NH₃ and N₂O emissions were reduced in comparison to broadcast surface application in two years of a three-year study at two sites in Saskatchewan. Urea is usually injected whereas its injection is restricted to temperate conditions presenting low volatilisation. Moreover, other techniques can be implemented for urea application rather than injection to reduce ammonia volatilisation, like use of nitrogen stabiliser products³⁰. However, N losses through ammonia volatilization can be reduced by using a urease inhibitor to delay hydrolysis process. One of the available most effective inhibitors is called Agrotain™. It should be mentioned that the efficiency of this inhibitor depends upon soil and atmospheric conditions during or after the application of a urea-containing fertiliser (Bovis and Touchton, 1998).

³⁰ E.g. Agrotain® are nitrogen stabiliser products that secure the nitrogen investment. If the conditions are not favourable for ammonia volatilization, the benefits of the Agrotain™ product will not be realised.

Table 5.28. Summary of best practice (category 1) NH₃ abatement techniques listed in TFRN (2011)

Abatement measure	Land use	Emission reduction (%)	Factors affecting emission reduction	Applicability compared with the reference	Cost (€/Kg NH ₃ abated/year)
(a) Band-spreading slurry with a trailing hose	Grassland Arable	30-35%	More crop canopy will increase reduction, depending on placement precision and the extent of herbage contamination	Less suitable where: Slope > 15% Can be used on solid seeded crops and wide units may be compatible with tramlines	-0.5 to 1.5 (note that the costs may be reduced if the equipment is locally designed and built)
Band spreading with trailing shoe	Grassland Arable (pre-seeding) and row crops	30-60%	More crop canopy will increase reduction, depending on placement precision and the extent of herbage contamination	Not suitable for use in growing solid seeded crops but may be possible to use in the rosette stage and row crops.	-0.5 to 1.5
(b) Injecting slurry (open slot)	Grassland	70%	Injection depth < 5 cm	Unsuitable where: Slope > 15%; High stone content;	-0.5 to 1.5
(c) Injecting slurry (closed slot)	Grassland Arable	80% (shallow slot 5-10 cm)	Effective slit closure	Shallow soils; High clay soils (>35%) in very dry conditions, Peat soils (>25% organic matter content). Tile drained soils susceptible to leaching	-0.5 to 1.2
(d) Incorporation of surface applied slurry	Arable	Immediately by ploughing = 90%	Efficiency depends on application method and weather conditions between application and incorporation		-0.5 to 1.0
		Immediately by non-inversion cultivation (such as discing) = 70%			-0.5 to 1.0
		Incorporation within 4 hrs = 45-65%			-0.5 to 1.0
		Incorporation within 24 hrs = 30%			0 to 2.0
(e) Active dilution of slurry of >4% DM to <2% DM for use in water irrigation systems	Arable Grassland	30%	Emissions reduction is proportional to the extent of dilution. A 50% reduction in dry matter (DM) content is necessary to give a 30% reduction in emission	Limited to low pressure water irrigation systems (not 'big guns'). Not appropriate where irrigation is not required	-0.5 to 1.0

Appropriate environmental performance indicators

Management indicators

- Apply the 4Rs: right fertiliser, right time, right rate, right method.
- Measure nutrient content of manures annually
- Use efficient (trailing shoe/injection/incorporation) techniques for spreading manures to maximise NUE_N (section 9.6 and 9.7)
- Choose compound fertilisers that complement organic amendments
- Apply nutrients to coincide with plant demand
- Use GPS technology to optimise nutrient delivery
- Periodic testing of available nutrient content in organic amendments
- Periodic soil testing
- Coefficient of Variation of spreading uniformity (target $\leq 15\%$)

Nutrient indicators

- Soil P, K indices (section 5.1)
- N surplus (section 5.1)
- Crop NUE (section 5.1)
- NUE (section 5.1)
- Soil Mineralisable N (section 5.1)
- Available nutrient content of manures (section 5.1)

Cross-media effects

No major cross-media effects foreseen for this technique, which is about maximising the efficiency of resource use and avoiding environmental burdens associated with excess nutrient loading.

Operational data

Organic amendments

In order to accurately account for the nutrient supply from organic amendments, representative samples should be taken for assessment periodically, more frequently if animal diet changes or suppliers have been subject to change.

Rapid on-farm kits can be used, such as an ammonium detection tool for available N. These work by adding sodium hydroxide to the slurry and reading off the evolution of ammonia gas from a pressure gauge. It is best practice for the farmer or contractor (more likely to have precision machinery) who undertakes the spreading to assess either ammonium-N or % dry matter (by hydrometer) of slurry before spreading and to use this in conjunction with flow meters on pipes for trailing hose, shoe and injection systems to accurately dose slurry. A slurry hydrometer estimates N content of slurry relying on the assumption that N is proportional to %DM of the slurry. However, it is best practice to send samples to an accredited laboratory for analysis. Refer to slurry spreading techniques in sections 6.5, 9.4.

In the UK, examples of online fertiliser calculators include:

- MANNER NPK (ADAS, 2013), that calculates the available nutrients delivered by different organic amendments and application methods;
- Yara NPK website based on RB209 fertiliser manual (DEFRA, 2010): http://www.yara.co.uk/fertilizer/tools_and_services/npk_online_calculator/index.aspx

As a general remark, when organic manures and inorganic fertilisers are both applied it is important to exploit best the N inputs. Therefore an integrated policy is required aiming to supply up to 50–60% of the crop's expected N requirement for optimum yield from the applied organic manure, with inorganic fertiliser N used to 'top up' crop needs.

Figure 5.17 illustrates the winter wheat responding up to an optimum rate of 200 kg/ha N. In case when half of this is supplied from organic manure and the other one is covered by an inorganic fertiliser then the potential impact of variations in manure N supply will be minimised, as crop N requirements will be at the top of the yield response curve. Rough and/or bad calculations/estimations regarding the full N value of manure can impact yield, quality as well as increase the costs (ADAS, 2001).

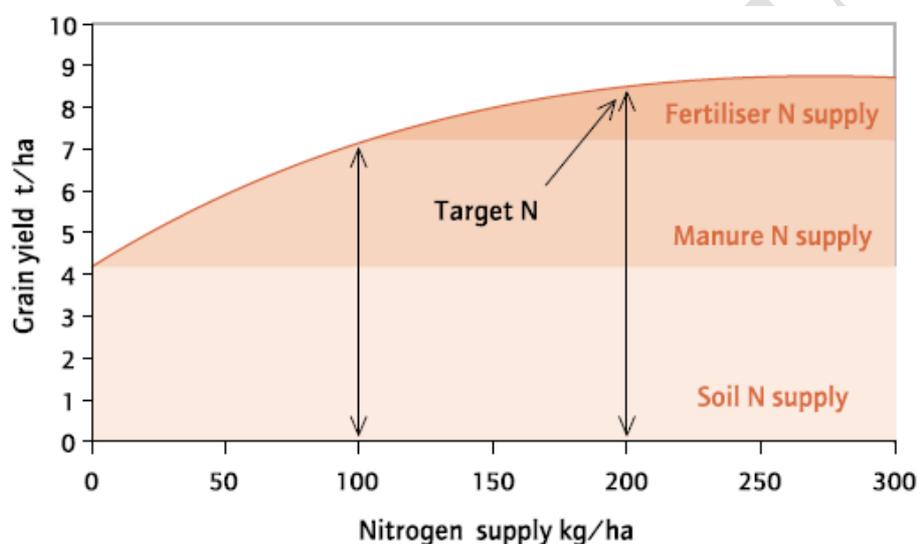


Figure 5.17. Supplying winter wheat N requirement from manure and fertiliser sources (ADAS, 2001)

Fertiliser spreading

To check spreading uniformity, DEFRA (2010) recommend use of catch-trays on an annual basis or whenever faulty spreading is suspected. Computerised analysis of the data will give the Coefficient of Variation (CV) which indicates the non-uniformity of spreading. CV values greater than 15% indicate imprecise spreading requiring action to improve the performance of the spreader. More information is provided in the leaflet *Fertiliser Spreaders – Choosing, Maintaining and Using* (Agricultural Industries Confederation), or the new guidance book: *Spreading Fertilisers and Applying Slug Pellets* (BCPC). For manure and slurry spreaders, checks should be made for mechanical condition before spreading and for rate of application during spreading.

Fertiliser-coated seed

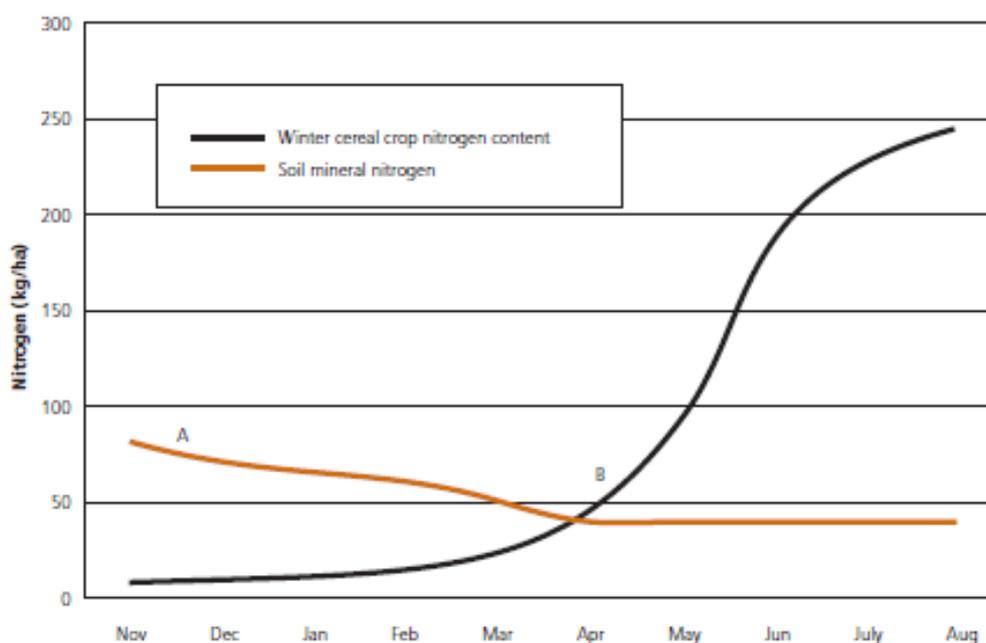
Grass seeds have little storage for nutrients and a fertiliser coating may provide immediate external N and P to boost seedling development - better roots and good early establishment of green phytomass. Though by no means always successful, it has been shown in some cases to have merit in over-sowing old pasture:

- Increased leaf growth after germination.
- Better plant density.
- Increases first and second cut yields

- Fertilises the seed not the weeds.
- Reduces need for further fertiliser applications where phosphate and potash indices are adequate.
- Better ground contact leading to better germination.
- Heavier seed means more even application and penetration through any grass sward present.
- Faster root development allowing leys to be grazed quicker after sowing and avoiding any potential weather changes.

Timing

Correct timing of N fertiliser application is crucial to ensure efficient uptake and high NUE. For many crops, split application throughout the establishment and growing phases. Productive grassland may require five applications over the growing season (DEFRA, 2010). Nitrogen should be applied at the start of periods of rapid crop growth, as indicated in Figure 5.18 for a winter sown wheat crop where the N requirement is low during the autumn and winter and the supply from soil reserves (A) is adequate to meet the requirement (DEFRA, 2010). Figure 5.18 also shows that the main period of N uptake (B) is March-June and during this growth period there is usually insufficient soil N to support unrestricted growth. Nitrogen fertiliser should be applied at the start and during this period of growth.



Source: DEFRA (2010)

Figure 5.18. Winter wheat N demand versus soil mineral N supply

In case where the plant available N inputs from cattle slurry were accounted for, the effective N surplus became a much better predictor of nitrate N concentrations in the upper groundwater.

Table 5.29 presents the nitrogen replacement value (NRV) of cattle slurry based on the ratio of apparent N recoveries of mineral fertilizer and slurry, as affected by total N-rate, the nature of N-input, site and numbers of years involved.

Table 5.29. Nitrogen fertilizer replacement value of cattle slurry (kg N/100 kg slurry N applied); assumption: the value for years 2007 and 2008 reflects the average of those two years (Schröder et al., 2010)

N application rate (kg/ha)		Site						
		wet			dry			Mean 2007 and 2008
Total N	Slurry N	2007	2007+2008	2008	2007	2007+2008	2008	
374	85	61	5	55	72	97	122	78
408	170	32	32	32	62	69	77	51
440	250	39	39	39	52	56	61	48
474	335	48	49	50	72	81	90	65
Mean		45	45	44	64	76	88	60

Some important considerations for N application timing (DEFRA, 2010):

- Too much seedbed N can reduce the establishment of small seeded crops.
- Early spring N will increase tillering of cereals. This may be beneficial, but too much N at this stage can increase the risk of lodging.
- Late applied N will increase the grain N/protein concentration of cereals.

Precision farming

Environmental benefit comes from lower inputs enabled by precision tools. The tractor-mounted N-Sensor reads N requirements and adjusts fertilizer application rates as the tractor moves across the field. One of the most cost-beneficial tasks from GPS technology is guidance, which dramatically reduces over or under-lapping of field working, saving fuel and materials (overlapping) and increases yields (underlapping) (HGCA, 2009).

Automatic steering implies that the steering is done by the positioning system using an electric steering wheel or a hydraulic block and sensor. First the driver makes a tour around the contours of the field. After entering the working width of the machine and the preferred row direction, the automate takes care of the steering except for the turning to a new pass. Accuracies around 10cm allow accurate sowing and planting while the RTK accuracy of 2.5cm is required for inter-row weeding, row fertilizing or controlled traffic farming.

Applicability

All farms can implement some aspects of precision application. Precise application of organic amendments is particularly important for organic farms, whilst precise application of mineral fertilisers is important for all non-organic farms, and most readily applicable on intensive livestock and arable farms and outdoor horticultural farms.

The introduction of the UK's Voluntary Initiative Organisation has fully supported the use of technology to improve the accuracy of spraying operations and GPS is seen as part of the solution towards minimising the risk of additional regulatory controls. Whilst the technology can be used to benefit this sector in reducing environmental impact, it can also aid profitability and sustainability.

Systems accuracies around 10 cm allow accurate sowing and planting while the RTK accuracy of 2.5 cm is required for inter-row weeding, row fertilizing or controlled traffic farming.

For Arable farms:

- Yield mapping and monitoring.
- Enabling you to know what is being produced from where within the field; and which areas are not delivering, having had the same level of investment.
- Variable rate seeding of the fields – soils are the biggest variable
- Variable rate fertiliser applications – a financial and environmental benefit
- Weed Mapping and scouting

- Variable rate spraying
- Boundary mapping and Topography Mapping, (maybe erosion mapping in the future?)
- Guidance Recording and analysis – using it to make decisions

For livestock farms:

- automated feeding and remote monitoring to assess individual cow performance;
- monitoring of temperature, humidity, water use, energy consumption, growth rates, mortality and health issues in indoor intensive pig and poultry units;
- electronic identification within the national sheep flocks and beef herds
- grassland based farming can benefit from lower-cost light bar guidance systems that can still deliver substantial savings when applying fertiliser or pesticides where there are no tramlines.

Direct Placement of fertilisers near crops in bands on rain fed land requires the use of specialised machinery for fertilizing and sowing. On irrigated land, fertigation via drip irrigation could be of interest. Besides the investment in drip irrigation, no other installations are necessary beside those for other irrigation systems.

Economics

There is a strong economic case for adopting precision farming. One study in HGCA (2002) estimated the following costs and savings:

- Equipping a farm for precision farming costs from £2/ha to £18/ha (EUR 2.35-21.20/ha) depending upon the complexity of the system and farm size.
- Data collection and interpretation to enable real time agronomy incurs costs from £7/ha (EUR 8.25/ha) depending upon the total area surveyed by aircraft or tractor-mounted radiometry.
- Correcting waterlogging was worth £185/ha (EUR 220/ha)
- Rectifying uneven N application returned up to £65/ha (76.5/ha) in a year.

The urea is used because it is one of the cheapest sources of nitrogen. Nonetheless the urea injection it could make this particular application less viable increasing the competition amongst other application techniques.

Slurry ammonium-N measuring equipment costs c. £250 (EUR 295) + consumables (e.g. AgrosNitro, or Quantofix).

Further economic case studies can be found in Freestone, 2013.

The HGCA has produced a Precision farming Calculator tool (HGCA, 2009b) designed to help farmers gauge what savings can be achieved using precision farming technology.

The LEAF Marque audit includes the use of precision farming techniques to help demonstrate compliance in crop protection standards. Being LEAF-Marque certificated, which is a global standard, can secured a premium for products.

Simple GPS units can be purchased for around £300-400 (EUR 350-475)-and these can be transferred between vehicles. Where there is a built-in unit then these can be either a standard item where the cost is built in to the vehicle cost or as an optional extra with a price range of up to £10,000 (EUR 11,750) depending upon the complexity of the unit. Farmers' Weekly (2013) reported a situation where GPS installation costs of almost EUR 12 000 were paid back in about three years.

HGCA (2010) report on projects where benefits from precision farming compared to standard input programmes have been:

- Nitrogen – up to £22/ha (EUR 26/ha)
- Herbicides – up to £18/ha (EUR 21/ha)
- Fungicides and PGRs – up to £20/ha (EUR 24/ha)

Equipping a farm for precision farming costs from £2/ha to £18/ha (EUR 2.35-21.20/ha) depending upon the complexity of the system and farm size. Data collection and interpretation to enable real time agronomy incurs costs from £7/ha (EUR 8.25/ha) depending upon the total area surveyed by aircraft or tractor-mounted radiometry. The project highlighted additional benefits. Correcting waterlogging was worth £185/ha; rectifying uneven nitrogen application returned up to £65/ha (76.5/ha) in a year (HGCA, 2010).

Direct fertiliser placement is economically feasible mostly in arid and semi-arid regions where irrigation occurs. On irrigated fields, the estimated additional costs per hectare could be around 2,500-3,000 € when compared with furrow irrigation, and range between 0 and 1,000 € when compared with high efficient sprinkler irrigation (depending on whether PVC or polyethylene is used). Subsidies for covering costs of investment could be of interest because potential benefits include not only the reduction of non-point pollution (N, P, pesticides), but also because of soil conservation and water saving, which are important topics in arid and semi-arid regions (Delgado, 2011). Furthermore the Nitrogen Use Efficiency (NUE) will be possible to calculate if not at field level, at least at the level of the whole farm

Driving forces for implementation

- Fertiliser cost savings
- Legislative restrictions on nutrient applications (e.g. NVZ rules)
- Reducing water pollution
- Reduced use of artificial nitrogen fertiliser
- More efficient use of chemicals and fertilisers
- Reduced crop damage (e.g. by lodging)
- Improved yields
- Maximising profit margins
- Improving sustainability
- Improving business viability
- Minimising environmental impact by avoiding run-off
- Management information for business planning

Reference literature

- ADAS, 2001. Making better use of livestock manures on arable land. Booklet 1, edited by: Chambers B., Nicholson N., Smith K., Pain B., Cumby T. and Cotford I., available online: <http://www.rothamsted.ac.uk/sites/default/files/Booklet1ManuresArableLand.pdf>, accessed November 2014.
- ADAS, 2013. MANNER NPK. <http://www.planet4farmers.co.uk/Manner> Accessed May 2013.
- AgrosNitro <http://www.agros.se/engelska.html> Accessed Oct 2013.

- AIC *Fertiliser Spreaders – Choosing, Maintaining and Using* <http://www.nutrientmanagement.org/fertiliser-spreader-manual> accessed Jan 2014
- BCPC *Spreading Fertilisers and Applying Slug Pellets* <http://www.bcpc.org/shop/Spreading-Fertilisers-and-Applying-Slug-Pellets.html> accessed Jan 2014.
- Bovis M. and Touchton J. 1998. Nitrogen Efficiency of Urea Fertilizers. Highlights of Agricultural Research, Volume 45 Number 1, online article: <http://www.aaes.auburn.edu/comm/pubs/highlightsonline/spring98/urea.html>, accessed November 2014.
- Dairyman project www.interregdairyman.eu/upload_mm/b/6/9/fe74f64b-af8a-4464-b82a-e4ea3d0a1811_GPS%20on%20tractor%20Hooibeekhoeve%20Belgium.pdf Accessed Oct 2013.
- Dan Fertilizers www.danfertilizers.com/site/index.php?id=622
- DEFRA, 2010. *Fertiliser Manual RB209*. UK: TSO. Retrievable at <http://www.defra.gov.uk/publications/2011/03/25/fertiliser-manual-rb209/>
- Delgado, A., 2010. Fertilizer placement near crops. COST 869 Factsheet, Alterra, Netherlands. http://www.cost869.alterra.nl/Fs/FS_placement_near_crops.pdf accessed Oct 2013.
- Farmers' Weekly, 2013. *How to cut your diesel costs*. Article published May 2013, and available to download at: <http://www.fwi.co.uk/articles/14/05/2013/139042/how-to-cut-your-diesel-costs.htm#.UbcS36ynerA>
- Freestone, J. 2012. Will precision farming change the face of UK agriculture? Oxford Farming Conference, 2012. www.ofc.org.uk/papers
- HGCA, 2002. <http://www.hgca.com/media/189883/g7-precision-farming-of-cereals-practical-guidelines-and-crop-nutrition.pdf> accessed Nov 2013.
- HGCA, 2009. Research Review No. 71 An up-to-date cost/benefit analysis of precision farming techniques to guide growers of cereals and oilseeds. Stuart Knight, Paul Miller and Jim Orson.
- HGCA, 2010. *Precision farming information*. Accessed August 2013: www.publications.hgca.com/publications/documents/cropresearch/PrecisionFarmingG7.pdf
- HGCA, 2013. *Soil management*. Accessed August 2013: <http://www.hgca.com/content.output/6255/6255/Crop%20Management/Crop%20Management/Soil%20management.msp>.
- Hultgreen, G. and Leduc, P., 2003. *The effect of nitrogen fertilizer placement, formulation, timing, and rate on greenhouse gas emissions and agronomic performance*. Final Report, Project No. 5300G, ADF#19990028, Saskatchewan Department of Agriculture and Food, Regina, SK. Available from: http://www.agr.gov.sk.ca/apps/adf/adf_admin/reports/19990028.pdf
- IFA, 2010. *Greenhouse gas budgets of crop production – current and likely future trends*. Helen C. Flynn and Pete Smith. Publ. IFA, Paris.
- Leaf Marque, 2013. Website accessed November 2013: <http://www.leafuk.org/leaf/farmers/LEAFmarquecertification/standard.eb>
- IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Retrieved from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>
- Misselbrook, T.H., Gilhespy, S.L., Cardenas, L.M. (Eds.), 2012. *Inventory of Ammonia Emissions from UK Agriculture 2011*. DEFRA, London.
- Oenema, O., Veltof, G., Klimont, Z., Winiwter, W. 2012 *Emissions from agriculture and their control potentials*. TSAP Report #3 Version 2.1 Editor: Markus Amann. ENV.C.3/SER/2011/0009.
- Quantofix, 2013. *Quantofix Nitrogen Meter Details*: <http://www.pembrokeshireonline.co.uk/quantofix/details.html>, accessed Oct 2013.
- Schröder J.J., Assinck F.B.T., Uenk D., Velthof G.L. 2010, Nitrate leaching from cut grassland as affected by the substitution of slurry with nitrogen mineral fertilizer on two soil types, Grass and Forage Science, 65, 49-57.
- SOYL, 2013. *SOYL Precision farming – 'Soil Sense' project*: www.soyl.co.uk/soylsense.aspx, accessed Sep 2013.
- Sutton M.A., Bleeker A., Howard C.M., Bekunda M., Grizzetti B., de Vries W., van Grinsven H.J.M., Abrol Y.P., Adhya T.K., Billen G., Davidson E.A, Datta A., Diaz R., Erisman J.W., Liu

X.J., Oenema O., Palm C., Raghuram N., Reis S., Scholz R.W., Sims T., Westhoek H. & Zhang F.S., with contributions from Ayyappan S., Bouwman A.F., Bustamante M., Fowler D., Galloway J.N., Gavito M.E., Garnier J., Greenwood S., Hellums D.T., Holland M., Hoysall C., Jaramillo V.J., Klimont Z., Ometto J.P., Pathak H., Plocq Fichelet V., Powlson D., Ramakrishna K., Roy A., Sanders K., Sharma C., Singh B., Singh U., Yan X.Y. & Zhang Y., 2013. *Our Nutrient World: The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management*. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.

- TFRN, 2011. *Draft Guidance Document for preventing and abating ammonia emissions from agricultural sources*. Informal document no. 20. TFRN. Downloaded May 2013: <http://www.clrtap-tfrn.org/documents>
- UNDP, 2004. *Inventory of Mineral Fertiliser Use in the Danube River Basin Countries with Reference to Manure and Land Management Practices, UNDP/GEF Danube Regional Project Policies for the Control of Agricultural Point and Non-point Sources of Pollution & Pilot Projects on Agricultural Pollution Reduction (Project Outputs 1.2 and 1.3)*.

FINAL DRAFT

5.3.1 Precision nutrient application case studies

Case Study 1. Simon Sturrock farmer/contractor, Caernarfon, Wales.

The farmer opted for the Advance Farming System (AFS) provided with his new (2013) tractor purchase. The auto-guidance system cost £9,000 (€10,600) and is linked to the steering of the tractor effectively providing a “hands-free” operation thus reducing stress on the operator. Uses nearby mobile phone mast signal and is accurate to 2.5 cm. This was considered to be the most advanced and reliable system available on the market at the time of the new tractor purchase and thus was a factory fitted option rather than a retro-fit. This system offers significant advantages to the older “light bar” system that was previously used which relied on operator control of the steering with reduced accuracy compared to the more advanced auto steering system.

Whilst the use of GPS systems in North Wales is something of a novelty, Simon considered that it was time to “bite the bullet” and move with the technological advances as he can see that this is a major step forward in improving efficiency and farm profitability.

The farmer/contractor has just secured the contract for spreading digestate from a new, local green waste digester with field spreading operations due to commence in February 2014 and it is anticipated that this GPS system/tractor unit will be used exclusively on this operation. The system will identify precisely where the last load finished and where the next load is to start to prevent overlap/striping or missed areas of the field thus providing precision application. The use of GPS technology was a major “selling point” when bidding for the contract.

Case Study 2: Assessing economic benefit of GPS for dairy farming in Flanders (Dairyman project).

The most important advantages of the GPS systems for dairy farmers at this moment is the reduction of overlap, increased comfort for the driver and the possibility to work in the dark. The reduced overlap allows to save time, fuel and cost of fertilizer, herbicides, etc. However, due to the high equipment and correction signal cost GPS systems are generally not cost efficient at this moment for standard field operations done by dairy farmers in Flanders. Further research is required to measure the benefits of controlled traffic farming, specific tillage (e.g. strip till) and row operations.

Case Study 3: HGCA, UK, example.

The application of organic fertilisers, changes in soil type, topography and yields can all contribute to the nutrient variability in soils. FYM and sewage cake had been applied for several years, soil P indices were exceeding K indices led to average variation of nutrient indices from 1 to 3 within a field. If a uniform rate of fertiliser is applied there are areas that will receive more or less than is needed. Targeting fertiliser with GPS application equipment ensures yield-limiting areas are removed, while fertiliser is not wasted in areas with high nutrient levels. The HGCA has developed a tool to help growers calculate the costs and the benefits associated with precision farming equipment, the online Precision Farm Calculator.

5.4 Select lower impact synthetic fertilisers

Description

Within this BEMP, the following measures are discussed:

- Select synthetic nitrate-based fertilisers manufactured according to best available technology
- Select urea-based fertilisers containing a urease inhibitor (and/or slot injection of urea fertilisers)

Manufacture of mineral N requires large quantities of energy and gives rise to considerable GHG emissions, depending on the type of compounds, the efficiency of the manufacturing plants and the (N_2O) abatement techniques applied. Meanwhile, as shown elsewhere, application of fertiliser N leads to NH_3 and N_2O emissions to air and n leaching or runoff to water. Fertiliser Europe produced the graphic in Figure 5.19 which puts EU27 fertiliser manufacture and use into the context of EU27 GHG emissions (also Figure 5.20).

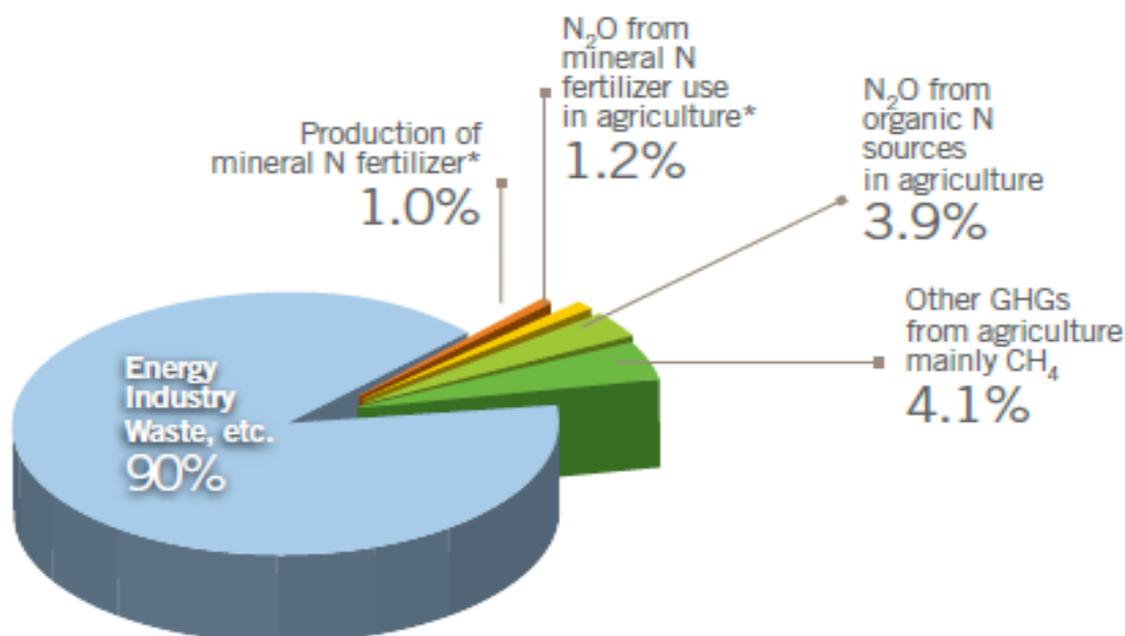
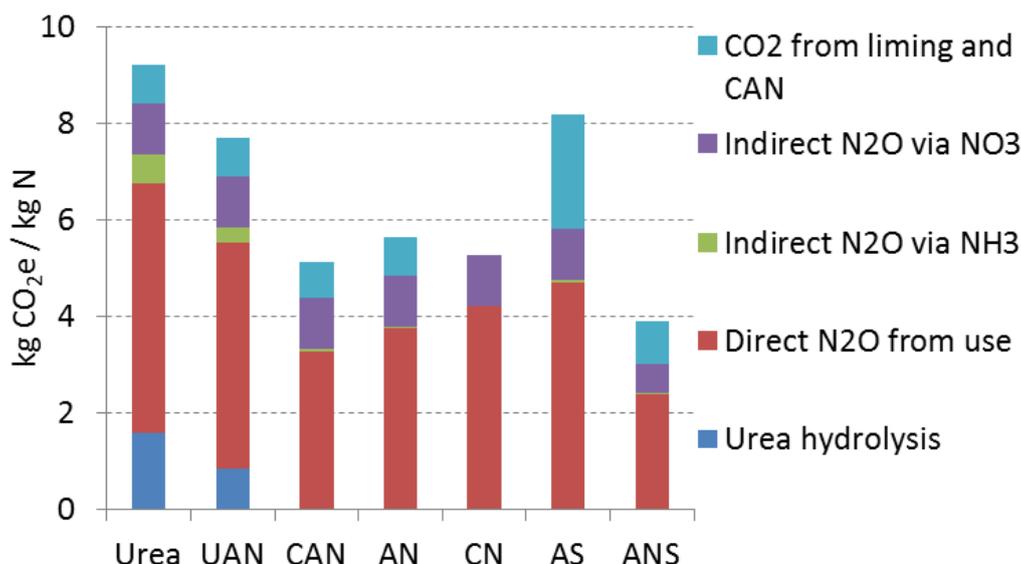


Figure 5.19. The contribution of fertiliser manufacture and use to EU27 GHG emissions (Fertilisers Europe, 2010)



UAN= Urea Ammonium nitrate; CAN = Calcium Ammonium Nitrate; AN = Ammonium Nitrate; CN = Calcium Nitrate; AS = Ammonium Sulphate; ANS = Ammonium Nitrate Sulphate.

Figure 5.20. Life cycle global warming potential (kg CO₂e) per kg N for different types of fertiliser-N, based on 2010 data, considering all major direct and indirect GHG emission pathways (Fertiliser Europe, 2014)

Ammonium nitrate is made up of ammonia and nitric acid. The lifecycle carbon footprint of manufacture depends on the energy consumption and the feedstock used in the ammonia production, as well as the quantity of unabated N₂O emission from nitric acid production. The EU has defined “best available techniques” (BAT) for these processes. Applying BAT results in a total emission of 3.6 kg CO₂e per kg N for fertilizers that use ammonium nitrate as the nitrogen source, which is the predominant case in Europe. However, many fertiliser plants exceed BAT emission levels.

There is considerable variation in the proportion of applied nutrients, in the form of either organic or mineral fertiliser, lost to the environment – depending on the application timing, technology and conditions, soil characteristics and crop type, amongst other factors. Values provided in Table 5.30 for mineral N reflect average NH₃-N emission factors across common fertiliser types.

Table 5.30. Ammonia-N emission factors (% total N applied) for artificial fertilisers (Kremer, 2009)

Type of artificial fertiliser	Emission factor
Ammonium sulphate	8
Di-ammonium phosphate	5
Potassium saltpetre	5
Fluid ammonia	4
Ammonia nitrate	2
Other NPK, NP and NK fertilisers	5
Nitrogen phosphate potassium magnesium fertilisers	5
Ammonia water	4
Sulphur coated urea	15
Ammonium sulphate saltpetre	5
Calcium Ammonium saltpetre	2
Nitrogen magnesia	2
Chile saltpetre	2
Calcium saltpetre	2

Type of artificial fertiliser	Emission factor
Urea	15
Mixed nitrogen fertiliser	5
Mono-ammonium phosphate	2

Urea and ammonium-nitrate are common types of N fertiliser with different advantages and disadvantages from an environmental perspective. Ammonium nitrate is the main source of manufactured N fertilizer used in the UK. Urea-based N (in solid urea and as liquid urea ammonium nitrate - UAN) accounts for c. 20% of total fertiliser N application in the UK (Chambers & Dampney, 2009). Although urea manufacture gives rise to considerably lower emissions than ammonium nitrate manufacture, approximately 30% of applied urea-N volatilises (compared with < 5% for ammonium nitrate), leading to lower N availability, higher NH₃ emissions and higher indirect N₂O following deposition of NH₃, so that the overall environmental performance of urea can be worse than ammonium nitrate (Yara, 2011). Emissions following application of urea fertilisers can be considerably reduced through various manufacturing and application measures. Controlled release urea fertilisers range from simple sulphur coated urea to more sophisticated forms such as polyolefin coated products that have specific release patterns and timelines that correspond to the required crop nutrient uptake but these tend to be costly. N losses from urea can be significantly reduced when prills are coated with a urease inhibitor which slows the rate of hydrolysis to ammonium and ammonia; by 64% according to one study (MSU, 2013). Nitrification inhibitors (NIs) are now more commonly used as the demand for better N-use efficiency, pollution prevention and sustainable agriculture exert pressure (Table 5.31). NI allow for more precise N delivery to the crop by slowing nitrate production to a rate which more closely matches crop uptake whilst soils remain cool in spring, so reducing nitrate leaching and N₂O. The inhibitor can be coated onto the fertiliser prill, e.g. Nitrotyrin on urea, or it can be sprayed post fertiliser application, or applied with liquid fertiliser e.g. dicyandiamide with slurry. Section 7.5 addresses use of NIs.

Table 5.31. Reported effectiveness of NIs and urea coatings (IFA, 2010); partially adapted from Weiske, 2006)

Type of inhibitor or coating	Fertilizer type	Crop	Length of monitoring	% N ₂ O emission reduction	Reference
Nitrapyrin	Ammonium sulphate	Lab study, soil only	30 days	93	Bremner and Blackmer, 1978
Nitrapyrin	Urea	Lab study, soil only	30 days	96	Bremner and Blackmer, 1978
Nitrapyrin	Urea	Corn	100 days	40-65	Bronson et al., 1992
Calcium carbide	Urea	Corn	100 days	33-82	Bronson et al., 1992
DCD ^a	Liquid manure	Pasture grass	14 days	50-88	De Klein and van Logtestijn, 1994
DCD	Ammonium sulphate	Pasture grass	64 days	40-92	Skiba et al., 1993
DCD	Urea	Spring barley	90 days	82-95	Delgado and Mosier, 1996
DCD	Urea	Spring barley	1 growing season	81	Shoji et al., 2001
DCD	Urea	Wheat	95 days	49	Majumdar et al., 2002
DCD	Urea	Spring barley	56 days	40	McTaggart et al., 1997
POCU ^b	Urea	Spring barley	90 days	35-71	Delgado and Mosier, 1996
POCU	Urea	Spring barley	1 growing season	35	Shoji et al., 2001

Type of inhibitor or coating	Fertilizer type	Crop	Length of monitoring	% N ₂ O emission reduction	Reference
DCS ^c	Ammonium sulphate	Pasture grass	64 days	62	Skiba et al., 1993
DMPP ^d	Ammonium sulphate nitrate	Spring barley, corn and winter wheat	3 years (spring and summer only)	51	Weiske et al., 2006
Neem' coating	Urea	Wheat	95 days	9	Majumdar et al., 2002
Nimin' coating	Urea	Wheat	95 days	63	Majumdar et al., 2002
Thiosulphate	Urea	Wheat	95 days	35	Majumdar et al., 2002
Polymer coating	Urea	Corn (no-till)	159 days	55	Halvorson et al., 2009

^aDCD = dicyandiamide
^bPOCU = polyolefin coated urea
^cDCS = N (2.5 dichlorophenyl) succinic acid monoamide
^dDMPP = 3,4-dimethylpyrazole phosphate

Achieved environmental benefits

The selection of efficiently manufactured and low application emission fertilisers leads to the following benefits:

- Reduced GWP, EP and AP impacts from manufacture
- Reduced GWP, EP and AP impacts following land application
- Higher NUE and associated lifecycle environmental benefits

Figure 5.21 indicates that the lifecycle GHG emissions arising from CAN fertiliser can be significantly lower than from urea fertiliser e.g. 8 versus 10.5 kg CO₂e per kg N, when CAN is manufactured using BAT with an N₂O abatement catalyst.

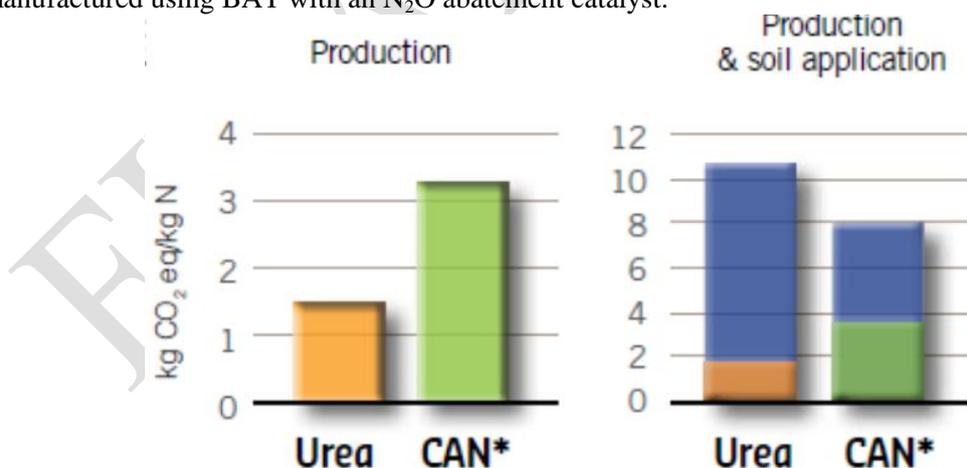


Figure 5.21. Production, and production and post-application, GHG emissions attributable to CAN and urea fertilisers (e.g. CAN manufacture includes N₂O abatement catalyst) (Fertilisers Europe, 2010)

The following benefits (Table 5.32) of nitrate- over urea-based fertilisers (for equivalent N application rates) have been published in Yara, (2011).

Table 5.32. Benefits of nitrate-over urea-based fertilisers (Yara, 2011)

Efficiency	7.5–18% extra N needed to maintain yield with urea-based fertilizers
Yield	2–5% higher yield with ammonium nitrate at same N application rate
Quality	0.3 – 0.9% higher protein content with ammonium nitrate
Reliability	High reliability of ammonium nitrate due to predictable volatilization losses
Volatilization	1–3% volatilization with ammonium nitrate, compared with up to 27 % with urea
Leaching	Better control of leaching with ammonium nitrate due to faster plant uptake and lower dosage
Carbon footprint	12.5% lower life cycle carbon footprint of ammonium nitrate compared to urea
Environmental index	46.6% lower environmental index of ammonium nitrate compared to urea

These claims are largely corroborated by data from Chambers and Dampney (2009). Based on NH₃ loss measurements using wind tunnels, they showed that the average NH₃-N emission factor (EF) from granular urea was 27% on grassland and 22% on winter cereals (relative to total N applied). The average ammonia EF from AN was less than 3%. Ammonia emissions from liquid UAN were intermediate between granular urea and AN. An extra 20% of urea-N was needed to achieve the same cereal crop yield and quality as from the use of AN.

Snyder et al. (2009) stated that when urea-containing N sources are applied on the soil surface and not incorporated, a substantial proportion is lost via volatilization of ammonia (NH₃), especially with manure or urea in humid environments: this reduces N levels available for plant uptake without reducing N₂O emissions. Therefore, best practice measures which reduce NH₃ volatilization also reduce N₂O emission in the same proportion as the amount of N conserved (cited in IFA, 2010).

However, post application NH₃ (and thus indirect N₂O) emissions arising from urea-based N fertilisers can be reduced considerably through various measures, listed alongside abatement potentials in Table 5.33 copied from TFRN (2011). Chambers and Dampney (2009) found that use of the urease inhibitor nBTPT reduced ammonia emissions from granular urea by 70%, and from liquid UAN by 40%.

Table 5.33. Best practice mitigation options for reducing ammonia emissions for urea-based fertilisers (TFRN, 2011)

Abatement measure	Fertilizer type	Emission reduction (%)	Factors affecting emission reduction	Applicability	Cost (€/Kg NH₃ abated/year)
Surface broadcast	Urea-based	Reference			
Urease inhibitor	Urea-based	70% for solid urea 40% for liquid urea ammonium nitrate		All	-0.5 to 2.0
Slow release fertilizer (polymer coatings)	Urea-based	c. 30%	Polymer coating type and integrity: fertilizer application technique (surface or injected)	All	-0.5 to 2.0

Abatement measure	Fertilizer type	Emission reduction (%)	Factors affecting emission reduction	Applicability	Cost (€/Kg NH ₃ abated/year)
Closed-slot injection	Urea-based and anhydrous ammonia fertilizers	80-90%	Depth of placement; soil texture; closure of slot (improperly closed slots may lead to high emissions due to high concentration of urea in the slot increasing pH)	Tilled or reduced-till land prior to seeding or during the seeding operation or during the mechanical weed control operation after emergence	-0.5 to 1.0
Incorporation	Urea-based fertilizers	50-80%	Delay after fertilizer application; depth of mixing; soil texture	Tilled land prior to crop establishment	-0.5 to 2.0
Irrigation	All	40-70%	Irrigation timing and volume (immediate with c. 10mm is more effective); soil humidity; soil texture	Where crop irrigation is commonly practiced	-0.5 to 1.0
Substitution with ammonium nitrate	Urea-based and anhydrous ammonia fertilizers	Up to 90%	Under conditions where urea based fertilizers would have emissions of at least 40%	All, especially where only surface application of fertilizer and no irrigation is possible	-0.5 to 1.0
NB: Local costs/benefits will vary, though trials have shown that the financial benefit of increased crop productivity can more than outweigh the costs of the technique for some abatement measures.					

Appropriate environmental performance indicators

Management indicators

- Source synthetic fertilisers with lower embodied (upstream) GHG emissions and energy
- Source synthetic fertilisers with lower post application ammonia and GHG emissions

Fertiliser indicators

- Certified fertiliser carbon footprint (kg CO₂ e/kg N)
- % synthetic fertilisers that are certified 'low C'
- % synthetic fertilisers used that are 'enhanced efficiency'
- % fertilisers produced in factories implementing best available technology (BAT) as defined in the European Industrial Emissions Directive

Upstream carbon footprints of fertiliser manufacture may be specified by manufacturers, through certification (e.g. Carbon Trust, Swedish Climate Certification for Food), or estimated through use of

online tools such as the Cool Farm Tool based on some knowledge of where and how fertilisers are produced (Table 5.34).

Table 5.34. GHG arising from upstream production of ammonium nitrate and urea fertilisers

Production technology type	Ammonium nitrate	Urea
	kg CO ₂ e kg ⁻¹ N	
Old technology (1990s European plants)	8.7	5.5
Older technology (1990s European plants with steam heat export)	6.8	1.3
Average current technology (average European plants c.2010)	6.1	1.6
Best available technology	2.7	1.1
<i>Source:</i> Based on outputs of Cool Farm Tool (2012)		

Triggered by the N₂O catalyst technology, the world’s first Carbon Footprint Guarantee was launched in Scandinavia in 2010. This guarantees that the carbon footprint for nitrate fertilizers sold in Denmark, Finland, Norway and Sweden is below 3.6 kg CO₂e per kg N. Such nitrate fertilizers meet requirements for the Swedish Climate Certification for Food. One fertiliser manufacturer claim a 54% reduction in total GHG emissions since 2004 (Yara, 2014).

Cross-media effects

As described above, there is a trade-off between nitrate- and urea-based fertilisers in terms of upstream and field emissions. Emissions abatement in manufacture may require small amounts of additional energy and CO₂ emissions, but this is vastly outweighed by the GHG mitigation benefits. Similarly, production of coated urea pellets, urease and NIs requires energy and gives rise to small additional quantities of GHG emission compared with significant NH₃ and N₂O avoidance. Slot injection of urea fertilisers leads to higher diesel consumption and soil disturbance that could increase C release.

Operational data

GrowHow case study

GrowHow has been working with the Carbon Trust (UK) since 2010 to advise on better types of fertilisers for farmers to use in order to meet supply chain demands for more environmentally responsible practices. Since 2010, GrowHow has reduced its emissions of the potent GHG N₂O by 90 per cent through investment in £9.7 million (EUR 11.4 million) of abatement technology. Overall, GrowHow has achieved a 40 per cent reduction in the carbon footprint of its ammonium nitrate product Nitram. The footprints are certified by the Carbon Trust according to the PAS 2050 standard, and products carry the carbon Trust label.

Applicability

All farms purchasing mineral fertiliser can select more environmentally responsible types.

Economics

TFRN (2011) estimated that NH₃ mitigation costs for low-NH₃ urea fertiliser selection/application or urea substitution with values range from €0.8 to €2.2 per kg NH₃-N avoided (Figure 5.22).

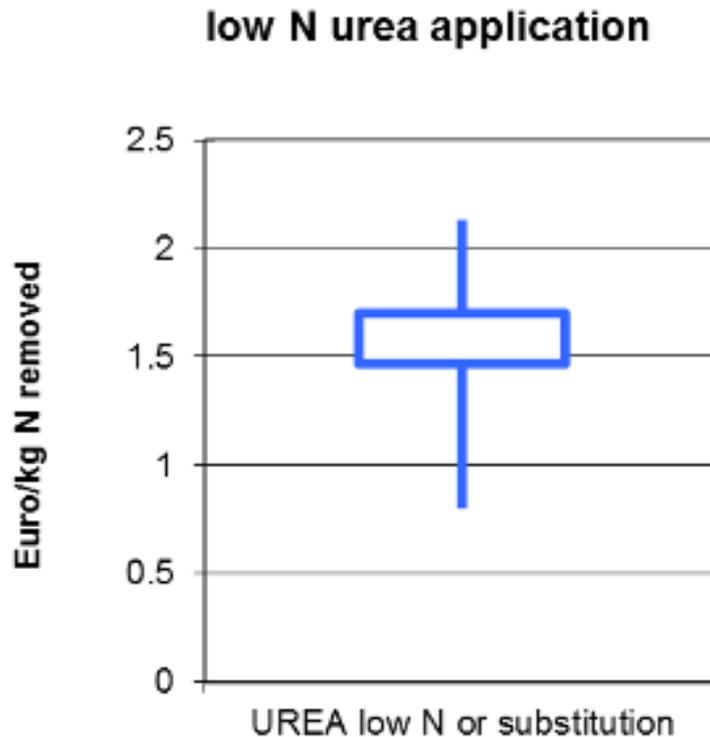


Figure 5.22. Ammonia abatement cost of urea fertiliser substitution or abatement measures (TFRN 2011)

Driving forces for implementation

- Ammonia Emissions Ceiling
- EU ETS III
- Industrial Emissions Directive
- Marketing for fertiliser manufacturers
- Reduced overall fertiliser costs for farmers
- Legislative restrictions on N application rates
- Improved NUE

Reference literature

- Carbon Trust, GrowHow fertiliser. <http://www.carbontrust.com/our-clients/g/growhow>, accessed Oct 2013.
- Chambers, B., Dampney, P., 2009. *Nitrogen Efficiency and Ammonia Emissions from Urea-based and Ammonium Nitrate Fertilizers*. Proceeding of the International fertiliser Society 657: 1-20. ISBN: 978-0-85310-294-6. <http://fertiliser-society.org/society-proceedings/proceeding-657/c-23/p-862>
- Cool Farm Tool CFT, 2012. *Cool Farm Tool* webpage. Tool downloaded August 2012: <http://www.coolfarmtool.org/>
- Fertilizers Europe 2010. *Towards smart agriculture*. Publ. Fertilizers Europe: www.danfertilizers.com
- Fertilisers Europe, 2014. Personal communication January 2014.
- IFA (International Fertiliser Association Industry), 2010. *Greenhouse gas budgets of crop production – current and likely future trends*. Helen C. Flynn and Pete Smith. Publ. IFA, Paris.
- IPCC, 2006. *IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>

- Klimatmärkning för mät. (2010). *Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010.* Sweden: Klimatmärkning för mät.
- Kremer, A.M., 2009. *Calculating Regional Gross Nutrient Balances for the Netherlands.* Statistics Netherlands, The Hague.
- MSU, 2013. *Ammonia volatilization and urea fertilizer.* College of Agriculture, Montana State University: accessed May 2013 from: <http://landresources.montana.edu/ureavolatilization/results.htm>
- Snyder, C.S., Bruulsema, T.W., Jensen, T.L. and Fixen, P.E., 2009. Review of Greenhouse Gas Emissions from Crop Production Systems and Fertilizer Management Effects. *Agriculture, Ecosystems and Environment* 133, 247–266.
- TFRN, 2011. *Draft Guidance Document for preventing and abating ammonia emissions from agricultural sources.* Informal document no. 20. TFRN. Downloaded May 2013: <http://www.clrtap-tfrn.org/documents>
- Yara, 2011. *Nitrate fertilizer: Optimizing yield, preserving the environment.* [www.yara.com/doc/33521_Nitrate - Pure Nutrient.pdf](http://www.yara.com/doc/33521_Nitrate_-_Pure_Nutrient.pdf): accessed Sept 2013.
- Yara, 2012. *Creating impact by developing sustainable solutions for improved productivity,* Publ. Yara, Norway, 38 pp

FINAL DRAFT

6 SOIL PREPARATION AND CROP PLANNING

Introduction

This section is relevant to mixed, arable and horticulture farms and covers five BEMPs, namely:

1. **Matching tillage operations to soil conditions;**
2. **Minimise tillage disturbance;**
3. **Low-impact tillage options;**
4. **Crop rotations for soil quality;**
5. **Establish cover and catch crops.**

Chapter 4 deals with the risks, planning, regular monitoring and measurement of soil quality indicators whilst this chapter covers cultivation techniques used to protect and enhance soil quality.

Inappropriate Soil tillage operations can be responsible for:

- Disruption of soil structure
- Soil compaction
- Faster decomposition of SOC
- Reduction of aggregate stability
- Increased surface sealing
- Reduced soil infiltration - > higher surface runoff
- Increasing soil erosion

The annual soil erosion risk for Europe (Figure 6.1) is based on empirical rules and data coming from CORINE land cover database and meteorological data (Boardman and Poesen, 2006).



Figure 6.1. Annual erosion risk (Boardman and Poesen, 2006)

The Pan-European Soil Erosion Risk Assessment (PESERA) project developed and evaluated a physically based and spatially distributed model to quantify soil erosion focusing on environmentally sensitive areas relevant to a European scale. That model calculates expected mean erosion rates at 1-

km resolution at a European scale. Characteristics like topography, soil, climate, land use and land management data are used in order to estimate ground cover, surface crusting, runoff and sediment transport and to provide an estimation of water and sediment delivered to stream channels (Boardman and Poesen, 2006).

Soil preparation and crop planning must take into account current soil condition and the need to sustain or improve soil condition over time. Soil degradation is occurring world-wide and it is estimated that 16% of Europe's land area is degraded. The highest erosion rates occur in Southern Spain, Italy, Sicily, Sardinia and Greece (Figure 6.2). A closer analysis of the map in Figure 6.1 shows that 16.7% of the EU-15 (excluding Finland and Sweden) is susceptible to considerable erosion risk, while the highest rates occurring in Mediterranean area (Figure 6.2). In Mediterranean area the main problem is the physical, chemical and biological quality of soil, whilst it is particularly difficult to reduce soil erosion. In particular, high rainfall intensity and frequent occurrence of extreme events increase the risks of soil losses. Moreover, the intense agriculture activities, the drought conditions, the highly mechanised farms, the forest fires, land abandonment increase the risk of soil degradation (Boardman and Poesen, 2006).

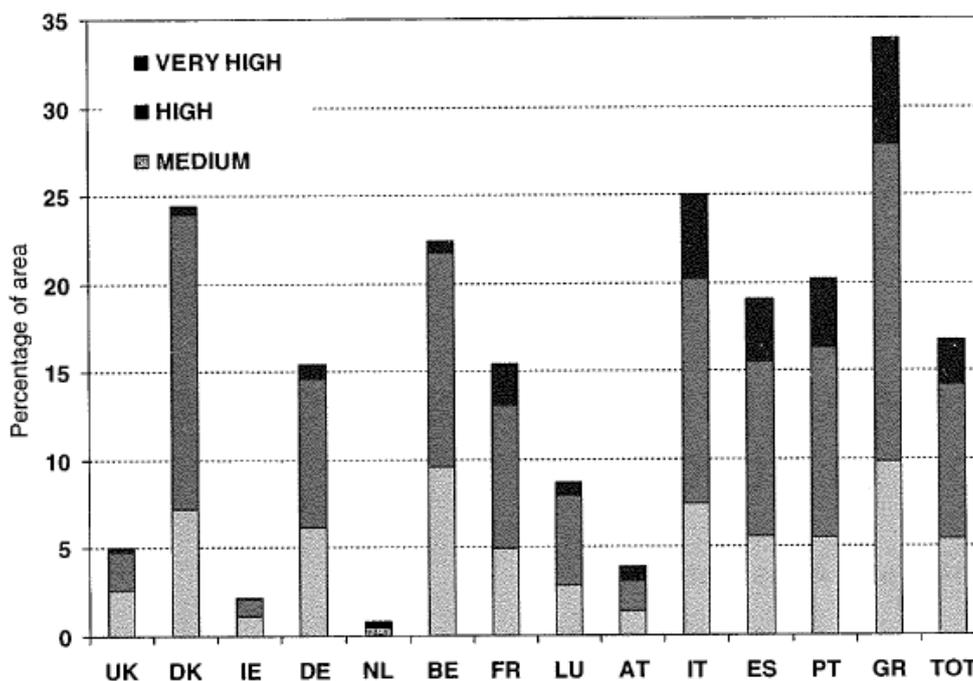
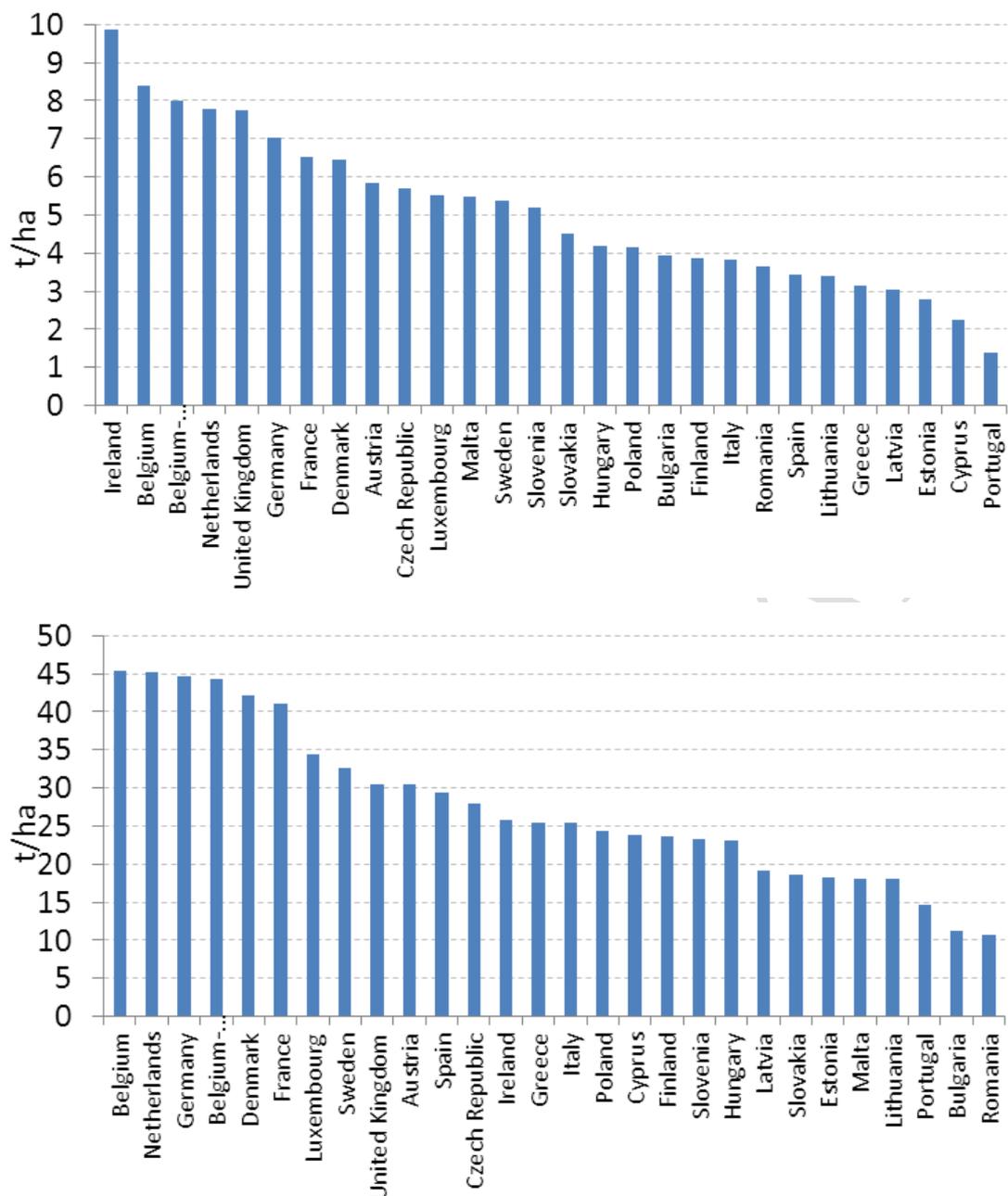


Figure 6.2. Risk of erosion by water in Europe (Boardman and Poesen, 2006)

There is considerable variation in average yields of various tillage crops across EU member states. Whilst some of this variation may reflect biophysical constraints, it has been reported that lower yields in Eastern Europe reflect less developed management practices in former eastern-block countries (EC, 2008). Therefore, it is likely that there is considerable scope for yield improvements with little additional environmental burden per hectare, resulting in lower burdens per tonne produced, in a number of EU member states such as Bulgaria and Romania. Yield improvements could also lead to land sparing, with numerous potential environmental benefits. Nonetheless, there are also arguments in favour of maintaining lower average yields with more extensive management practices that can lead to improvements in environmental aspects such as biodiversity and soil quality.



Source:

FAO Stat (2013).

Figure 6.1. Average yields of wheat (top) and potatoes (below) across EU member states in 2011 (wheat) and 2012 (potatoes).

Reference literature

- Boardman J. and Poesen J. 2006. Soil erosion in Europe, John Wiley and Sons Ltd., ISBN: 13-978 0-470-859-10-0.
- FAO Stat, 2013. Agricultural statistics gateway page. Accessed Aug 2013: http://faostat3.fao.org/faostat-gateway/go/to/download/Q/*/E
- EC, 2008. *Environmental Improvement Potentials of Meat and Dairy Products*. Weidema, B. P., Wesnæs, M., Hermansen, J., Kristensen, T., Halberg, N., Peter Eder and Luis Delgado (Editors). JRC/IPTS, Seville. 217 pp.
-

6.1 Matching tillage operations to soil conditions

Description

Within this BEMP, the following measures are discussed:

- Soil damage risk related to type and slope
- Careful timing of operations with respect to soil moisture and weather
- Remove peat soils from cultivation where possible

The following considerations can both optimise crop establishment and protect soils (Westcountry Rivers Trust, undated):

- Aim to match cultivation techniques to crops with field topography and soil type (section 6.1);
- Timeliness is the key to good soil management and successful crop establishment. Take account of weather and soil conditions. Avoid working wet land to minimise the potential for capping, compaction, smearing, runoff and erosion of soils. Check soil wetness by digging a small hole before operations (section 6.1);
- Consider ploughing less deeply and less often to reduce energy input (section 6.2);
- Use low ground pressure impact tyres or tracked vehicles to reduce wheeling damage (section 4.3);
- Plan weed control. Use herbicide sparingly and at the right time. Rotate crops to improve soil structure, fertility and control weeds (section 6.4);
- Consider the use of machinery rings or contractors to increase work rates and ensure timeliness of operations;
- Consider adopting minimum tillage, direct drilling, rough ploughing and contour ploughing where possible (section 6.2 and 6.3).

Timing

Soil workability under field capacity conditions depends on soil type. Trafficking over wet soils results in compaction, smearing, increased sediment and nutrient run-off, erosion, poor crop germination and root development. Sandy soils are easier to work when wet than clay soils. However, reduced tillage techniques work best on clay loam soils and are not recommended for sandy soils.

Where soil conditions allow, it is best practice to sow winter cereal crops early if a reduced cultivation option is used; cover crops should be sown if cereals are not sown until spring. Establishment of autumn drilled combinable crops by early October would enable the crop to take up some N before the onset of over-winter drainage and provide good vegetation cover (at least 25 to 30%) over the winter months to protect the soil from rainfall induced surface runoff and associated erosion.

However, in both aforementioned cases, it should be stressed that the presence of the crops/plants in the field reduces the erosion incidents. For instance, during the mulch-till, the tillage tools must be equipped, adjusted and operated to ensure that adequate residue cover remains for erosion control and the number of operations must also be limited. In particular, at least 30% of the soil surface must be covered with plant residue after planting³¹.

³¹ More information can be found at the book 'Soil erosion in Europe' edited by Boardman J. and Poesen J. (2006), by Wiley and Sons Ltd.

Advantages and disadvantages of early or late autumn sowing of winter cereal crops

Early sowing			Late sowing	
✓	A	Yield	B	x
✓	A	Opportunities for cultivation/spraying	B	x
✓	A	Crop vigour & competition	B	x
✓	B	Seed-rate	A	x
✓	B	Nitrate leaching	A	x
✓	B	Slug damage	A	x
✓	A	Workload spread	A	✓
x	A	Weeds	B	✓
x	A	Diseases	B	✓
x	A	Pests	B	✓
x	A	Pesticide costs	B	✓

A = increase B = decrease ✓ = advantage x = disadvantage

Source

: HGCA (2002)

Figure 6.3. Considerations to be taken into account when deciding when to sow winter cereals

<p>Sowing date</p> <ul style="list-style-type: none"> Where appropriate (site-specific) sow winter cereals early. 	<ul style="list-style-type: none"> Reduced nitrate leaching on high risk sites. Improved workload spread. Lower seed costs. Higher yields.
<ul style="list-style-type: none"> Where appropriate (site-specific) sow winter cereals late. 	<ul style="list-style-type: none"> Opportunity to use stale seedbeds to improve weed control. Reduced risk of BYDV as aphid vectors are more prevalent on early-sown crops. Less autumn disease pressure. Improved workload spread. Lower crop protection inputs.
<ul style="list-style-type: none"> Sow spring crops when seedbed conditions are suitable. 	<ul style="list-style-type: none"> Optimal establishment.

Source: HGCA (2002)

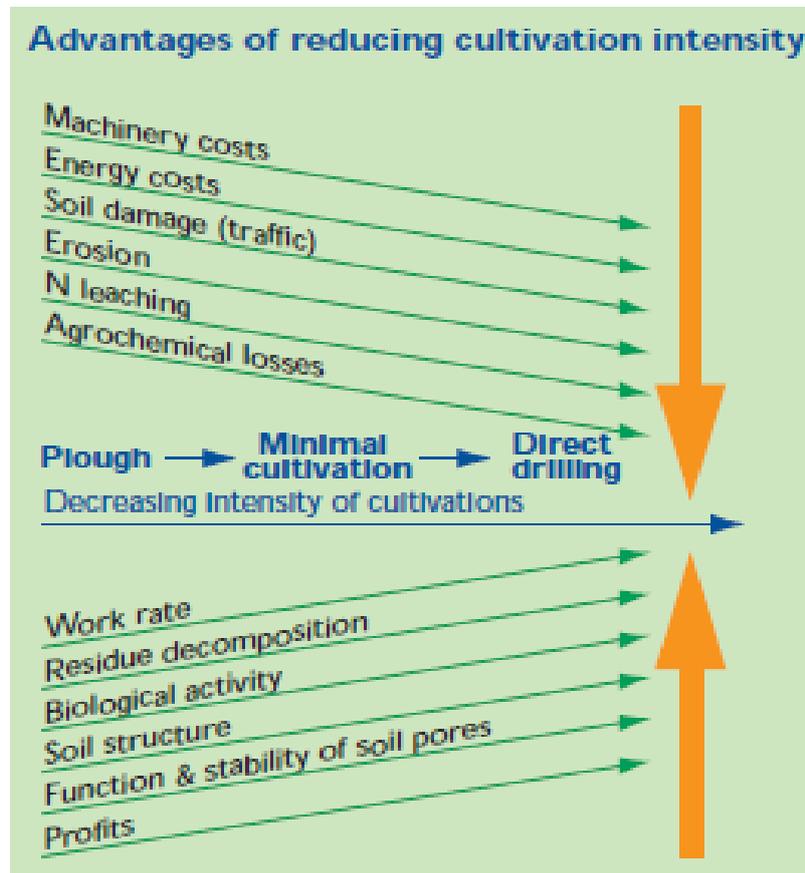
Figure 6.4. Sowing date versus benefits

Where conventional tillage has to be used, for example to remove a deep pan /compacted zone, then it is best done in spring to reduce N-leaching potential. In this scenario, a catch crop should be planted in winter after stubble (high C:N material) has been incorporated to immobilise soil mineral N.

Cultivation techniques

Cultivation techniques that reduce the depth and extent of soil disturbance protect soils by avoiding (Figure 6.5 and Figure 6.6):

- Burial of organic matter and nutrients to soil depths beyond the major rooting zone;
- Fragmentation of soil aggregates resulting in mineralisation of organic matter (flushes of CO₂ and NO₃-N);
- Disrupting continuity of natural channels that allow water and oxygen infiltration.



Source: HGCA (2002)

Figure 6.5. Advantages of reducing cultivation intensity

Cultivation by soil type

✓ good fit ✓✗ Use with care ✗ No/ poor fit

Soil types	Light unstable	Medium unstable	Light stable	Medium stable	Heavy stable
Equipment	Sandy	Silty	Light loamy	Medium loamy	Clayey
Plough	✓	✓	✓	✓	✓✗
Chisel plough	✓	✓	✓	✓	✓✗
Tined cultivator	✓	✓	✓	✓	✓✗
Heavy disc harrows	✗	✗	✓✗	✓	✓
Disc+tine+consolidation	✓✗	✓	✓	✓	✓
Light disc harrows	✗	✓✗	✓	✗	✗

Source: SMI, (2000)

Figure 6.6. Align cultivation technique to soil type

Avoid cropping and cultivation of peat soils

IPCC (2006) default C and N₂O losses from drained peat land:

- 0.25-2.5 t C/ha/y, mean for cold temperate 0.25 (0.9-9.1 t CO₂e/y)
- 2-24 kg N₂O-N/ha/y, mean 8 (0.9 - 11 t CO₂e/y)

There is a high risk of leaching of P from peat soils. Especially in the Nordic countries of the EU (Figure 6.7 and Figure 6.8), large areas of low decomposed sphagnum peat is cultivated and these soils can contribute significantly to the P loading of surface and groundwater (Schoumans et al., 2011). Use organic soils only for permanent pasture or extensive grazing (BEMP 5.1).



© Copyright [Keith Evans](#) and licensed for reuse under this [Creative Commons Licence](#)

Source: Photo taken by Keith Evans

Figure 6.7. Picture of Holme post in Cambridgeshire, UK, showing the depth of peat soil oxidation and shrinkage over the past one hundred years, relative to top of the post that was level with the soil surface on initial burial.



Source: Photo taken by Helen Taft

Figure 6.8. A dust storm on cultivated peat soil in Cambridgeshire.

Achieved environmental benefits

Soil quality and emissions

The key environmental benefits are soil conservation and energy efficiency from reduced fuel use. Table 6.1 indicates the benefits of reduced tillage operations.

Table 6.1. Effects of tillage practices on soil quality and pollutant translocation over a 14-year period in Austria.

	Conventional Tillage	Mulch-seed	Direct drilling
Soil loss t/ha	6.1	1.8	1.0
reduction		70%	83%
Corg - loss kg/ha	76.7	27.5	19.2
reduction		64%	75%
N - loss kg/ha	9.2	3.7	2.5
reduction		61%	73%
P - loss kg/ha	4.7	1.3	0.75
reduction		72%	84%
runoff in mm	23.5	21.4	18.3
Herbicide loss % sprayed active substance	2.20%	1.01%	0.57%
reduction		55%	74%
Herbicide loss in runoff	1.73%	0.87%	0.17%
reduction		50%	90%
Herbicide loss in sediment	3.09%	1.16%	1.99%
reduction		62%	36%

Source: Rosner et al. (2008) citing Klik et al. (2008).

Lower fuel consumption is an important benefit of reduced tillage (Table 6.2): 250 L/ha (conventional) cf. <80 L/ha (no-till) (Rosner et al., 2008).

Table 6.2. Energy use (MJ/ha) of differing tillage operations. Example energy values, reflecting the complexity, capital involvement, draught requirement and work rate of each operation are given for some equipment. Direct energy – that used in operating equipment on farm. Indirect energy – an estimate of that used in manufacturing inputs and machinery.

Equipment	Direct energy	Indirect energy	Total energy
Plough	1,160	890	2,050
Heavy disc	860	700	1,560
Power harrow	840	750	1,590
Seed drill	280	200	480
Fertiliser spreader	32	18	50
Sprayer	51	34	85

Source: HGCA, 2002

Appropriate environmental performance indicators

Management Indicators

Matching tillage operations to soil conditions requires extra vigilance from the farmer who will need to invest the time to know each field's characteristics and work to a plan.

- Monitor soil condition for erosion and compaction (see section 4.3)
- Slope of tillage fields
- Refer to erosion risk plan / matrix
- Produce a plan for cultivations for each field as part of annual soil protection review
- Implement reduced tillage techniques wherever possible

- Avoid tillage of peat soils
- Visible signs of erosion e.g. gullies

Environmental indicators

- Soil organic matter content (% change) in topsoil
- Earthworm population per m²
- Winter soil cover by vegetation, %
- Energy use (L fuel or MJ/ha)
- % soils cultivated that are peat
- Emission factors CO₂ and N₂O
- Emission factors CO₂ and N₂O for cultivated peat soils
- NO₃ leaching losses would be reduced by up to 30% through early winter cereal establishment and associated indirect N₂O emissions (Newell-Price et al., 2011).
- Particulate P and associated sediment losses would typically be reduced in surface runoff by 20-50% (Newell-Price et al., 2011).
- Presence of earthworms (Y/N)

Cross-media effects

Possible increase in N₂O EF from soil compaction if not ploughed (heavier soils in particular), may require more weed management, otherwise little or no effect (EC, 2013).

Applicability

Reduced cultivation techniques recommended for early winter sowing are not suitable for sandy or structure-less soils.

Economics

Case Study: Protecting soil over winter (Westcountry Rivers Trust, no date)

To avoid bare ground after maize harvest from October until the following May, on soils which often cannot be ploughed in autumn, a 5 ha maize crop was undersown with herbicide tolerant Italian ryegrass for worm-free ewe/lamb winter and spring grazing.

Broadcasting and seed costs were approximately £86/ha = £430 (EUR 500).

The undersown crop produced six tonnes DM/ha with a Relative Feed Value (RFV) of approximately £38/tonne, which was worth £1140 (EUR 1340).

The total saving was £1140, which represents a net saving of £710 and payback in less than a year.

This excludes the uncoded benefits of reduced soil damage and productivity loss associated with untimely operations, runoff and soil erosion.

Driving forces for implementation

- Soil Protection Strategy
- Nitrates Directive
- Water Framework Directive
- Single Farm Payment requires annual, documented Soil Protection Review as part of Cross Compliance
- Long-term yields and profitability

Reference literature

- EA, 2008. *Think Soils: Soil assessment to avoid erosion and runoff*. Environment Agency, Bristol, UK

- FAO Stat, 2013. Agricultural statistics gateway page, accessed August 2013: http://faostat3.fao.org/faostat-gateway/go/to/download/Q/*E
- HGCA, 2002 Arable cropping and the environment– a guide. HGCA, London.
- IPCC, 2006. *IPCC guidelines for national greenhouse gas inventories*. In: Eggleston H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (Eds.), Volume 4 – Agriculture, Forestry and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme, Institute for Global Environmental Strategies, Japan.
- EC, 2008. *Environmental Improvement Potentials of Meat and Dairy Products*. Weidema, B. P., Wesnæs, M., Hermansen, J., Kristensen, T., Halberg, N., Peter Eder and Luis Delgado (Editors). JRC/IPTS, Seville. 217 pp.
- EC, 2013. *River Basin Network on Water Framework Directive and Agriculture*. (Ed.) F.Somma. Luxembourg: Publications Office of the European Union. 260 pp.
- Klik, A. 2011. *Soil Conservation and Soil Protection*. VU 815.321 Universität für Bodenkultur Wien, Austria. Accessed from: http://www.wau.boku.ac.at/fileadmin/ /H81/H815/Skripten/Sonstige/Soil_Conservation.pdf
- Klimatmärkning för mät, 2010. *Criteria for Mitigation of Climate Impact from Food Production and Distribution*. Version 2010:3, accepted by the project steering group on October 5th, 2010. Sweden: Klimatmärkning för mät.
- Newell-Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R., Misselbrook, T.H., 2011. *An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture*. ‘ADAS’ and ‘Rothamsted Research, North Wyke’; Defra Project WQ0106 (Dec. 2011).
- Rosner, J., Zwatz, E., Klik, A. 2008. *Influence of different Tillage Systems at yield and quality – results of field trials in Lower Austria*. International Soil Tillage Research Organisation (ISTRO)-Czech Republic Branch, Proceedings 5th. International Soil Conference ‘Soil tillage – New Perspectives’, Brno, Czech Republic, June 30 - July 2, 2008. http://istro.cz/soub/Proc_2008.pdf
- Schoumans, O.F. (Ed.), Chardon, W.J. (Ed.), Bechmann, M., Gascuel-Oudou, C., Hofman, G., Kronvang, B., Litaor, M.I., Lo Porto, A., Newell-Price, P., and Rubæk, G., 2011. *Mitigation options for reducing nutrient emissions from agriculture*. A study amongst European member states of Cost action 869. Wageningen, Alterra, Alterra-Report 2141. 144 pp.
- SMI, 2000. *Soil Management Initiative Guide 2000: A guide to managing crop establishment*. SMI Ltd., Chester, England. 52pp. Accessed on Feb 2014: <http://adlib.everysite.co.uk/resources/000/091/259/vicjordancropguide.pdf>
- Westcountry Rivers Trust (no date) Pinpoint Best Practice Information Sheets: Cultivation techniques to protect soils no 22a and 22b. Callington, England. http://www.riverstrust.org/pinpoint/info_sheets/Pinpoint%20-%2022.0%20Cultivation%20techniques%20to%20protect%20soils%20-%20Introduction.pdf.

6.2 Minimise soil preparation operations

Description

Within this BEMP, the following measures are discussed:

- Zero tillage direct drilling
- Strip tillage (direct drilling with a degree of cultivation and root loosening).
- Reduced tillage operations

Best practice is to use appropriate field operations to improve soil structure, porosity and microbial activity (EISA, 2012). If soil type, condition and structure are appropriate, then consider using minimum tillage/non inversion tillage techniques for crop establishment. Farmers should also record field conditions under which specific soil operations were chosen.

The main reasons for adopting minimum tillage or no-till are to reduce production costs and enable a greater area to be cultivated in a given time, with the goal of maintaining or increasing yields (and margins) per unit area, but environmental benefits are also possible.

Establishment of crops without conventional ploughing involves the use of non-inversion cultivators and/or specialist drills. There are fewer passes than conventional tillage, and it is shallower, which leaves most crop residues in the top 10 cm (Knight et al., 2012, citing Morris et al., 2010). This is referred to as minimum or reduced tillage. Another method of non-inversion tillage is no-till (also known as direct drilling and zero tillage). Crops are sown without any prior loosening of the soil by cultivation other than the very shallow disturbance (< 5cm) which may arise by the passage of the drill coulters and after which usually 30-100% of the surface remains covered with plant residues (Knight et al., 2012, citing Soane et al., 2012).

Strip-tillage can combine seeding and fertiliser application in a single pass while still giving residue cover to the soil between the rows. Advantages are less trafficking over the field, saving in time and fuel and accurate placement of fertiliser to the seed (or seedling), which improves nutrient use efficiency.

Chisel plough is a process where to get deep tillage with limited soil inversion/disruption. The main approach of this technique is to loosen and aerate the soils while leaving crop residue at the top of the soil. Since the soil surface still contains some amount of plant and stubble a good surface layer is formed. It is very effective against root propagating weeds as well as can be used on extremely heavy soils where other types of tillage tools are quality and capacity wise unsatisfactory. After stubble tillage the soil surface still contains adequate amount of plant and stubble that helps to control wind and water erosion. Chisel Plough should not be used when the soil is too wet.

It is estimated that about 40% of crops in England are now managed by reduced tillage (Figure 6.9). It is common for farmers in the EU to view yield reduction as a constraint to adopting reduced tillage but evidence for effects of minimum tillage over a long period on crop yields is sparse. It is however generally shown that where there are reductions in yield, these are small (4% for winter cereals) and that this was usually offset by a significant increase in gross margins. Additionally, the soil organic matter content and micro-organism are higher in soil under reduced tillage operations. In particular, in fields with reduced or no tillage soil organic matter is more abundant in soil surface layer as a result of plant residue decomposition. Therefore the crust formation is prevented whilst soil porosity and infiltration rates are increased (Isikwue and Adakole, 2011)

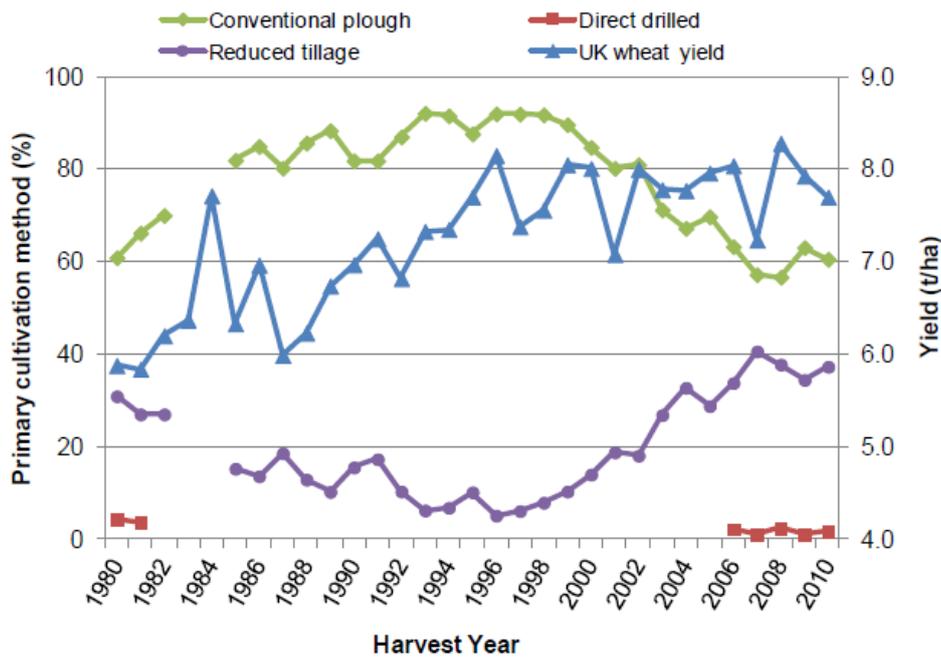


Figure 6.9. Trend over time in wheat yields and three types of cultivation intensity (Knight et al., 2012)

The soil preparation operations are associated with the applied farming system. From a technical point of view, the application of different farming system set an effect to the related management practices. For instance, the use of a crop rotation scheme may influence the amount and the type of the applied pesticides, fertilisers needed in the field. As a general remark, the no-tillage choice reduces soil losses, conserves soil moisture, changes the weed management needs, increases water infiltration rates and reduces surface flows. Therefore, there are the conventional farming systems, which use synthetic inputs and on the contrary there are the organic farms, which do not use synthetic inputs. The farming systems between the conventional and the organics take into account local resource situations, available technology, producer preferences and other techno-economic and management options. Table 6.3 presents the combination of production management practices including soil, pest and nutrient management (Richard Magleby, (2002).

Table 6.3. Presenting the farming systems including different soil, pest and nutrient management options (Richard Magleby, 2002)

Farming system	Soil management	Pest management	Nutrient management
Synthetic input, high precision, diversified	Corn/wheat/soybean rotation using no-till, rye as a cover crop	Synthetic pesticides applied where needed as determined by scouting	Synthetic fertiliser nutrients applied in specific amounts using precision equipment
Organic farming		Only biological and cultural pest management practices used	Only legume, manure, or other organic fertiliser used
Cropping pattern	Tillage type	Pest management options	Nutrient management options
Row crop rotation	Reduced-till	Synthetic pesticide application to selective parts of field based on scouting and economic threshold	Synthetic fertiliser applied generally to entire field
Rotation with pasture	No-till	Only biological and cultural pest control methods used	Synthetic fertiliser applied in variable amounts using precision equipment

More relevant data collection sources are presented below³².

The trial comprises four rotations and four cultivation systems (giving a total of 16 treatments):

Winter cropping Spring cropping Continuous winter wheat Alternate fallow	X	Annual plough Managed approach* Shallow tillage Deep tillage
---	----------	---

* Managed approach decisions are based on ‘best practice’ at the time, taking into account soil/water conditions, previous cropping, weed burden and soil assessments.

Table 6.4. Wheat crop yields following non inversion tillage compared to ploughing. Mean of 4 crop rotations and 3 seasons (2007, 2009 & 2011) (Knight et al., 2012)

Primary Cultivation	Mean winter wheat yield (% of ploughed)			
	2007	2009	2011	Mean
Plough	100	100	100	100
Deep non-inversion	89	107	109	101
Shallow non-inversion	86	106	108	100

The trial is now completing its seventh year (in 2013). Key findings so far include (Norris, 2013):

- Plough-based systems tending to give the higher yields;
- Managed approach tending to give the highest margins;
- Lowest yields and margins with shallow non-inversion tillage;
- Winter cropping giving highest and most consistent cumulative gross margin;
- Continuous wheat plots established with non-inversion systems show an increasing grass weed burden;
- Changes in gross margin ranking are being seen as the trial progresses;
- Long term impacts of systems on soil structure becoming apparent as the study develops.

Strip tillage only cultivates the soil into which the seed is to be placed and leaves the space between rows totally undisturbed (Figure 6.10).



³² STAR is a NIAB TAG with Felix Cobbold; Trust project: <http://www.felixcobboldtrust.org.uk/star-project.html> Useful data has started to emerge from this long-term fully replicated field trial.



Figure 6.10. Strip tillage minimises soil disturbance (Hosting pics, 2014)

Achieved environmental benefits

The West Country Rivers' Trust (no date) report the following benefits of reduced tillage:

- Emission factors CO₂ and N₂O: total carbon loss (as CO₂) from ploughed land can be 5 times higher than from unploughed land (SMI, 2000)
- Lower costs and energy inputs
- Less wear and tear on machinery
- Improved soil structure and less risk of damage from machinery
- Reduced soil erosion and runoff
- Increased beneficial invertebrates and earthworms
- Reduced mineralisation of nitrogen and reduced leaching risk.

Improved soil management can have many benefits (SMI, 2000)

- When crop residues are left on the surface or incorporated, a more stable soil habitat with high organic matter content created.
- Micro-organisms break down organic matter and perform many useful functions: they recycle crop residues making the nutrients available to the crop; a richer soil biota ensures pesticides are efficiently degraded and they promote good soil structure and quality;
- Earthworms numbers increase and recycle organic material thus promoting soil health;
- Soil fauna which over winter are better able to survive and contribute to both pest control and food sources for farmland birds;
- Weed and crop seeds remaining on the surface are available for birds, mammals and insects;
- Biodiversity and species richness is increased;
- The presence of vegetation, soil organic matter and improved soil structure increases infiltration;
- By creating a more healthy soil with better structure, crop rooting is improved, crop stress created by extremes is lower and consequently there may be less need for pesticides;
- Nutrient and agrochemical losses are reduced;
- Soil erosion and off site impacts are reduced for example, control of soil erosion reduces silt; deposition in river beds protecting fish spawning and their food supply;
- Reduced cultivations offer possibilities to lower CO₂ emissions and reduce energy use (fuel).

No and reduced tillage have both been associated with a reduction in N₂O emissions, however reports differ on degree of benefit with some even showing an increase in emissions (Table 6.5). This reflects the highly ephemeral nature of conditions that lead to N₂O production, including soil moisture content, porosity and texture.

Table 6.5. Reported effects of no-till soil N₂O emissions in terms of % increase or decrease in comparison with conventional tillage treatment (Flynn and Smith, 2010)

Location and duration	Change in N ₂ O emissions mean (range%)	Reference
Canada, 4 years	-14.5 (-35 to 4.5)	Malhi and Lemke, 2007
Canada, 2 years	-51 (-52 to -50)	Malhi et al., 2006
Denmark, 91 days	-25	Chatskikh and Olesen, 2007
Canada, 3 years	13 (-25 to 63)	Gregorich et al., 2005
Canada, 3 years	145 (98 to 220)	Gregorich et al., 2005
Canada, 2 years	-27 (-31 to -24)	Gregorich et al., 2005
Canada, 2 years	23 (-27 to 49)	Gregorich et al., 2005
Canada, 1 year	-14	MacKenzie et al., 1998
Canada, 1 year	-37	MacKenzie et al., 1998
Canada, 1 year	60	Gregorich et al., 2005
Canada, 2 years	-15 (-26 to -3)	Kaharabata et al., 2003
USA, 1 year	-65	Elder and Lal, 2008
Canada, 2 years	87.5	Mkhabela et al., 2008
Scotland, 12 weeks	280	Ball et al., 2008

Unlike N₂O, the effects of reduced and no-till on soil C storage are generally more likely to increase SOC than not, but even so there are reports that find the opposite (Table 6.6). Discrepancies in effect can result from differences in how deep soil is sampled.

It is possible that some study results may not necessarily represent equilibrium conditions in the experimental treatment. Rather, they reflect the transient response of the system after tillage conversion and associated practices like crop residue incorporation and cover crop addition. It can be expected that soil microbes take time to adjust to the reduction in tillage and increased C inputs. Therefore, continued, long-term monitoring is needed to elucidate what happens once equilibrium conditions are attained. Schulte et al. (2012) marginal abatement cost curve model assumes a change in C stocks as a result of changing to non-inversion tillage will take 40-60 years to attain equilibrium.

Compared to conventional tillage, CT or NT reduces CO₂, improves SOC and soil structure but can also lead to increase in N₂O, depending on climate and soil type; moist, warm soils tend to emit more N₂O under CT. Global warming may exacerbate this in the future (Abdalla et al., 2013).

Table 6.6. Reported effects of reduced or conservation tillage on soil C storage compared to conventional tillage (Flynn and Smith, 2010)

Measure/treatment	Location and duration	Change in C storage (tCO ₂ /ha)	Reference
Conserv. till	Argentina, 6 years	31.2	Diaz-Zorita, 1999
Conserv. till	Argentina, 6 years	20.5	Krüger, 1996
Reduced till	Argentina, 6 years	18.3	Diaz-Zorita, 1999
Reduced till	Argentina, 6 years	4.4	Krüger, 1996
Conserv. till	Canada, 3-8 years	-23.5 to 2.6	Angers et al., 1997
Conserv. till	Canada, 4 years	16.9 to 26.4	Franzluebbbers and Arshad, 1996a
Conserv. till	Canada, 4 years	13.6	Grant and Lafond, 1994
Conserv. till	Canada, 6 years	9.9	Franzluebbbers and Arshad, 1996b
Conserv. till	Canada, 7 years	-2.6 to 3.7	Franzluebbbers and Arshad, 1996a
Conserv. till	Canada, 16 years	-21.3 to 12.1	Franzluebbbers and Arshad, 1996a

Measure/treatment	Location and duration	Change in C storage (tCO ₂ /ha)	Reference
Reduced till	Canada, 3 years	33	Angers et al., 1997
Reduced till	Canada, 4 years	0.7	Grant and Lafond, 1994
Reduced till	Canada, 3-11 years	2.9 to 11	Campbell et al., 1998
Conserv. till	Spain, 13 years	-4.8 to 5.9	Hernanz et al., 2002
Reduced till	Spain, 13 years	13.9 to 17.2	Hernanz et al., 2002
Conserv. till	USA, 11 years	12.8	Yang and Wander, 1999
Conserv. till	USA, 12 years	-0.4 to 17.6	Halvorson et al., 2002
Reduced till	USA, 3 years	-25.7 to -11.4	Dao et al., 2002
Reduced till	USA, 8.5 years	9.2	Yang and Wander, 1999
Reduced till	USA, 11 years	-9.5	Yang and Wander, 1999
Reduced till	USA, 12 years	-9.5 to 6.2	Halvorson et al., 2002

Benefits of reduced and no-till according to Newell-Price et al. (2011) are:

- Particulate P and associated sediment loss reductions can be up to 60% on medium/heavy soils and up to 90% on light soils.
- CO₂ emissions would be reduced as a result of the lower power requirements of reduced/no-till cultivation. Soil carbon storage would be increased by a small amount typically 0.57 t CO₂e/ha/year for reduced tillage and 1.14 t CO₂e/ha/year for no-till.

According to Schulte et al., (2012), application of min-till across Irish cereal production would lead to a 0.77 t CO₂e/ha/y increase in SOC but also an increase in N₂O of 0.1 t CO₂e/ha/y and a total saving of €43.58, principally from savings in fuel usage (Figure 6.11 and Figure 6.12).

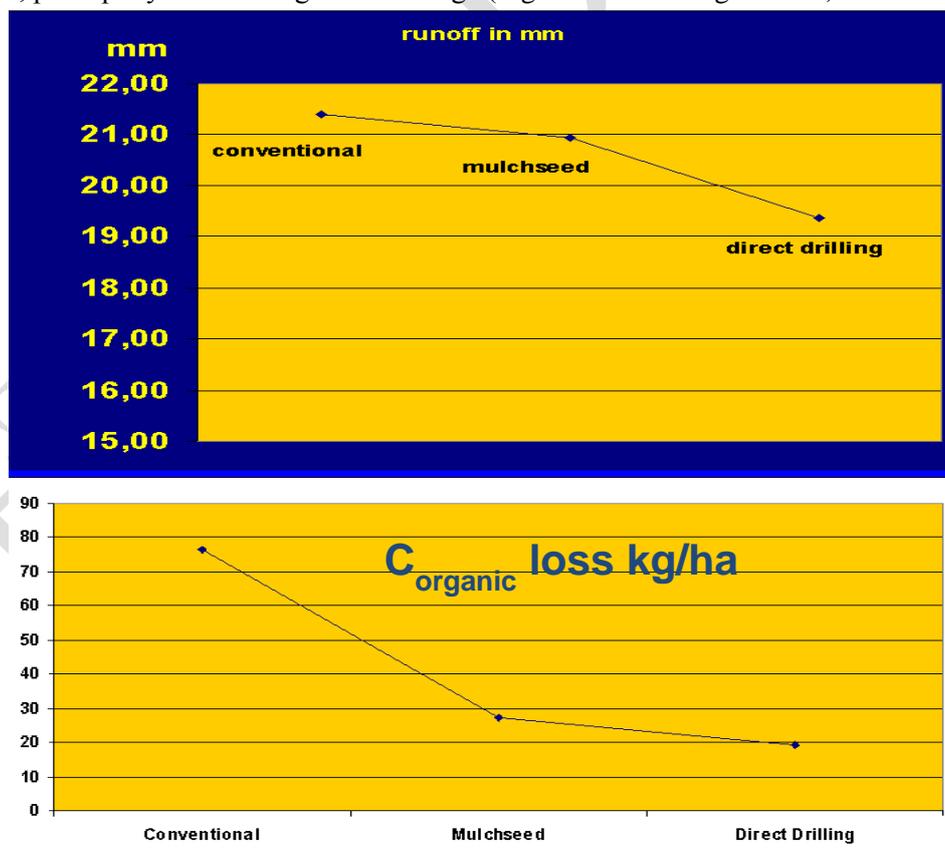


Figure 6.11. Effect of different seeding techniques on runoff (mm) and SOC loss (kg/ha) (Rosner et al., 2011)

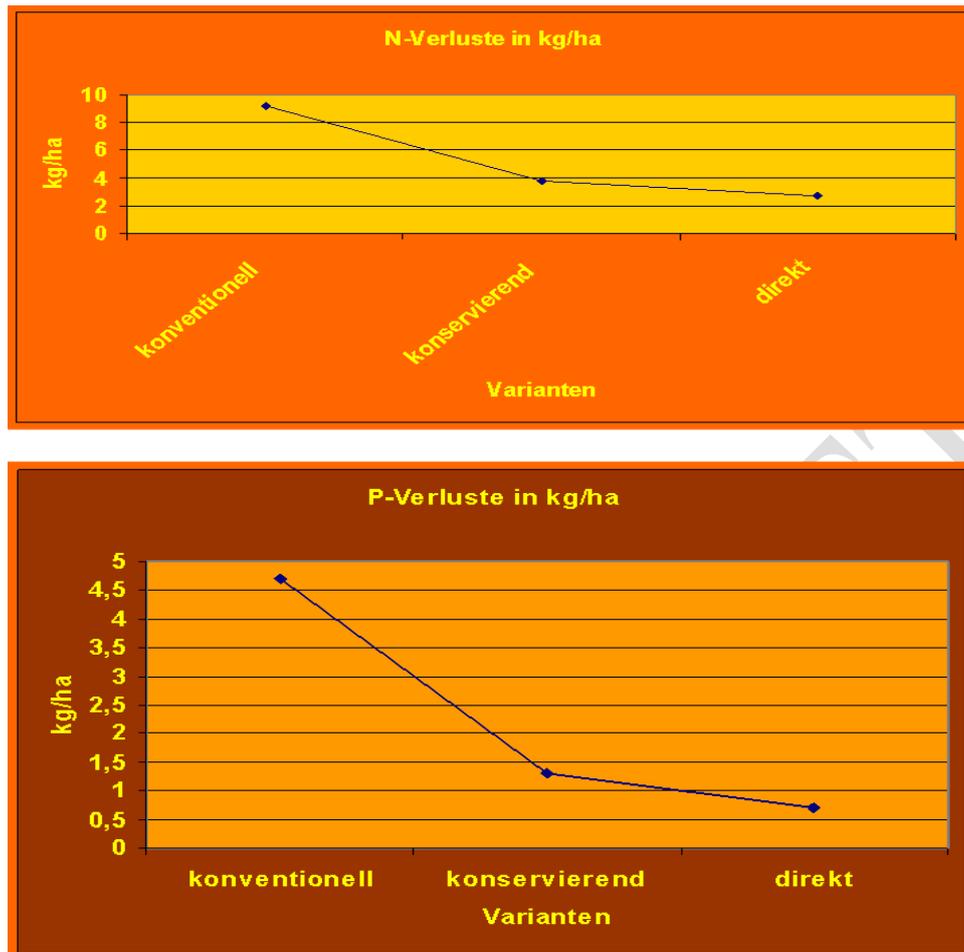


Figure 6.12. Effect of different cultivation intensities (conventional, conservation, no-till) on N and P losses (kg/ha) (Rosner et al., 2011)

Concluding, in general the chisel plough contributes to the increase/maintenance of the water stored in soil, the increase in organic matter and the control of raindrop splash. In parallel contributes positively to soil fertility, reduction of the wind speed as well as the improvement of the soil structure.

Appropriate environmental indicators

Management Indicators

The key indicator for tillage strategies is to use minimum soil disturbance whilst simultaneously avoiding or addressing compaction issues with minimum cultivation.

- Employ direct drill practices or minimum tillage alternatives such as strip tillage
- Produce a plan for cultivations for each field as part of annual soil protection review
- Monitor soil colour and soil aggregate (crumb) structure
- % seeding area where direct drilling applied
- % area where low-impact soil preparation methods applied

Soil physical and biological properties

These reflect soil erosion and compaction risk in addition to general soil quality:

- Soil bulk density (g/cm^3) or penetrometer reading (MPa)
- Infiltration capacity mm/h
- Earthworm numbers or mass $/\text{m}^2$
- Erosion losses (t/ha/y)

- Erosion degree (visual inspection)
- % land area receiving low-impact tillage (cf. CT)
- Emission factors CO₂, N₂O
- Topsoil SOM content (%C, LOI) increase on 4-year rolling average
- Soil water holding capacity (section 4.3)
- Soil colour (brown = good; mottled or grey = anaerobic/waterlogged)

Table 6.7. Mean and high numbers and weights of macro and mega fauna in soil/m² soil in Middle and Northern Europe (Dunger, 1983, cited in Blume, 1992; Klik, 2011)

Group	No. of individuals		Weight (g/m ²)	
	m	h	m	h
Macrofauna				
snail	50	1,000	1	30
spiders	50	200	0.2	1
beetles	100	600	1.5	20
Megafauna				
earthworms	100	500	30	200
vertebrates	0.01	0.1	0.1	10

Figure 1: number and weight of Earthworms 0-30 cm 2004 - 2006

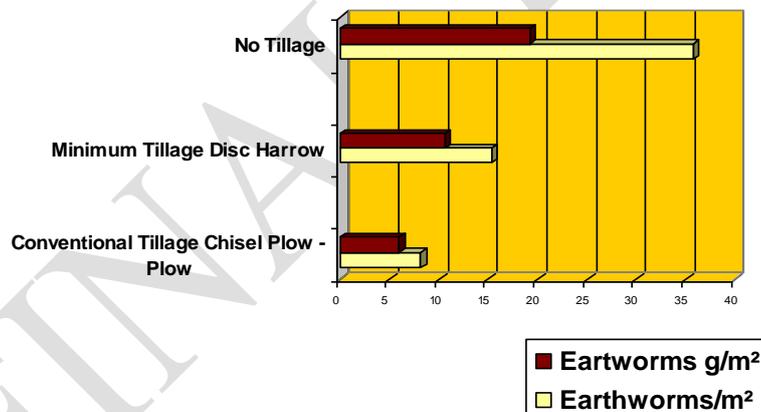


Figure 6.13. Earthworm numbers and weight g/m² in three different tillage intensities (Rosner et al., 2008)

Cross-media effects

- Min-till is sometimes linked to reduced yield and this could result in needing to cultivate more land if yield is the priority.
- It can also result in more weed problems leading to increased use of herbicide unless weed management is carefully incorporated into cultivation techniques e.g. stale seedbeds.
- A 1-in-5 yield penalty can occur via grass weed infestation (Schulte et al., 2012)

Operational data

Precautions and other measures to implement with reduced tillage EISA (2012):

- Crop residues must be evenly distributed on the soil surface: straw bundles negatively affect germination of following crops as well as the exchange of soil air and water.
- Crop residues on the soil surface can increase the risk of (adherent) diseases and pests remaining on the soil
- Because weeds not ploughed under, weed management must be adapted.
- Eventually, crop rotation changes may be required to avoid pest/disease problems.
- Precise nutrient application methods may be required to avoid/compensate for reduced mixing of soil nutrients with low disturbance tillage
- Reduced tillage does not work on all types of soil.

Regarding the chisel plough, this technique is set to operate to a depth range of 200-300 mm whereas some models may run much deeper. The individual ploughs/shanks can go deep from approximately 229 mm to 305 mm while a machine with significant power will be required for the implementation of this technique.

Case Study: David Jones (Morley farms)

Undertakes tillage operations in August and September rather than October; the risk of compaction or smearing is lower for drier soils in these months. See also drainage BEMP example for this farm (section 4.4).

For sowing, a Sumo cultivator is used to “lift” subsoil (30 cm depth) with minimum topsoil disturbance, rather than turn topsoil. Often, one pass is sufficient on these sandy soils to enable seed drilling in a subsequent pass. Sumo cultivation requires dry soils.

Strip tilling was trialled for sugar beet, but with limited success; sugar beet established very well in some rows but not those where the combine’s wheels had previously compacted the soil (the US strip till machine used may not have been the best, and was not able to loosen the soil sufficiently). Also it was noted that sugar-beet is particularly “fussy” regarding drilling conditions, and strip tilling may work well for other crops such as maize (refer to trials on Stephen Temple’s farm in north Norfolk). The machine used on this farm agitates top 20 cm.

Headland areas had become compacted and water-logged owing to farm machinery traffic, and produced poor yields at Morley Farms. Reduced and dry-weather cultivation has reduced this, and improved infiltration and yields in these areas so they are now no longer noticeably different.

Applicability

Minimum tillage is best carried out on any stable soil that maintains its structure throughout the growing season. Clays, silty clay loams and clay loams are particularly suitable. Avoid adopting minimum tillage on sands, compacted soil, fields with serious weed problems and with crops that require specific tillage conditions such as potatoes. However, the absolute zero-tillage is difficult to achieve due to the fact that at some extent light tillage is used for proper weed control.

Minimum tillage runs the risk of weed infestation. This can be managed by skilful crop rotation and practices such as stale seedbeds (section 6.4).

The use of min-till techniques is constrained to arable soils.

Economics

Minimum tillage generally works out with higher gross margin than conventional tillage, largely through reduced energy input. The lower fuel consumption is an important benefit of reduced tillage and in particular the conventional tillage requires 250 L/ha when less than 80 L/ha for no tillage are required (Rosner et al., 2008) (Table 6.8 and Table 6.9).

Table 6.8. Economic data regarding work rates for various cultivation techniques (Soil Management Initiative, 2000)

Operation	Output (ha/hr)	Cost (£/ha)	Time taken (min/ha)
Discing	2.8	15.00	22
Raking	6.0	6.25	10
Rolling	4.0	7.50	15
Direct-Drilling	2.8	25.00	22
Sub-soiling	1.6	20.00	38
Spraying	10.0	7.50	6

Table 6.9. Cost, time and cereal yield for three cultivations of differing intensity.

System	Depth (cm)	Cost (£/ha)	Time (min./ha)	Cereal yield %
Plough	15-35	100-135	150-220	100
Reduced cultivation	5-10	70-90	60-100	100.8*
Direct drilling	0	30-60	25-40	99.2*
*Average yield relative to ploughing for a medium loam soil Source: Westcountry Rivers Trust sheet Pinpoint 22, citing DEFRA, (2009)				

Cost of implementing reduced or no-till operations, based on contractor being used and the plough retained for occasional use in difficult seasons. The net effect from selling most cultivation equipment and using a contractor was a saving of £40/ha or € 47/ha (Newell-Price et al., 2011).

Future CO₂ trading may enable farmers to claim compensation with power generating companies for no-plough techniques, as already practiced in the US mid-west (SMI, 2000).

Case Study (Westcountry Rivers Trust, no date).

In this actual example, a farmer used minimum tillage for wheat on 10 ha of his steepest fields, which resulted in the following changes:

- Run-off has been substantially reduced.
- Soil erosion has been greatly reduced.
- Crop damage from gullies and rilling was reduced.
- Fewer soil and nutrient losses have occurred.
- There have been no operations needed to reinstate eroded soils and clean dirty ditches.
- Labour costs have been reduced.
- Machinery running costs have been reduced.
- Less herbicides and fungicides are used.

The quantifiable cost savings achieved were:

- A saving of 2% of the crop over the whole 10 ha (Average yield = 7.5 tonnes /ha; sale price £90/tonne; gross margin £394/ha [John Nix, 2009] giving a total saving of £135.
- Preventing rills and gullies - labour saving of 2 hours to repair damage at £80 per hour (John Nix, 2009) giving a total saving of £160.
- Preventing highway cleaning - labour saving of 5 hours at £60 per hour giving a total saving of £300.
- Preventing ditch cleaning - labour saving 2 hours at £24 per hour giving a total saving of £48.
- Conventional cultivation @ £102 /ha average, less minimum tillage @ £55 per hectare average, giving a saving of £47 /ha = £470 total.

Total financial saving per year on 10 ha = £1,113, with immediate payback.

Driving forces for implementation

- Soil quality improvement
- Long-term yields and profitability
- Reduced fuel costs

Reference literature

- Abdalla, M., Osborne, B., Lanigan, G., Forristal, D., Williams, M., Smith, P., Jones, M.B., 2013. Conservation tillage systems: a review of its consequences for greenhouse gas emissions. *Soil Use and Management* 29, 199-209.
- Angers, D.A., Bolinder, M.A., Carter, M.R., Gregorich, E.G., Drury, C.F., Liang, B.C., Voroney, R.P., Simard, R.R., Donald, R.G., Beyaert, R.P. and Martel, J., 1997. Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. *Soil and Tillage Research* 41, 191-201.
- Boardman, J., Shephard, M., Walker, E., Foster, I., 2009. Soil erosion and risk-assessment for on- and off-farm impacts: a test case using the Midhurst area, West Sussex, U.K. *Journal Environmental Management* 90, 2578-2588.
- Campbell, C.A., McConkey, B.G., Biederbeck, V.O., Zentner, R.P., Curtin, D. and Peru, M.R., 1998. Long-term effects of tillage and fallow-frequency on soil quality attributes in a clay soil in semiarid southwestern Saskatchewan. *Soil and Tillage Research* 46, 135-144.
- Dao, T.H., Stiegler, J.H., Banks, J.C., Boerngen, L.B. and Adams, B., 2002. Post-contract land use effects on soil carbon and nitrogen in conservation reserve grasslands. *Agronomy Journal* 94, 146-152.
- Diaz-Zorita, M., 1999. Efectos de seis años de labranza en un Hapludol del noroeste de Buenos Aires, Argentina. *Ciencia del Suelo* 17, 31-36.
- EISA, 2012. European Integrated Farming Framework. *A European Definition and Characterisation of Integrated Farming (IF) as Guideline for Sustainable Development of Agriculture*. February 2012
- FAO Stat, 2013. Agricultural statistics gateway page, accessed August 2013: http://faostat3.fao.org/faostat-gateway/go/to/download/Q/*E
- Flynn, H and Smith, P., 2010. *Greenhouse gas budgets of crop production – current and likely future trends*. International Fertilizer Industry Association, Paris, France. 67 pp.
- Franzluebbers, A.J. and Arshad, M.A., 1996a. Soil organic matter pools with conventional and zero tillage in a cold, semi-arid climate. *Soil and Tillage Research* 39, 1-11.
- Franzluebbers, A.J. and Arshad, M.A., 1996b. Water stable aggregation and organic matter in four soils under conventional and zero-tillage. *Canadian Journal of Soil Science* 76, 387-393.
- Grant, C.A. and Lafond, G.P., 1994. The effects of tillage systems and crop rotation on soil chemical properties of a Black Chernozemic soil. *Canadian Journal of Soil Science* 74, 301-306.
- Halvorson, A.D., Wienhold, B.J. and Black, A.L., 2002. Tillage, nitrogen, and cropping systems effects on soil carbon sequestration. *Soil Science Society of America Journal* 66, 906-912.
- Hernanz, J.L., López, R., Navarrete, L. and Sánchez-Girón, V., 2002. Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain. *Soil and Tillage Research* 66 (2), 129–141.
- Hosting Pics, 2014. <http://www.hostingpics.net/viewer.php?id=576366Lurson1.jpg>. Accessed Feb 2014
- Isikwue M.O., Adakole S.A. 2011. Effect of Tillage and Soil cover on Soil Erosion in the Lower Benue River Basin of Nigeria, conference proceedings in: Tillage for agricultural productivity and environmental sustainability, Ilorin, Nigeria, February 21-23.
- Klik, A., 2011. *Soil Conservation and Soil Protection*. VU 815.321 Universität für Bodenkultur Wien, Austria. Accessed from: http://www.wau.boku.ac.at/fileadmin//H81/H815/Skripten/Sonstige/Soil_Conservation.pdf

- Knight, S., Kightley, S., Bingham, I., Hoad, S., Lang, B., Philpott, H., Stobart, R., Thomas, J., Barnes, A. and Ball, B., 2012. *Desk study to evaluate contributory causes of the current 'yield plateau' in wheat and oilseed rape*. HGCA Report 502, HGCA, London. 225 pp.
- Krüger, H.R., 1996. Sistemas de labranza y variación de propiedades químicas en un Hapludol Entico. *Ciencia del Suelo* 14, 53-55.
- Newell-Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R., Misselbrook, T.H., 2011. *An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture*. 'ADAS' and 'Rothamsted Research, North Wyke'; Defra Project WQ0106 (Dec. 2011).
- Rosner, J., Zwatz, E., Klik, A. 2008. *Influence of different Tillage Systems at yield and quality – results of field trials in Lower Austria*. International Soil Tillage Research Organisation (ISTRO)-Czech Republic Branch, Proceedings 5th. International Soil Conference 'Soil tillage – New Perspectives', Brno, Czech Republic, June 30 - July 2, 2008. http://istro.cz/soub/Proc_2008.pdf
- Schulte et al., 2012. *A marginal Abatement Cost curve for Irish Agriculture*. Appendix B: Detailed methodologies for the computation of the marginal cost-abatement potential of individual measures. Teagasc, Ireland. 32 pp.
- SMI, 2000. *Soil Management Initiative Guide 2000: A guide to managing crop establishment*. SMI Ltd., Chester, England. 52 pp. <http://adlib.everysite.co.uk/resources/000/091/259/vicjordancropguide.pdf>
- Westcountry Rivers Trust 2007. *Pinpoint Best Practice Information Sheets: Cultivation techniques to protect soils no 22a, 22b, 23a and 23b*. Association of Rivers Trust, England. Accessed from: http://www.riverstrust.org/pinpoint/info_sheets/Pinpoint%20-%202022.0%20Cultivation%20techniques%20to%20protect%20soils%20-%20Introduction.pdf.
- Yang, X. and Wander, M.M., 1999. Tillage effects on soil organic carbon distribution and storage in a silt loam soil in Illinois. *Soil and Tillage Research* 52, 1-9.

6.3 Mitigate tillage impacts

Description

Within this BEMP, the following measures are discussed:

- Contour ploughing
- Break slopes
- Cultivate tramlines
- Avoid compaction (refer to section 4.3)
- Low ground pressure impact tyres on vehicles, considered BMP by EISA (2012)
- Erosion risk planning (refer to section 3.3 and 4.3)

Cultivate and drill land along the slope (contour) to reduce the risk of developing surface runoff. On fields with simple slope patterns, cultivating and drilling across the slope reduces the risk of surface runoff being initiated and increase re-deposition rates where surface runoff does occur. The ridges created across the slope increase down-slope surface roughness and provide a barrier to surface runoff. As a result, particulate P and associated sediment losses will be reduced. Avoid growing furrow crops e.g. potatoes on slopes where it is not always pragmatic to create furrows across slope and avoid cultivating across steep slopes for H&S reasons (Figure 6.14).

Break slopes describes the technique of sowing a grass strip across slope to intercept run off and nutrients. Breaking up long slopes by a ditch, hedge or wide grass strip on the contour will reduce the chances of surface water flow building up and causing rilling. If field shape is changed so that the long side is across the slope, cultivations will tend to follow this and help reduce erosion risk. On longer slopes, it may be appropriate to install a new ditch across the slope to intercept water part-way down. This will help stop the accumulation of large volumes of surface water run-off. The ditch should have a grass strip a few metres wide on its upper side to filter sediments from run-off and reduce discharge to watercourses.

Hedges give a long-term slope break, and if additional drainage is not required, they are more effective if planted on a wide bank running along the contour to help retain sediment and prevent fine particles from reaching watercourses.

Where long slopes are unavoidable or cannot be broken by planting hedges, consideration should be given to contour strips. These work on the principle that close ground cover such as creeping grass will both slow surface flow from above, and increase infiltration rates.

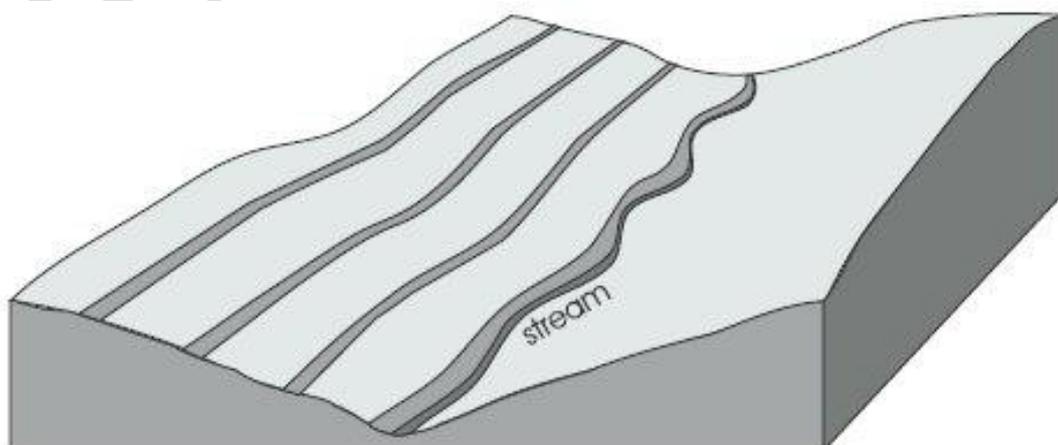


Figure 6.14. Grass, stubble, or set-aside Contour Strips will reduce water scouring and reduce rilling risk. A buffer strip protects the stream in the valley bottom (DEFRA, 2005)

As a guide, strips 5-15 metres in width positioned every 50-150 metres down the slope, should be effective on most erosion susceptible areas. On steeper slopes, the width should increase and the distance between strips decreases. Contour strips should not be used as additional track ways.

Tramlines caused from machinery during autumn sowing can act as conduits for runoff. It is best practice to cultivate tramlines after tillage operations. Use tines to disrupt tramlines. Costs based on a light cultivation to remove the compaction and channelling created by tramlines is £10/ha (€ 12/ha) (Newell-Price et al., 2011).



Figure 6.15. Cultivated tramlines (EA, 2008)

Controlled traffic farming (CTF) is a system which confines all machinery loads to the least possible area, as permanent traffic lanes. Conventional approach where machines track randomly over the land can compact around 75% of the area within one season and at least the whole area by the second season. Soils can take years to recover. A CTF system can reduce tracking to just 15% and this is always in the same place. Controlling where wheels go reduces soil damage when harvesting in wet weather, because the permanent tramlines support traffic better. CTF uses RTK auto steer GPS guidance (Section 5.3) and matching equipment widths to reduce soil compaction and crop damage. CTF has taken the concept of no-till farming to an improved level of efficiency and accuracy.

Create roughened seedbeds that provide increased surface area to rain drops, so reducing surface capping and run off, compared with fine seed beds. Leaving the autumn seedbed rough encourages surface water infiltration and reduces the risk of surface runoff, thereby reducing particulate P and associated sediment loss risks (Figure 6.16).

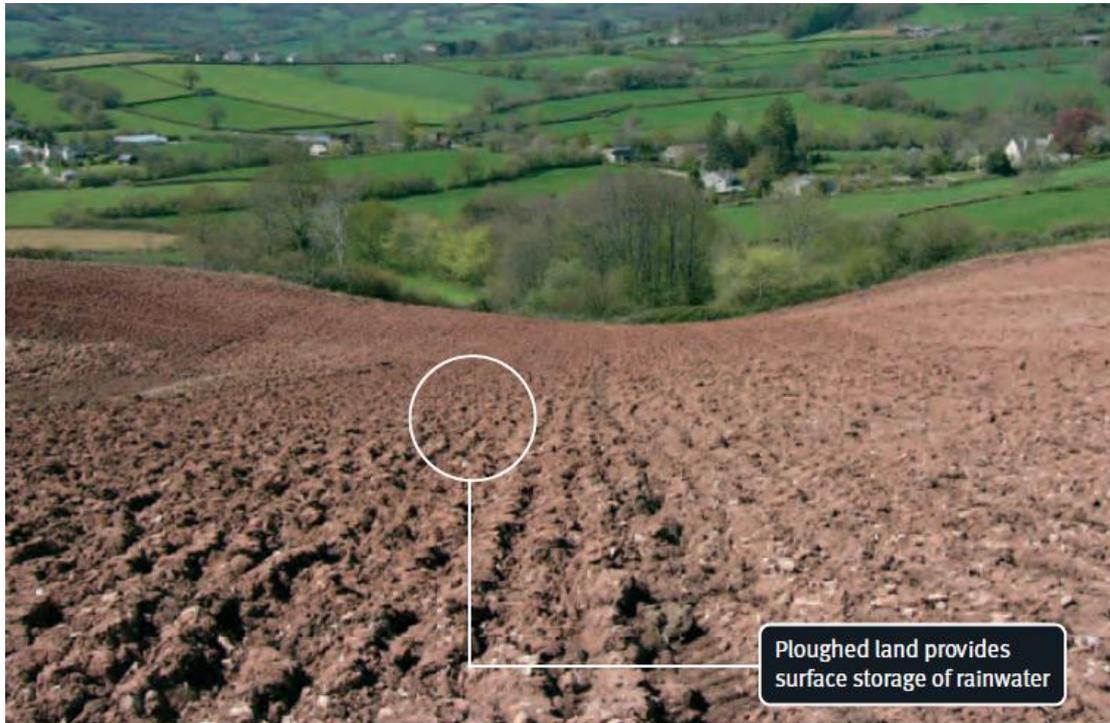


Figure 6.16. Roughened seedbeds improves water infiltration (EA, 2008).

The mixture of clover seeds with fertilisers results to less tillage operations. In particular, high amount of fertiliser is avoided in the field as well as the seed segregation on the way to the field is minimized.

Achieved environmental benefits

- Reduced run off, P loss, agrochemical loss, soil loss
- Using a grass strip 6 m wide to break up a slope can filter out up to 60% of soil particles (EA, 2008).
- Improved soil structure
- Higher crop yield.

Appropriate environmental performance indicators

Management indicators

As with the previous measure on ‘Minimise tillage disturbance’ (Section 6.2), compaction and erosion are the key risks to manage.

- Monitor Soil colour
- Monitor Soil crumb structure
- Monitor Erosion degree (visual inspection)
- Use low impact tillage wherever appropriate

Soil indicators

- Erosion losses (t/ha/y)
- % land area receiving low-impact tillage (cf. CT)
- Soil bulk density (g/cm^3)

- Topsoil SOM content (%C, LOI)
- Soil Water holding capacity (% by mass)
- Emission factors CO₂, N₂O

Cross-media effects

Improved soil water-holding capacity can lead to an increase in N₂O emissions.

According to Schulte et al. (2012) application of min-till across Irish cereal production would lead to a 0.77 t CO₂e/ha/y increase in SOC but also an increase in N₂O of 0.1 t CO₂e/ha/y.

Applicability

Minimum tillage is best carried out on any stable soil that maintains its structure throughout the growing season. Clays, silty clay loams and clay loams are particularly suitable. Avoid adopting minimum tillage on sands, compacted soil, fields with serious weed problems and with crops that require specific tillage conditions such as potatoes. Minimum tillage runs the risk of weed infestation. This can be managed by skilful crop rotation and practices such as stale seedbeds (see section 6.4). The use of min-till techniques is constrained to arable soils.

Economics

Cost of implementing reduced or no-till operations, based on contractor being used and the plough retained for occasional use in difficult seasons. The net effect from selling most cultivation equipment and using a contractor was a saving of £40/ha (Newell-Price et al., 2011). According to Schulte et al. (2012), application of min-till across Irish cereal production would lead to a total saving of €43.58 million annually, principally from savings in fuel usage of €29.20 /ha saving.

Driving forces for implementation

- Soil quality improvement
- Long-term yields and profitability
- Reduced fuel costs

Reference literature

- DEFRA, 2005. Controlling soil erosion: A manual for the assessment and management of agricultural land at risk of water erosion in lowland England. Revised 2005. Defra, London: PB4093. 56 pp.
- EA, 2008a. *Think Soils: Soil assessment to avoid erosion and runoff*. Environment Agency, Bristol, UK
- EA, 2008b. *Best Farming Practice*. Publ. Environment Agency, Bristol. UK.
- EISA, 2012. European Integrated Farming Framework. *A European Definition and Characterisation of Integrated Farming (IF) as Guideline for Sustainable Development of Agriculture*. February 2012
- Newell-Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R., Misselbrook, T.H., 2011. *An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture*. ‘ADAS’ and ‘Rothamsted Research, North Wyke’; Defra Project WQ0106 (Dec. 2011).
- Schulte et al., 2012. *A marginal Abatement Cost curve for Irish Agriculture*. Appendix B: Detailed methodologies for the computation of the marginal cost-abatement potential of individual measures. Teagasc, Ireland. 32 pp.

6.4 Crop rotations as one measure for soil protection

Description

Within this BEMP, the following measures are discussed:

- Longer mixed rotations including legumes
- Temporary grass leys on mixed farms
- Weed management
- Biofumigation

Crop rotation offers a broad range of environmental benefits beyond soil protection and nutrient management, including the promotion of biodiversity or pest control leading to a reduction in pesticide use and improved water efficiency. However, it should be also mentioned that there is not only a temporal but a spatial dimension to crop rotation e.g. two adjacent fields planted with the same crop will be more prone to erosion rather with different varieties. In this section the methods how to design crop rotations for soil protection and enhancement are covered (Figure 6.17 and Figure 6.18). On the other hand, section 5.2 deals with how crop rotation is used for maximising organic matter especially in arable land.

Crop Rotation Design

The following criteria must be met when choosing crops for a crop rotation (Table 6.10):

- supply of N to meet crop demands,
- sustain Soil Organic Matter (SOM),
- phyto-sanitary provision and
- avoid erosion.

Table 6.10. Relative value of different crop types to following crops in rotation (adapted from Stein-Bachinger et al., 2013)

Crop	Benefits	Disadvantages
Legumes	<ul style="list-style-type: none"> • Fix atmospheric N • Supply N to next crop • Deep roots for soil structure • Promote P availability • Maintain SOM 	
Leafy and root crops	<ul style="list-style-type: none"> • Suppress weeds • Improve soil structure • Low C:N residues 	<ul style="list-style-type: none"> • Deplete SOM • Vulnerable to diseases
Cereals		<ul style="list-style-type: none"> • High C:N residues • Increase weed growth risk • Deplete SOM and nutrients • Oat > rye > wheat > sp. barley in decreasing value

Suitability of different crop combinations in the rotation ^[adapted from 23]



W. = winter; S. = spring Note: Plan to include catch crops before spring crops



Source: Stein-Bachinger et al., (2013), cit. adapted from Kolbe, (2006)

Figure 6.17. Optimising crop rotations

		Sweden	Finland	Germany	Latvia	Poland	Belarus	
Year 1	Spring	Clover-grass	Clover-grass	Clover-grass	Clover-grass	Clover-grass	Clover-grass	
	Summer							
	Fall							
	Winter							
Year 2	Spring							
	Summer			Clover-grass	Winter wheat	Winter cereal		Winter cereal
	Fall							
	Winter							
Year 3	Spring							
	Summer	Winter cereal	Triticale	Catch crop	Catch crop			
	Fall							
	Winter							
Year 4	Spring		Fallow	Fallow	Catch crop	Fallow	Fallow	
	Summer							
	Fall							
	Winter							
Year 5	Spring	Spring wheat/ clover-grass (US)	Oats and peas	Grain legumes	Spring cereal/ grain legume	Spring cereal/ clover-grass (US)	Winter triticale	
	Summer	Clover-grass	Fallow	Winter rye/ clover-grass (US)	Winter cereal	Clover-grass	Fallow	
	Fall							
	Winter							
Year 6	Spring							Oats/clover- grass (US)
	Summer							
	Fall							
	Winter							
Year 7	Spring	Clover-grass	Clover-grass	Clover-grass	Clover-grass	Clover-grass	Clover-grass	
	Summer							
	Fall							
	Winter							

US = undersown; organic manure/compost is applied but not listed in the figure

Legumes
Legume-cereals
Cereals
Root crops
Fallow/catch crop

Source: Stein-Bachinger et al., (2013)

Figure 6.18. Examples of good crop rotations for Baltic Sea countries

Use a crop rotation planner – example of an organic one, ROTOR, can be found at: www.beras.eu (BERAS - Building Ecological Recycling Agriculture and Societies); www.hgca.com/publications/documents/cropresearch/Rotation.pdf (HGCA - Agriculture and Horticulture Development Board)

In a rotation plan based on cereals, potatoes and sugar beet for example, early harvested potato varieties would be selected for the most susceptible land to allow earlier establishment of the following winter wheat crop. A winter cereal seedbed prepared after late harvested sugar beet can be especially vulnerable (DEFRA, 2005). For instance, rotations are 4 to 6 year cycles usually and it is recommended that organic rotations have two-years of legume to kick start N build-up.

Two-year grass-legume leys are useful as a break crop to enhance soil fertility especially for adding N, and a legume content of 70% can be used in arable farms with no livestock, SOM, and phytosanitation. Also two-year leys are useful on mixed farms to provide grazing and/or silage whilst providing the above benefits; legume content could be reduced to 30% in this case (in agreement with

Stein-Bachinger et al., 2013). Short term leys are 1-2 years duration, medium term 3-5 years (IBERS, no date). Grass leys also reduce the total arable land area at risk of erosion in any one season.

Constraints and opportunities of leys (IBERS, no date)

Grazing:

- Manage to sward height guidelines for optimum production (Section 7.1)
- Establish a clean or 'safe' grazing system for vulnerable livestock.
- Do not graze ewes on red clover six weeks either side of tugging.

Hay/silage:

- Choose harvest date according to needs of quality and quantity.
- Red clover and lucerne hay are prone to leaf shatter. Consider silage instead

Arable /whole crop silage:

- Palatable forage that gives good feed intakes
- Useful cover crop for an undersown ley. Cut at milky-dough stage for best yield and quality, or earlier if crop has lodged, or to protect the undersown ley.

Green manure:

- Cut and mulch, or plough in before 'cash' crop.

Weed management must be built into rotation cycles otherwise the system is prone to weed infestation. Alternate between leaf and straw crops e.g. mustard is an effective break crop between cereal cropping for phytosanitation, by virtue of its allelopathic properties. Other allelopathic crops include rye, oats, sunflowers, barley, wheat, buckwheat, clovers (red, white, sweet), tall fescue, creeping red fescue, hairy vetch and perennial ryegrass. Also, alternate between winter and spring crops and include root crops. Rotate grassy, leafy and legume crops. Manage the frequency of a crop within a rotation. Use grazing and mowing to control perennial weeds. Cover crops (section 6.5) also have a weed reduction role.

Stale seedbeds is a technique that involves preparing a seedbed in early spring prior to seeding the intended crop. This results in bringing weed seed to the surface and allowing them to germinate; they are then hoed off or tilled under and the new crop is sown.

Biofumigation is a process where crops from the Brassicaceae family (e.g. canola, rapeseed, broccoli, cabbage, cauliflower etc.) are used to reduce potential diseases. Those crops are primarily used as green manures in order to get the most out of their biofumigation potential. Also, the incorporation of the biofumigation crops increases the organic matter and the microbial biomass and activity. When biofumigation is properly applied, the plant material is broken down in soil in order to release the volatile toxins, which eventually can reduce soil population of weeds resulting in changing the soil microbial communities. For instance, it has been reported that the use of biofumigant Brassica crops as green manures in suitable crop rotation schemes, has given effective control of black scurf and stem canker of potato as well as have been associated with reductions in soil-borne pests and other pathogens (Larkin and Honeycutt, 2006; Larkin et al., 2003; Cheah et al., 2008).

Achieved environmental benefits

- Reduction in synthetic N-fertiliser applied and manufactured
- Reduction in nematicides, herbicides and pesticides applied
- Increase in land under perennial crops (especially S. Europe) leading to improved soil protection and quality
- Increase in biodiversity

Appropriate environmental performance indicators

Management indicators

Crop rotation requires a careful balancing of soil health and crop yield.

- Rotate crops according to integrated pest management plan (BEMP 11.1)
- Integrate legumes and break crops into rotation

Performance indicators

Successful crop rotation can increase SOM and N, reducing need for synthetic fertiliser N application.

- No. of break crops (ley, legume, oilseed) in a rotation
- Length of rotation (y)
- Soil quality indicators %: Soil organic matter (SOM), Soil Mineral Nitrogen (SMN) mg/kg (BEMP 4.1, 4.2).
- Soil coverage during water (%)

Cross-media effects

There may be some trade-off between short-term yield maximisation and soil protection via sustainable rotations. However, soil protection will lead to higher long-term yields.

Operational data

Figure 6.19 summarises management practices for run-off and erosion control on heavier soils. Inter alia, it is important to avoid crops on vulnerable heavy soils and manage properly the grazing livestock in order to avoid poaching (DEFRA, 2005). Likewise, DEFRA (2005) contains more information on reducing erosion risk for specific crops. Figure 6.20 presents a ten-point plan for crop rotation design, which initially starts from the proper selection of crops and ends-up in the prevention of nutrient leaching and minimising the erosion periods when soil is bare (Stein-Bachinger et al., 2013, citing Haas, 2009 and Lampkin, 1990).

Summary of Management Practices for Run-Off and Erosion Control on Heavier Soils

- Ideally keep the most vulnerable sites in grassland.
- Avoid trafficking land when wet and ensure timeliness of cultivations.
- Establish autumn sown cereals, oilseed rape and grass reseed early enough to achieve good ground cover before early winter and follow other good husbandry practices for these crops (see Chapter 5).
- Avoid root crops on vulnerable heavy soils.
- Maintain field drainage where appropriate, including secondary treatments (mole drainage) where the system depends on this method.
- Subsoil where necessary to remove compaction.
- Manage grazing livestock to avoid poaching.
- Avoid slurry applications on vulnerable sites in winter or in summer if soil is cracked over drains.

Source: DEFRA, (2005)

Figure 6.19. Information on reducing erosion risk for specific crops; for more information please consult the Defra Soil Erosion Manual (DEFRA, 2005).

1. Select crops according to market potential and prices, feed requirements, soil type, climate and crop rotation characteristics.
2. A balanced rotation has from 30 % (pure legumes) to 40 % (legume-grass mixtures) legumes, a maximum of 20 % root crops and up to 60 % cereals. In cereal dominated rotations, integrate spring cereals and catch crops.
3. To achieve self-sufficiency in fodder, calculate the fodder requirements from field crops and arable forage taking the additional supply from permanent grassland into account.
4. To prevent serious soil borne pests and diseases (those with strong agronomic and economic consequences), apply cultivation breaks and maximum frequencies of host crops and crop families e.g. brassicas, cereals, grain legumes.
5. To prevent serious weed infestation, alternate between leaf and straw crops and between winter and spring crops and include at least one root crop.
6. Check the P, K, pH and humus status via soil analyses (soil fertility) and plan manure distribution carefully for each field during the crop rotation for best nutrient utilization and soil improvement to secure good yields and product quality, and to prevent nutrient leaching.
7. To determine the amount of cereals calculate the amount of straw needed for bedding.
8. To improve soil structure and the mobilization of nutrients and to assist drainage, grow deep rooting crops after shallow rooting crops and minimize soil compaction caused by heavy machinery especially during wet conditions.
9. To even out the work load and promote the germination of different weed species alternate between autumn sown and spring sown crops.
10. To prevent nutrient leaching and erosion minimize periods when soil is bare. Plant cover crops, plant catch crops after spring crops and vice versa, grow undercrops (legumes) and crop mixtures.

And finally: document failures and successes to help redesign the crop rotation for the future!

Source: Stein-Bachinger et al., (2013), citing Haas, (2009) and Lampkin, (1990)

Figure 6.20. Ten-point plan for crop rotation design

A set of parameters contribute to the success of the soil biofumigation. In particular, the growth stage of the crop, the amount of biomass produced and the correct incorporation into the soil are the main parameters. Figure 6.21 illustrates all the aforementioned parameters with different variables and presents them nicely in a schematic way.

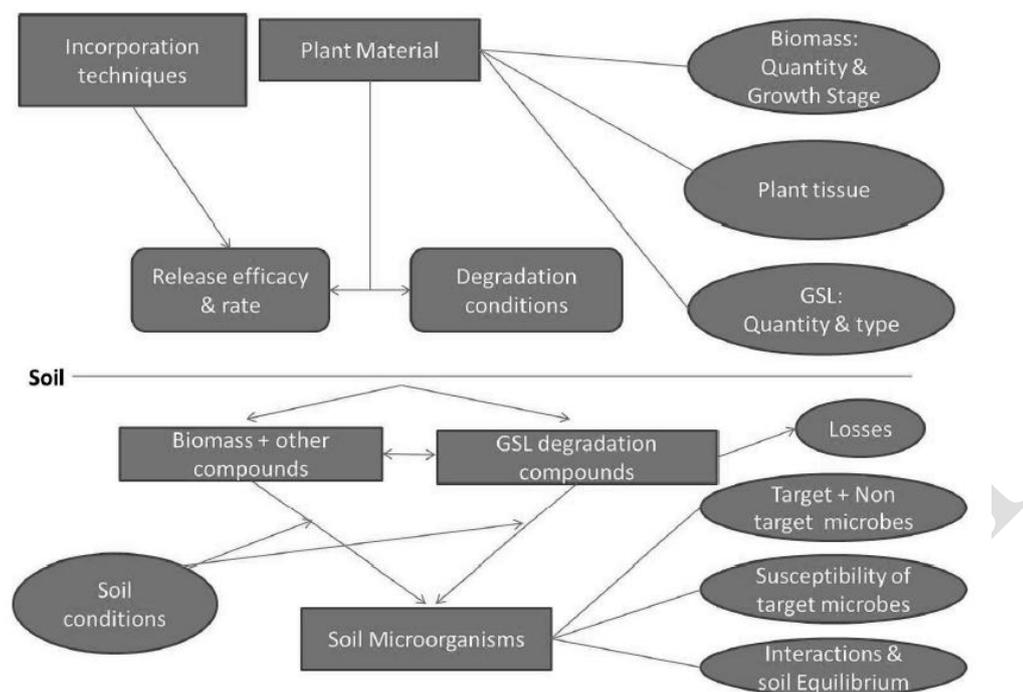


Figure 6.21. Set of parameters that contribute to a successful soil biofumigation process (Kruger et al., 2013, citing Bellostas *et al.*, 2004)

Table 6.11 presents some characteristics of the different commercial biofumigant crops tested in Tasmania and Australia. The key points for incorporating the biofumigant crops or green manures into the soil are listed below:

- For maximum biomass production, break crops may need fertiliser input if nutrients in soil from previous crops are low.
- For temperate regions, cold tolerant green manure crops should be selected for winter plantings to obtain good biomass production.
- The existing different varieties biofumigant crops have different maturity time e.g. in cold weather the maturity time ranges from 60 to 100 days.
- In particular, brassica biofumigant crops provide best weed suppression to grasses and cereals.

Table 6.11. Characteristics of the different commercial biofumigant crops tested in Victoria, Tasmania and Australia (Queensland) (Bioscience Research, 2010)

Cultivar	Site	Name ¹	Sown	Incorporate ²	Biomass (t/ha)
Mustclean™	V	Indian mustard	March	May	87
Mustclean™	T	Indian mustard	May	October	30
Mustclean™	T	Indian mustard	October	December	77
BQ Mulch™	V	Rae/turnip.	March	July	118
BQ Mulch™	T	Rae/turnip.	May	October	62
BQ Mulch™	T	Rae/turnip.	October	December	65
BQ Mulch™	Q	Rae/turnip.	February	April	-
BQ Mulch™	Q	Rae/turnip.	December	January	-
Caliente 199™	V	Indian mustard	March	July	95
Architekt™	T	White mustard	October	December	50
Adios™	T	Oilseed radish	May	October	83
Adios™	T	Oilseed radish	October	December	102

Index: V: Victoria, T: Tasmania and Q: Queensland

1: Architekt™ and Abraham™ were highly susceptible to frost damage.

2: Mustards incorporated at flowering. Variation in biomass levels is due to sowing time and soil types.

The optimum time to incorporate brassica biofumigant crops is at flowering stage, before the formation of any seed. In order to reach the best result, the crop should be macerated before incorporation into moist soil in order to release the isothiocyanate compounds. Those compounds are highly volatile and thus the soil surface must be sealed by rolling or irrigation after incorporation to minimise their escape from the soil (Bioscience research, 2010).

In the box below, practical incorporation methods are presented.

Practical methods to optimise the effects of Brassica biofumigants crops (Bioscience research, 2010):

- Pulverising plant tissue using a flail mower with hammer blades before incorporation into moist soils
- Sealing the soil surface with a roller attached to the back of the rotary hoe and/or with irrigation
- Incorporate tissue into moist soil to initiate the breakdown of glucosinates into isothiocyanate compounds which are biocidal to soilborne pathogens

Applicability

Crop rotation, as a part of integrated farm management, should only be practiced where there is the potential to develop it over the long-term.

Economics

Crop rotation carries an economic cost, at least initially and as a result, needs to be viewed as a long-term investment.

However, there are economic gains to be had from reduced use of herbicides, pesticides, and synthetic fertilisers. There are also gains in Ecosystem Goods and Services (ESG) such as C sequestration as SOM and enhanced biodiversity.

There may be opportunities for grant-aid through agri-environment schemes (EC, 2013 has details for individual EU-27 countries).

Driving forces for implementation

- Water Framework Directive
- Long term yields and profitability

The political pressure on reducing the impact of pesticides, the knock-on effect on resistance building, particularly to weed killers, and increasing input costs, including fertilisers, could all add to the pressure to introduce longer crop rotations and cover crops in future.

Reference literature

- Bellostas N., Sørensen J.C., Sørensen H., 2004. Qualitative and quantitative evaluation of glucosinolates in cruciferous plants during their life cycles. *Agroindustria* 4, 267-272.
- Bioscience research, 2010. Managing soilborne diseases in vegetables. Rotation with green manure and biofumigant crops shows disease control and yield benefits. Department of primary industries, The State of Victoria.
- Chea, L.H., Marsh A.T., Hedderley D., Falloon R.E. 2008. Crop rotation with brassicas reduces phytophthora populations in potato soil. *Arable and Vegetable Crops, New Zealand Plant protection* 61:256-250.
- Defra 2005 Defra, 2005. Controlling soil erosion. A manual for the assessment and management of agricultural land at risk of water erosion in lowland England. Revised 2005. Defra, London. 56 pp.

- European Commission JRC-IES 2013 River Basin Network on Water Framework Directive and Agriculture. Ed. F.Somma. Luxembourg: Publications Office of the European Union 260 pp.
- Haas, G. (2009): Wasserschutz im Ökologischen Landbau.- Bundesprogramm Ökologischer Landbau, 61 pp.
- http://www.organiccentrewales.org.uk/uploads/211.01_grass_clover_leys.pdf
- IBERS, no date. 211.01 Grass-clover leys in organic rotations. Aberystwyth University, Wales. 2 pp.
- Klimatmärkning för mat. (2010). Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010. Sweden: Klimatmärkning för mat.
- Kolbe, H. (2006): Fruchtfolgegestaltung im ökologischen und extensiven Landbau: Bewertung von Vorfruchtwirkungen. Pflanzenbauwissenschaften 10, pp 82-89
- Kruger D.H.M., Fourie j.C., Malan A.P. 2013. Cover Crops with Biofumigation Properties for the Suppression of Plant-Parasitic Nematodes: A Review.S. Afr. J. Enol. Vitic., 34(2).
- Lampkin, N. (1990): Organic Farming. Farming Press Books, UK, 70 pp.
- Larkin R.P., Albert M., Griffin T.S. 2003. Control of soilborne poathogens of potato with Brassica green manures. Crop protection 26:1067-1077.
- Larkin R.P., Honeycutt C.W. 2006. Effects of different 3-year cropping systems on soil microbial communities and soilborne diseases of potato. Phytopathology 96:68-79.
- Stein-Bachinger, K., Reckling, M. & Granstedt, A. (2013): Ecological Recycling Agriculture - Farming Guidelines, Vol. 1. Järna, Sweden. ISBN 978-3-00-042440-3, www.beras.eu. 136.

6.5 Establish cover/catch crops

Description

Within this BEMP, the following measures are discussed:

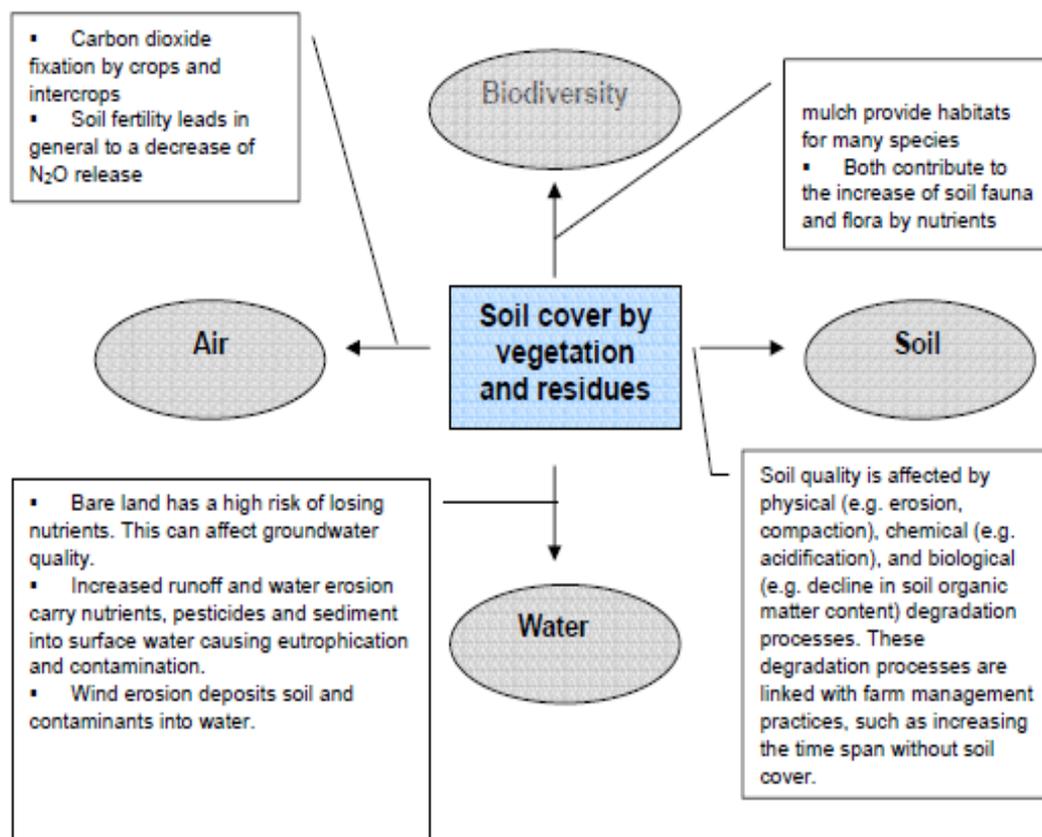
- Minimise erosion from winter rain
- Reduce N leaching losses
- Protect soil surface during first tillage/seeding
- Soil crusting
- Under-sowing e.g. grass into maize (de Marke)
- Increase Soil Organic matter (SOM)
- Capture and subsequent release of N
- Case studies from the Netherlands and England

Catch/cover crops are grown in the period between two main crops in order to retain nutrients in the root zone (catch crops) or to protect the soil against erosion and minimise the risk of surface runoff by improving the infiltration (cover crops). Catch/cover crops can be under sown with the previous main crop or sown immediately after harvest of the previous main crop. Catch/cover crops are mainly used prior to spring sown crops while the main related environmental impacts are presented in Figure 6.22.

Soil Erosion

Twelve percent, 115M ha of Europe's total land area is subjected to accelerated water erosion and 42M ha to wind erosion (EC, 2008a). By 2050, it is expected that, on a "business-as-usual" basis, there will be an 80% increase in erosion risk in EU agricultural areas (EEA, 2000).

Cover crops add Organic Matter (OM) and reduce damage to soil structure by protecting surface (reduce erosion, prevent soil crusting) over winter and in spring operations – sometimes referred to as green manures. Cover crops can also act as a 'catch crop' to mop up spring flush of nitrate-N (e.g. barley, rye) and as a 'nurse crop' for reseeded pasture – see Case Study 2 below. The incorporation of cover/catch crops also provides available N, reducing fertiliser N needs.



Source: Piorr and Eppler, (2004)

Figure 6.22. Environmental impacts of soil cover on biotic and abiotic resources taken from

N leaching

The eutrophication potential of cereal crops is largely determined by leaching of N from the area, resulting from a mismatch in N-availability and crop uptake. Leaching is most prevalent in winter if there is no crop cover. Thus, by sowing a catch crop in the autumn, keeping the surface covered with vegetation during winter, and – before sowing the cereal – ploughing in the catch crop, empirically based models have shown that it is possible to retain considerable amounts of the N that would otherwise be lost by leaching (EC, 2008).

Hooker et al. (2008) found soil solution nitrate concentrations were between 38% and 70% lower when a cover crop was used, and total N load lost over the winter was between 18% and 83% lower, in a study conducted in Ireland.

Also in Ireland, Premov et al. (2012) reported a significant decrease in groundwater nitrate concentration under mustard cover compared to no cover.

Berntsen et al. (2004 and 2006) showed that nitrate leaching can be reduced by approximately 25 kg N/ha as an average for spring cereals on sandy and loamy soil, being greater on sandy soils than on loamy soils. Since this N is largely available for the cereal crop, the use of fertiliser can – and should – be reduced correspondingly, since part of the build-up of N in the soil may otherwise be lost through leaching.

Schroder et al. (2013) measured the nitrate leaching in maize, followed by a cover crop of rye and compared to maize with no cover crop; leaching to upper groundwater was reduced by 7.5 mg NO₃-N/L and 10.9 mg/L in first and second year, respectively.

Cover crops planted on land destined for spring crops can reduce nitrate leaching by 50% and thus help reduce fertiliser application rate (EA, 2008).

However, it should be mentioned that there is a trade-off about the use of cover/catch crops. In particular, farmers choose late-harvesting varieties precisely because they have higher yields. Therefore, in order to understand better the aforementioned trade-off, an example of winter corn (maize) is presented below. While there is a narrow window of opportunity to cover the ground shortly after maize harvest in winter, this can be widened by sowing in the rows before the harvest, expanding the opportunity to use cover crops. At the same time wind protection is provided for the cover seeds. In many parts of Europe there are severe issues of post maize harvest erosion and runoff caused by compaction, as well as nitrate leaching, which are exacerbated by the late dates of harvest into the autumn. Therefore this would advocate in favour of harvesting early to broaden the window for crop covering. Table 6.12 summarises the best windows for some cover crops (unnamed, Cornell University).

Table 6.12. Best windows for some cover crops

Cover crop	Planting window	Termination window	Comments
Hairy vetch	Before 15/09	After 15/05	Termination on 30/05 is much better
Field peas and oats - spring	April	July	They should grow for at least 75 days; use forage varieties
Field peas and oats - fall	Before 15/08	Winterkill	A mild fall can allow for planting a week or two later; special attention must be paid
Rye	Before 15/09	Late May	Best with hairy vetch
Red clover	Frost seed into winter grain	May of following year	Excellent rotational strategy
Buckwheat	June and July	40 days after planting	Do not wait to terminate; may produce seed

Source: unnamed, Cornell University

Achieved environmental benefits

Overview

- Reduced nitrate leaching
- Reduced sediment, SOC and P losses
- Improved N and P use efficiency
- Improved water quality – upper ground and surface
- Net abatement from SOC and N loss 1.49 t CO₂e/ha/y (Schulte et al., 2012)

Quantified benefits

1. It has been estimated (EC, 2008) that introduction of a catch crop together with reduced N fertilisation (under the assumption of an unchanged crop yield) will result in the following improvements per ha per year:
 - Artificial N fertiliser requirement is reduced from 130 kg to 105 kg N (19 %);
 - N-surplus is reduced from 59 kg to 34 kg N (42 %);
 - Nitrate leaching is reduced from 217 kg to 111 kg NO₃ (49 %);
 - N₂O emissions are reduced from 5.7 kg to 4.2 kg N₂O (26 %);
 - Ammonia emissions are reduced from 11 kg to 10 kg NH₃ (9 %).
2. Implementing catch crops on 7M ha is expected to reduce the leaching from the overall EU-27 cereal production by 9 % with only minor impacts on other emissions. In addition, this option tends to improve soil organic matter (EC, 2008).

3. Nitrate leaching loss reduction of 30-60% is typical in the year of cover establishment and particulate P and associated sediment losses would be reduced, typically in the range 20-80% (Newell-Price et al., 2011).
4. Plant cover can reduce nitrate leaching by accumulating nitrates in biomass and/or soils. In Germany, average rate of reduction that can be achieved is 40 kg N/ha. In Finland, it is estimated that winter plant cover can reduce erosion and nutrient leaching by 10-15%. In Denmark, the calculated total annual effect from 140,000 ha of targeted catch crops in reduced loading to the aquatic environment is 1950 tonnes of nitrogen, averaging to 13.9 kg N/ha/y. Overall, plant cover in winter can reduce erosion 10-40% and N leaching 10-70%. Under-sowing of ryegrass with barley reduced N leaching 27-68% depending on soil (EC, 2013).

Appropriate environmental performance indicators

Performance indicators

- DM t/ha cover crop biomass
- N-use efficiency
- % land under bare soil over winter
- % land with cover crops planted
- SOM %
- mg NO₃-N/L water
- Avoided fertiliser requirement (kg/ha)
- Earthworm abundance/m²

Management indicators

Implementing cover/catch crops requires a high level of knowledge from the farmer or advisor. Soil type, fit with rotation, weeds, plant pathogens, weather patterns, yield, market price and livestock requirements all need to be considered.

- Establishment of effective cover crop, usually by mid-September
- Use cover crops for N uptake in autumn followed by release in spring and natural pesticide cover crops for biofumigation (peas, mustard and brassicas).

Cross-media effects

Soil structural damage caused by establishing a cover crop (either late or in wet conditions) may compromise cover crop establishment and result in poor utilisation of soil N by both the cover crop and subsequent crops, and increased particulate P and sediment loss risks.

In some areas, bare tillage soils may provide habitat for certain bird species.

Operational data

Where cover crops were established as part of the Nitrate Sensitive Area scheme, it was shown to be preferable (for agronomic reasons) to destroy the crop in January or February (at the latest) (Newell-Price et al., 2011). In particular, cover crops provide at least 25% ground cover by early winter to offer effective protection against erosion.

Case Study 1. Morley Farms, England.

Morley Farm in is the Higher Level Stewardship (HLS) scheme and therefore receives a £60/ha subsidy to plant overwinter cover crops. They initiated a 5 ha trial, with mustard and vetch (legume). Mustard also acts as a nematicide.

Cover crops are established in first week of September, by surface spreading seeds then shallow discing soil (2 inches) to incorporate a mix of mustard and vetch seeds. This minimises soil disturbance. The cover crop is ploughed in in February, prior to drilling spring crop. Plant material provides a base for the tractor wheels, reducing compaction and smearing. Crop also reduces soil moisture content.

Morley Farm has a trial with vetch, a legume, planted as an overwinter cover crop. This can add 60 kg N/ha to the soil, which can supplement fertiliser use within the NVZ cap.

Case Study 2. de Marke Farm, Netherlands

The experimental farm de Marke has successfully trialled the use of a cover crop of summer barley as a nurse crop to protect new reseed pasture (Hilhorst and Verloop, 2013). Summer barley, grass and clover were seeded simultaneously in mid-March. Barley grew strongly and was harvested either as wholecrop silage or threshed. Harvest was followed by an application of slurry to the reseed and a first cut was taken early to remove small weeds and straw. This was then ensiled.

In Table 6.13, reseed pasture with a barley cover crop resulted in a dry matter yield that is almost equal to that the Reference. The N yield is lower than in the Reference, but equal to the reseed without barley cover. Barley as cover increases the N efficiency since the same N yield is achieved with lower N inputs. There was a good quality second cut in the autumn. The following year (first year of pasture) the field was fit to drive on and graze, with an acceptable yield.

Table 6.13. Inputs and yields in permanent grassland under normal conditions at the farm (reference) and in years where it is reseeded with and without cover crop (kg per ha).

Situation	Crops	N Input	Yield	
			DM	N
Reference (undisturbed permanent pasture)	Grass	300	10,000	250
Reseed in spring	Grass	300	7,000	175
Reseed in spring with barley as cover/nurse	Barley	95	6,500	80
	Grass	80	3,000	90
DM: Dry Matter				
Source: Hilhorst and Verloop (2013)				

The barley nurse provided shelter and prevented swamping by weeds which is problematic on this site.

Applicability

Cover and catch cropping can be considered effective for normal fertilised spring cereals grown in areas where there is a precipitation surplus during wintertime. Lacking data for the area currently without winter crops, the potential area for this measure is calculated as the area with barley (a typical spring cereal) in EU-15 countries excluding the drier countries Spain, Portugal, Italy and Greece. This gives a potential area of 7 M/ha (EC, 2008).

Cover and catch crops are suited for use in any cropping system, but constrained to tillage land, where bare soil is vulnerable to nutrient leaching, erosion or surface runoff in the period between the main crops and where there is opportunity for ample development of the catch or cover crop, in this period. It is best suited to lighter, sandy soils where a cover crop can be established using cheap methods (e.g. seed broadcasting followed by a light cultivation/rolling), (Newell-Price et al., 2011). Moreover, in some specific conditions, farmers and regional water managers may be against cover crops, on account of the perceived increase in evapotranspiration that they cause. At the other end of the spectrum some countries mandate minimum levels of cover over the winter; for instance, in Sweden less than 5% can stay uncovered (info provided on June 2014).

This technique should be avoided in areas of limiting summer rainfall where cover crops make result in subsequent drought. Therefore, the main advantage of having cover and catch crops is to provide protection against soil erosion and/or nutrient leaching.

Economics

Cost of implementation € 71.20 /ha (includes seed and fuel) according to Schulte et al. (2012).

Morley Farms

In 2013, a mix of peas and volunteer barely established, using barley seeds from a previous crop and un-harvested peas from a neighbouring farm. In total, seed costs were £30/ha (€35/ha), plus £5/ha (€6/ha) to spread and £5/ha (€6/ha) to disc at cost price (would be more for a contractor). Establishing mustard crop cost about £60/ha (€70/ha). Thus, £60/ha (€70/ha) subsidy covers costs, but probably wouldn't do this otherwise. David has not seen immediate benefits for following sugar beet crop, but expects long term soil fertility benefits. NIAB TAG trials have demonstrated higher infiltration capacities on soils where cover crops established (Morley Farms, 2013).

Under-sowing crops – example (Source: Pinpoint 22)

To avoid bare ground after maize harvest from October until the following May, on soils which often cannot be autumn ploughed, a 5 ha maize crop was undersown with herbicide tolerant Italian ryegrass for worm-free ewe/lamb winter and spring grazing. Broadcasting and seed costs were approximately £86/ha = £430 (€505). The undersown crop produced six tonnes DM/ha with a Relative Feed Value (RFV) of approximately £38/tonne (€45/tonne), which was worth £1140 (€1,340). The total saving was £1140 (€1,340), which represents a net saving of £710 (€835) and payback in less than a year. This excludes the uncoded benefits of reduced soil damage and productivity loss associated with untimely operations, runoff and soil erosion.

Table 6.14. Costs for cover crop establishment

Cost: Total cost for farm system (£/farm)	Dairy	Grazing Low	Mixed	Comb/Roots	Costs based on cover crop establishment through cultivations on 70% of spring cropping area.
Annual	400	100	750	3,300	

Source: Newell-Price et al., (2011)

In England, Environmental Stewardship Entry level pays £65/ha (€76/ha) for land put into winter cover crops (EC, 2013).

Driving forces for implementation

By using cover crops, growers can potentially reduce the pressure on some herbicides and reduce fertiliser costs, while also increasing the organic matter content and structure of the soil. In the Netherlands all farmers growing maize are required to grow a catch crop. In Germany the measure is primarily chosen for arable or vegetable farming and every farmer with plots in sensitive areas can apply. In Sweden and Denmark the measure is voluntary. In Sweden compensation for catch crops from the agro-environmental support scheme is directed to areas with high nitrogen leaching. The total extent of catch crops in Sweden was 120,000 ha in 2010, which corresponds to 10 % of the area with cereals, potato, sugar beets, legumes and oil seed crops, or 5 % of all arable land. Targeted efforts also take place in Denmark (EC, 2013).

Reference organisations

- Morley Farms, England
- de Marke Farm, Netherlands

Reference literature

- EA, 2008b. Best Farming Practice. Publ. Environment Agency, Bristol. UK.
- EEA, 2000. Down to earth: Soil degradation and sustainable development in Europe. A challenge for the 21st century. Environmental issue series No 16, European Environment Agency, Copenhagen. http://reports.eea.eu.int/Environmental_issue_series_16/en/envissue16.pdf
- Eurostat, 2011. Food: from farm to fork. Eurostat pocketbooks, European Commission. http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-32-11-743/EN/KS-32-11-743-EN.PDF
- Eurostat, (undated). IRENA Indicator Fact Sheet. Accessed from http://epp.eurostat.ec.europa.eu/portal/page/portal/agri_environmental_indicators/documents/IRENA%20IFS%2014%20-%20Farm%20management%20practices_FINAL.pdf.
- Hilhorst, G. and Verloop, K. 2013. Resowing grassland under cover crop. Accessed from: http://www.interregdairyman.eu/upload_mm/a/d/5/c40a6983-0f9e-41a3-a440-f94fa8f86cbd_Resowing%20grassland%20under%20cover%20crop%20De%20marke%20Netherlands.pdf
- EC, 2008. Environmental Improvement Potentials of Meat and Dairy Products. Weidema, B. P., Wesnæs, M., Hermansen, J., Kristensen, T., Halberg, N., Peter Eder and Luis Delgado (Editors). JRC/IPTS, Seville. 217 pp.
- EC, 2008. Threats to Soil Quality in Europe. Tóth, G., Montanarella, L. and Ezio Rusco, E. (Eds.) Luxembourg: Office for Official Publications of the European Communities. 162 pp.
- EC, 2013. River Basin Network on Water Framework Directive and Agriculture. F. Somma, F. (Ed.). Luxembourg: Publications Office of the European Union. 260 pp.
- Morley Farms, 2013. Personal communication with farm manager, February 2013.
- Newell-Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R., Misselbrook, T.H., 2011. An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture. 'ADAS' and 'Rothamsted Research, North Wyke'; Defra Project WQ0106 (Dec. 2011).
- Piorr, H.P., Eppler, U. 2004. PAIS project (Proposal on Agri Environmental Indicators), Intermediate report Phase II.
- Premrov, A. et al., 2012. Effects of over-winter green cover on groundwater nitrate and dissolved organic carbon concentrations beneath tillage land. *Science of the Total Environment* 438, 144–153.
- Schulte et al., 2012. A marginal Abatement Cost curve for Irish Agriculture. Appendix B: Detailed methodologies for the computation of the marginal cost-abatement potential of individual measures. Teagasc, Ireland. 32 pp.
- Schroder, J.J., Visser W., Assinck F.B.T. Velthof G.L. 2013. Effects of short-term nitrogen supply from livestock manures and cover crops on silage maize production and nitrate leaching. *Soil Use and Management*, 29, 151–160.
- Unnamed, Cover crops: What a difference a few weeks makes!, Cornell University, Available online at: <http://www.hort.cornell.edu/extension/organic/ocs/reports/Cover%20Crops%20Planting%20and%20Termination.pdf>, accessed January 2015.
- Westcountry Rivers Trust, 2007. PINPOINT best practice information sheet 22. Cultivation techniques to protect soils. Association of Rivers Trust, UK. 2 pp. http://www.therivertrust.org/pinpoint/info_sheets/Pinpoint%20-%2022.0%20Cultivation%20techniques%20to%20protect%20soils%20-%20Introduction.pdf

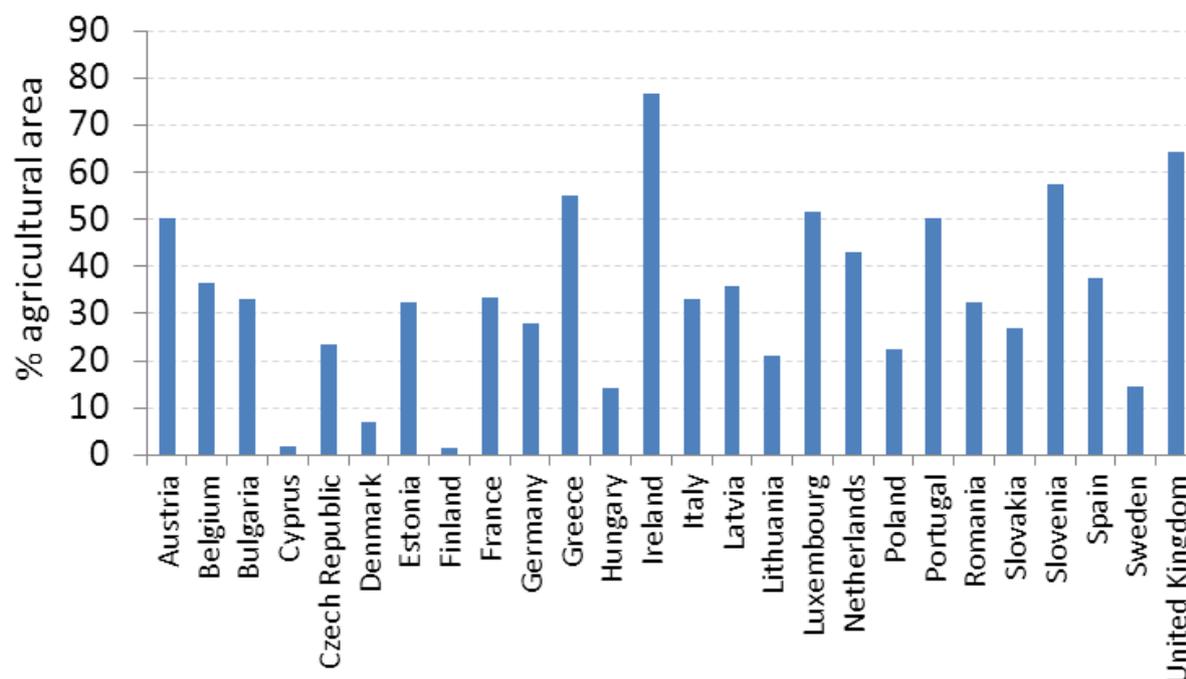
7 Grass and grazing management

Introduction

This section is relevant to livestock farms and covers five BEMPs, namely:

1. Manage grazing for efficient grass uptake (intensive systems);
2. Manage grazing in high nature value grasslands (extensive systems);
3. Pasture renewal and legume inclusion (permanent pasture and leys);
4. Efficient silage production;
5. Nitrification inhibitors.

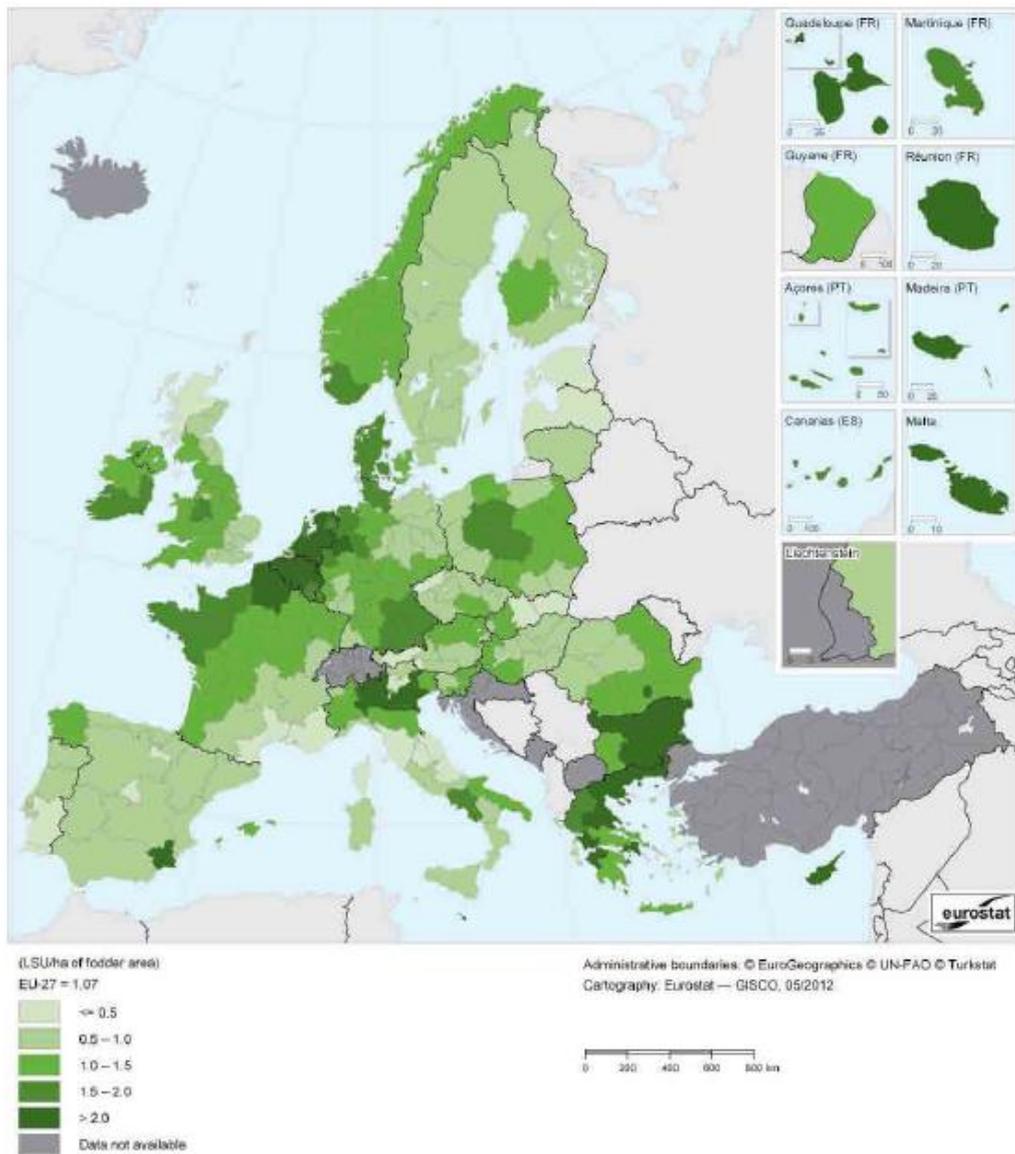
Grassland accounts for a large share of agricultural land, as indicated by FAO Stat data for permanent pasture in Figure 7.1.



Source: FAO Stat (2013)

Figure 7.1. The share of agricultural land area accounted for by permanent pasture across EU member states

Figure 7.2 displays the grazing livestock density across EU 27, showing the highest densities in northern France, Belgium, the Netherlands, Bulgaria and northern Italy, with high densities also in NW France, parts of the UK and Ireland, Germany, northern Italy, NW Spain and southern Sweden.



Source: Eurostat (2012).

Figure 7.2. Grazing livestock density (livestock units per hectare fodder area) across EU27 NUTS 2 regions in 2007

Feed production and grassland management account for between a third and half of the carbon footprint of milk production, and a larger share of other burdens such as eutrophication, for typical dairy farms (Figure 7.3), and other livestock farms. High environmental burdens from grassland management are attributable to: (i) high fertiliser N requirements for rye grass (up to 360 kg N per ha per year recommended for the highest yields in the UK: DEFRA (2010)); (ii) gaseous emissions and nutrient runoff following surface application of slurries and manures; (iii) gaseous emissions and nutrient runoff following surface deposition of excreta from grazing animals; (iv) damage to soil structure from excessive grazing. Grass also contains more N than other types of forage feed such as maize, leading to higher rates of N excretion and associated emissions during manure storage and spreading. For this reason, the environmental burden of large intensive dairy farms with a higher share of fodder maize and concentrate feed production can be lower according to some life cycle metrics, depending on how indirect effects are accounted for (Figure 7.3).

However, well managed grassland is also associated with environmental advantages compared with fodder maize and concentrate feeds, including soil C sequestration, reduced soil erosion, and maintenance of ecosystem services associated with grassy landscapes. Some studies have also

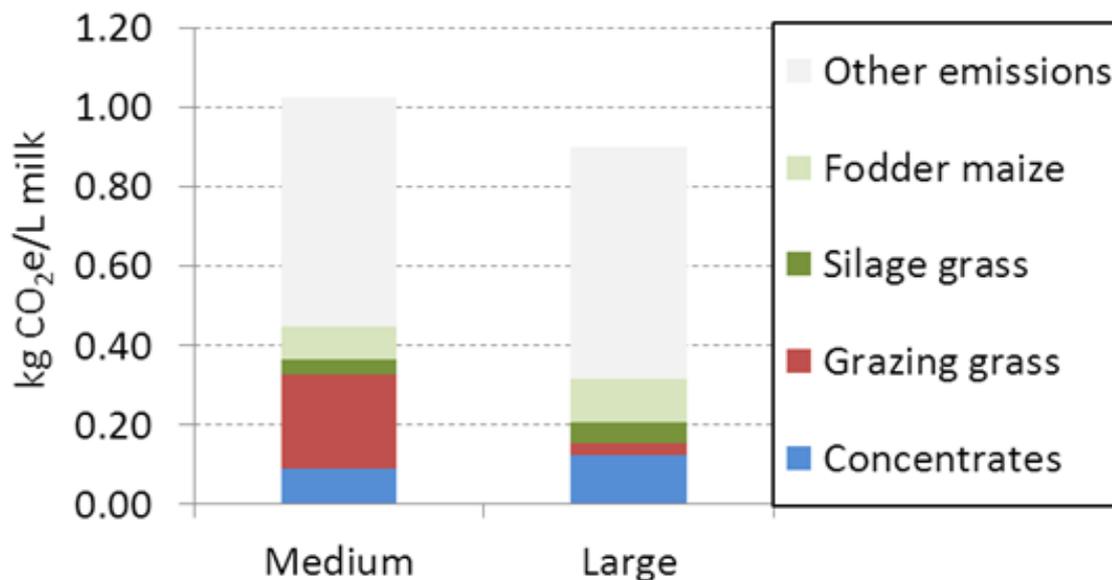
indicated that grass-fed animal products are richer in important micro-nutrients such as omega-3 fatty acids (Daley et al., 2010), a feature that is widely claimed in the food arena (GRACE Communications Foundation, 2014; Lasater Grassland Beef, 2014).

There is a trend towards reduced grazing of dairy cattle (% cows) in NW Europe: intensification and expansion of farms most threaten grazing, giving rise to a need for higher output (per cow or per ha), higher level management and a reduction in grazing land area (Reijs et al., 2013). Grazing however has a low infrastructure and increasingly there is a demand socially and recognition from experts of the need for cows to graze in fulfilment of their natural behaviour and well-being (Table 7.1). Modelling has shown extended grazing has a higher net income than no- or restricted grazing because of lower fixed and feed costs, as well as higher revenue from other non-output sources such as CAP greening and agri-environment schemes (Reijs et al., 2013).

Table 7.1. Summary of strengths, weaknesses, threats and opportunities of grazing in North-West Europe (based on expert judgement in six EU countries)

<p style="text-align: center;">Strengths</p> <p>Low costs for feed production Low costs for housing (when grazing season is long) Better opportunities for cows to express natural behaviour Better image of dairy farming through visibility in the landscape Improved cow health and fertility through lower production and more natural behaviour (depends on conditions) Farmer is working more in the field (depends on farmer preference)</p>	<p style="text-align: center;">Weaknesses</p> <p>Grazing requires additional management and organisational skills Grazing reduces controllability of management due to greater dependence on weather conditions Lower grassland yields per ha and less efficient feed production (depends on conditions) Animal health problems due to unbalanced diets and harsh weather conditions (depends on conditions) Lower yields per cow. Usually not popular amongst farmers</p>
<p style="text-align: center;">Opportunities</p> <p>Grazing as a low cost survival strategy in times where farmers have to deal with low milk prices and high costs Dairy industry is introducing or considering price premiums New ways of specialisation that creates new opportunities for grazing Technological innovation and education on grazing - Part of the farmers have more fun and get more satisfaction out of working in the fields</p>	<p style="text-align: center;">Threats</p> <p>Intensification and expansion of farms Poor field allocation Lack of knowledge and skills for efficient management on large farms Technological innovation on housing systems In some countries competition over land Climate change will result in more extreme weather conditions Young farmers lack knowledge, support and traditional values to maintain grazing</p>
<p><i>Source:</i> Reijs et al. (2013), results of semi-structured interviews with local grazing experts.</p>	

Irrespective of the relative merits of different feed types, good management of grasslands can minimise negative environmental effects and also reduce the quantity of other feeds, and associated environmental burdens, required to maintain animal production (Figure 7.3). At a European level, reduced concentrate feed requirement could lead to significant environmental protection if it leads to reduced imports of the common marginal concentrate feed type of SBME from South America that can be associated with huge land use change burdens.



“Other emissions” are dominated by enteric fermentation CH₄ and manure storage
 Source: Bangor University LCA tool (2013).

Figure 7.3. Feed and grassland GHG emissions for milk produced on optimised medium and large intensive dairy farms

Careful management of N cycling in grassland not only reduces unnecessary and costly fertiliser-N applications for a given yield, but also improves N use efficiency within animals: i.e. greater retention in animal live-weight/milk products and reduced N excretion with all the emissions entailed with that. Thus, there are strong economic and environmental drivers for improved management of grasslands. A recent study by Jones et al. (2013) for the sheep industry surveyed experts on the most effective mitigation measures for on-farm GHG reduction and then surveyed farmers about the most practical of the mitigation measures, and showed that including legumes in a pasture reseed mix and selecting pasture plants to minimise dietary N losses (e.g. high-sugar grasses), scored the highest under pasture management measures. Priority areas for grassland management identified by DairyCo (2013) include:

- Diet manipulation and feeding strategies at grass
- The impact of herbage genetics and sward quality and grass intake
- Optimum pasture management strategies
- Animal behaviour, breeding and performance on grazing systems
- The impact of climate change on future grassland productivity.

Reference literature

- Bangor University, 2013. Farm LCA tool (Styles, D., Gibbons, J., 2013).
- DairyCo. 2013. <http://www.dairyco.org.uk/research-development/grass-forage/current-projects/review-of-factors-influencing-grazed-grass-intake/> accessed July 2013
- DairyCo, 2014. <http://www.dairyco.org.uk/research-development/grass-forage/current-projects/>
- DairyCo, 2014. <http://www.dairyco.org.uk/resources-library/technical-information/grass-management/>
- Daley, C.A., Abbott, A., Doyle, P.S., Nader, G.A. and S. Larson, S. 2010. A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. *Nutrition Journal* 9:10 <http://www.nutritionj.com/content/9/1/10>
- DEFRA, 2010. Fertiliser Manual.RB209. 8 th.edition. TSO, Norwich, UK. 253 pp.
- Eurostat, 2012. *Eurostat regional yearbook 2012*. European union Publications office, Luxembourg. ISBN 978-92-79-24940-2.

- FAO Stat, 2013. *Agricultural statistics gateway page*, accessed August 2013: http://faostat3.fao.org/faostat-gateway/go/to/download/Q/*E
- GRACE Communications Foundation, 2014. “*Sustainable Livestock Husbandry*”. Accessed July 2013: www.sustainabletable.org/248/sustainable-livestock-husbandry.
- Hybu Cig Cymru – Meat Promotion Wales: http://hccmpw.org.uk/publications/farming_and_industry_development/grassland_management/
- Jones, A.K., Jones, D.L., Edwards-Jones, G. and Cross, P., 2013. Informing decision making in agricultural greenhouse gas mitigation policy: A Best-Worst Scaling survey of expert and farmer opinion in the sheep industry. *Environ. Sci. Policy*, 29, 46-56. <http://dx.doi.org/10.1016/j.envsci.2013.02.003>
- Lasater Grassland Beef, 2014. “Homepage”. Accessed July 2013: <http://www.lgbeef.com/>.
- Reijs, J.W., C.H.G. Daatselaar, J.F.M. Helming, J. Jager and A.C.G. Beldman. 2013. *Grazing dairy cows in North-West Europe; Economic farm performance and future developments with emphasis on the Dutch situation*. LEI Report 2013-001, Wageningen UR, The Hague, Netherlands. 124 pp.

FINAL DRAFT

7.1 Grass management

Description

TFRN (2011) stated that, were possible, best practice is to graze dairy cattle for over 18 hours per day during the grazing season, but note that poorly managed grazing can contribute to increased leaching or increased pathogen and nutrient loading of surface water. It should also be stated clearly that the definition of the graze period is based only on the grazing season itself and is not considered as an average over the whole year.

Within this BEMP, the following measures are discussed:

- Maximise grass uptake efficiency (within environmental constraints)
- Synchronise stocking rate to grass growth (grass wedge)
- Grass height monitoring to manage grazing rotation
- Extend grazing where and when appropriate (avoid wet soils -> poaching)

Home-grown grass is the most cost effective feed for livestock; comparing cost per t utilised dry matter, if grass has an associated cost of 1, silage cost is 1.6 and concentrate is 3 times more costly. However, in addition to yield, quality is also a key factor, which is listed in detail below (OCW, 2011).

Principles of Grazing Management

- Maximise pasture growth rates
- Maintain pasture quality
- Achieve high pasture utilisation
- Ensure average covers are achieved at critical times of the year
- Feed cows to their requirements

High quality pasture is green and leafy with minimal seed head and dead matter. Dead matter is the main driver in the loss of pasture quality. Visually, high quality pasture has:

- Less than 20% dead matter in the base of the sward
- Less than 10% seed head
- Greater than 60-70% green leafy material
- With the highest quality pasture having more than 80% green leaf (OCW, 2011).

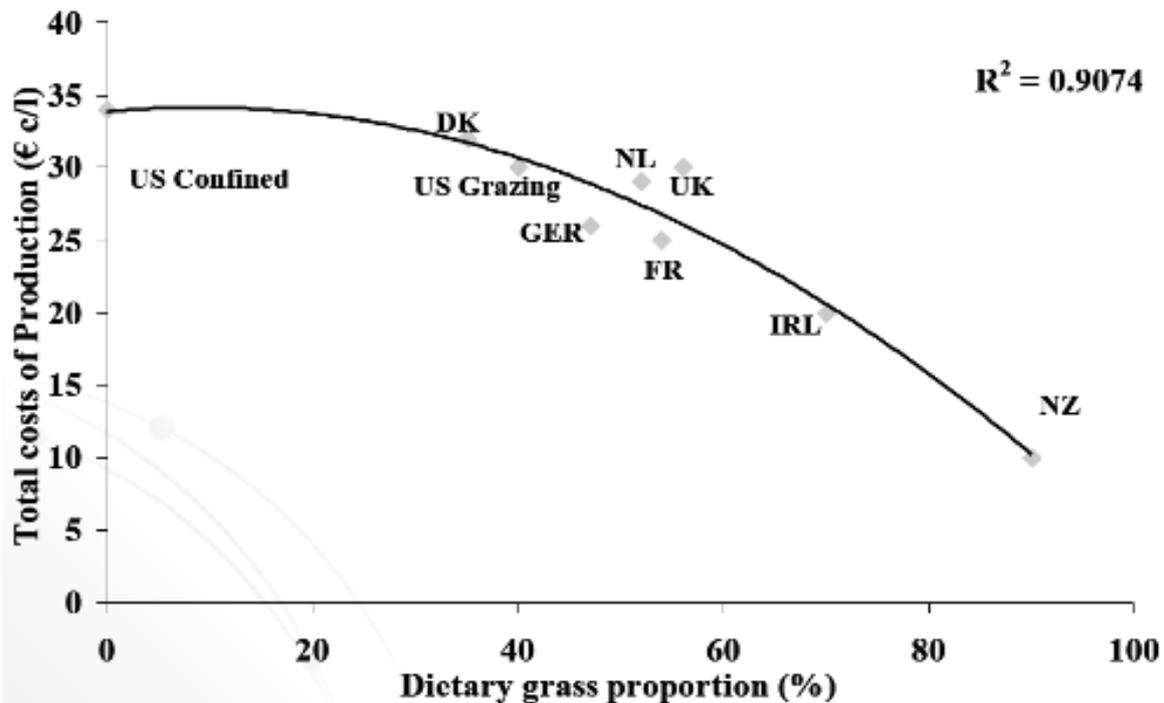
Length of grazing day

TFRN (2011) noted that increased grazing is an effective measure to reduce NH₃ emissions because the reduction in animal housing system emissions is greater than the increase in grazing emissions: housing and grazing excreta TAN emission factors of c. 30% and 6%, respectively (Webb and Misselbrook, 2004; Misselbrook et al., 2012). However, this partly depends on the surfaces in the animal housing being clean (non-NH₃-emitting) while the animals are grazing outside. TFRN (2011), citing Bracher et al. (2012), reported that the total annual emissions from housing, storage and spreading from dairy systems may decrease by up to 50% with all-day grazing compared with animals that are fully confined.

During the months of grass growth, grazing is considered BEMP according to the Swedish Climate Certification for Food (Klimatmärkning för mat, 2010) that states “High quality ley and grazing in the diet decreases the climate impact of production” and “Promoting an increase in grazing also promotes carbon storage in the soil”. High grass utilisation rates in dairy and other livestock diets is strongly related to higher profitability owing to reduce concentrate feed purchase (Figure 7.4), and leads to reductions in upstream environmental impacts associated with concentrate feed production, especially if potentially high-impact feeds such as soybean meal extract (SBME) are avoided. Dairy, beef and lamb production systems in Ireland and New Zealand are economically efficient because their climates sustain largely grass-based production (long grazing seasons).

In the Netherlands there is a societal requirement to see grazing in fields, from both aesthetic and animal welfare points of view. There is a minimum requirement for the number of days (120 days)

dairy cows are grazed and the number of hours (6 h) per day. There is a financial incentive of 1Eurocent per litre of milk for each grazing day (2013). There is similar grazing premium paid in NW Germany for farms that apply grazing for more than more than six hours a day over 120 days.



Source: French et al. (2010)

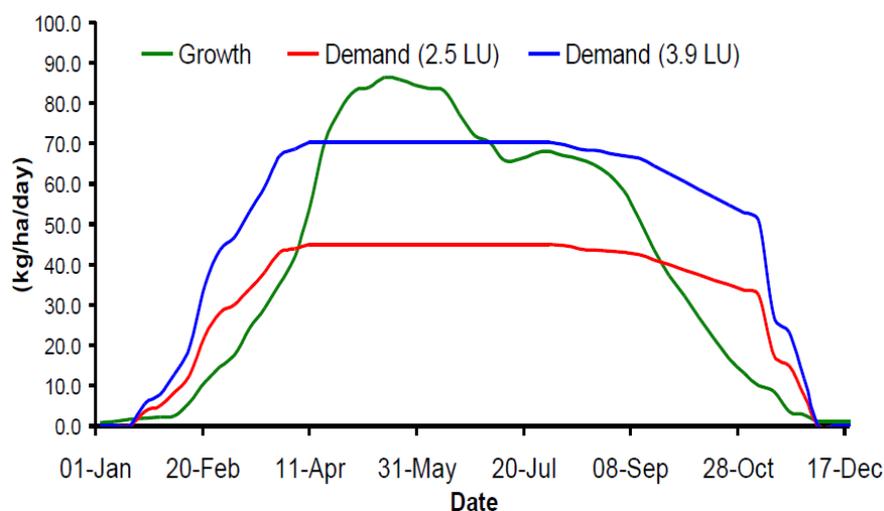
Figure 7.4. Relationship between the percentage of grass in dairy cows diet and cost of milk production

Teagasc (2012) also refer to studies showing that an increased proportion of grazed grass in animal diets (versus silage grass) improves feed digestibility and quality, reducing methane emissions per unit output through both improved animal productivity and reductions in the proportion of dietary energy lost as methane (Martin et al., 2010). They attribute this to a reduction in the fibre content of the sward owing to more leaf and less stem and dead material in high quality sward, leading to an increased proportion of propionate in rumen volatile fatty acids which acts as a sink for hydrogen and therefore reduces the amount available for methane synthesis (Teagasc, 2012). Although emissions from direct deposition are greater during extended grazing, the overall effect is normally to reduce total systems GHG emissions.

Thus, the purpose of this BEMP is to make sure that grass areas on livestock farms are fully utilised for grazing (or grass silage production), within appropriate regulatory restrictions and without incurring major environmental impacts, in particular:

- maximum N application rates (NVZ areas, organic farms)
- maximum stocking rates (related to N restrictions and field carrying capacity)

The optimum stocking rate and annual number of grazing days for a given farm depends heavily on climatic conditions as well as local soil and hydrological characteristics. Figure 7.5 shows a typical pattern of grass growth through the year relative to demand under different stocking rates for dairy cattle. An important aspect of grazing management is the monitoring of grass height to identify optimum grazing times (see “Operational data”) and complements silage production.



Source: French et al. (2010)

Figure 7.5. Annual growth pattern of grass in Ireland relative to demand under stocking rates

Grazing strategies

- **Set grazing** is when animals have unrestricted access over a wide area throughout the grazing season.
- **Rotational grazing** is when stock is moved around a small number of fields based on sward height or grass cover targets, or after a certain number of days.
- **Paddock grazing and strip grazing** achieve highest utilisation (Table 7.2) and describes when livestock is moved frequently through a series of paddocks or strips, based on measured grazing heights or grass covers to ensure that grazing occurs in synchrony with grass availability. These strategies are widely used in the dairy sector and for beef and sheep where these animals are being provided with root crops as their primary forage.

Table 7.2. Effect of moving from a set stocking system to paddock grazing

Strategy	Annual yield (DM/ha)	Utilisation (%)	Useable yield (DM/ha)	Percentage increase
Set stocking	8.5	50	4.3	
Rotational	10.2	65	6.6	56%
Paddock	10.2	80	8.2	92%

Source: EBLEX (2013)

Achieved environmental benefits

Extended grazing

As shown in Table 7.3, extended grazing results in reduced slurry NH_3 , CH_4 and N_2O emissions from storage and spreading, though this may be somewhat offset by higher direct N_2O emissions from grazing animals excreta depositions. Nonetheless, reductions in both the volume and duration of manure storage will reduce emissions overall, especially for NH_3 (TFRN, 2011).

More detailed NH_3 emission factors related to the $\text{NH}_4\text{-N}$ content of excreta are presented in Chapter 8.

Table 7.3. Default emission factors for liquid slurry storage and spreading, and for direct deposition of excreta by grazing animals

Emission	Housed excretion		Grazing excretion
	Liquid storage*	Spreading	Pasture
Methane MCF	0.20	NA	0.01

Emission (fraction)	Housed excretion		Grazing excretion
	Liquid storage*	Spreading	Pasture
Ammonia (fraction N)	0.4	0.2	0.2
Nitrous oxide (fraction N)	0 (0.005 with crust)	0.01	0.02 (cattle, poultry, pigs) 0.01 (sheep and others)

*Indicative values taken from IPCC tables, for dairy cow slurry at an average annual temperature of 12°C.

Source: IPCC (2006)

TFRN (2011) report that annual NH₃ emissions from housing, storage and spreading from dairy systems may decrease by up to 50% with all-day grazing, compared with animals that are fully confined.

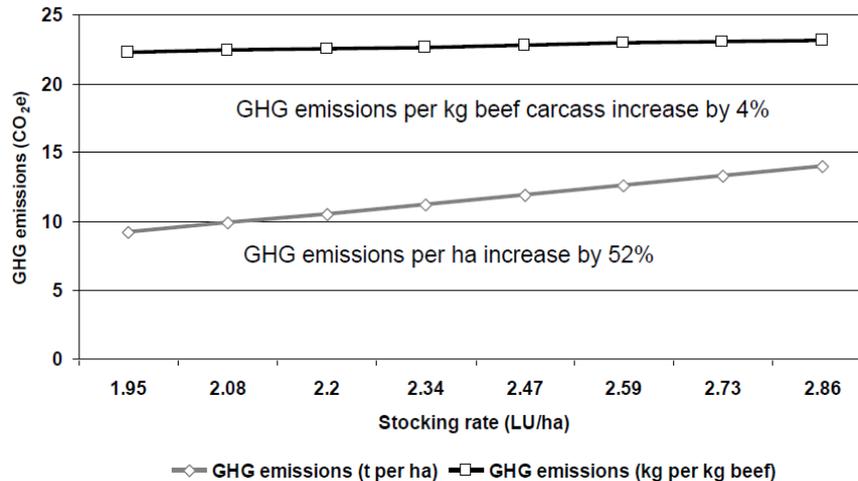
According to Teagasc (2012) extended grazing also results in:

- lower enteric fermentation emissions owing to higher digestibility of grazed forages compared with conserved forages
- lower fuel emissions as a result of reduced forage harvesting and feeding out requirements.

Crosson (2012) calculated that extended grazing could lead to a 5.5% reduction in the carbon footprint of beef production in Ireland.

Stocking rate

Whilst kg CO₂e/kg beef increased with stocking rate by 4%, t CO₂e/ha increased significantly by 52%: this has a land sparing effect with 32% less land at highest stocking rate (Figure 7.6). This land saving could allow for more grazing land for more cattle or be used for bioenergy crops/forestry (Clarke et al., 2012). Ireland currently has the 5th lowest kg GHG/kg beef in EU-27, at 20 (EC, 2011).



Source: Clarke (2012)

Figure 7.6. GHG emission interaction between meat production and land area

Grass monitoring

For highly managed pasture on e.g. dairy farms, careful grass height monitoring can lead to 20% better grass uptake efficiency (Annog-Mentor Môn, 2013)

Management Indicators

The principals of grazing management in intensive systems is to provide as much dry matter intake as possible from grass; this reduces the amount of concentrate bought in (and associated embedded C).

- Maximise utilization of grass in diet by matching stocking rate to grass growth and soil condition
- Use weekly grass height monitoring to manage grazing rotation
- Practice extended grazing where and when appropriate

- Livestock Units (LU) per hectare
- Grazing days per annum
- % grass DM uptake
- Increasing the yield of utilised DM/ha from 8 tonnes to 10 tonnes reduces the cost of grazed grass by almost 20% (DairyCo, 2011)
- Grazing utilisation % - 70-80% is a realistic target (DairyCo, 2011).
- Percentage of dietary energy requirement met by grass
- Supplementary feed requirement (kg or MJ imported feed per kg meat or milk output) at different stocking densities
- Soil quality indicators e.g., visible poaching
- Compaction of grassland soils (% area compacted)

Appropriate environmental performance indicators

Performance indicators

Relevant environmental performance indicators that may reflect better management practices include:

- Carbon footprint of production (kg CO₂e per kg live weight, per L milk or per EUR exported from farm gate)
- Nitrogen use efficiency related to final farm output
- N₂O, NH₃ and CH₄ emission factors, kg per livestock unit or per animal category, per year (e.g. based on IPCC, 2006; Webb and Misselbrook, 2004; Misselbrook et al., 2012)

Soil quality indicators

Indicators that can be used to identify potential problems arising from excessive or inappropriate timing of grazing include:

- Soil poaching
- Visible signs of soil erosion (section 3.3 and 4.1)
- Soil structure (section 4.1)
- Bulk density (kg/m³)
- SOM in topsoil (% weight)
- Percentage of compaction of grass (%)

Teagasc (2011 a,b) have targets for 238 and 248 grazing days per year for beef and dairy cattle in Ireland (Table 7.4). French et al. (2010) suggest optimum stocking rates up to 3 dairy cows/ha for good quality soils; 2.7 dairy cows/ha for poorer soils and 2-2.3 for poor quality pasture in Ireland. However, grazing days and optimum stocking rates may be significantly lower in other European member states where grass growth rates are unlikely to match the exceptional levels of >15 t DM/ha/y achieved in Ireland

Table 7.4. Current and target grazing days for Irish beef and dairy farms

Animal type	Grazing days per year	
	Current	Target
Suckler beef cattle	224	238
Dairy cattle	227	248

Source: Teagasc (2012)

In terms of beef carbon footprint, Crosson (2012) proposes a “high performance” benchmark of 18.9 kg CO₂e/kg beef, compared with an EU-27 mean value of 22 kg CO₂e/kg beef, ranging from 16-44 (EC, 2011).

Cross-media effects

Careful management is required to ensure that extended grazing and higher stocking rates on grazed pasture do not result in soil compaction and poaching damage, which can lead to elevated N₂O emissions and nutrient losses to water affecting also the biodiversity of the grassland (see BEMP 7.2). Usually farmers are keen to extend the grazing period well beyond the peak protein availability season in the spring, which can be damaging to the soil.

Increased grazing duration will increase emissions of NH₃ and N₂O from pasture fields. For N₂O, an emission factor of 0.02 is applied to excreta N from cattle compared with an emission factor of 0.01 for manure after storage (storage N₂O depends on type of storage: Section 9.4) (IPCC, 2006). Grazing is important for animal welfare. Animals perform better and respond positively to herd or flock grazing as it reinforces group cohesion (Reijs et al., 2013) and it is also important for grass utilisation efficiency, as young animals have to learn how to graze efficiently from mature animals in the herd/flock. In Sweden stocking rate is regulated by legislation for animal welfare rather than environmental reasons. This gives guidelines on densities of cows and how long they have to be on pastures. Maximum stocking rate for dairy cows is 7/ha and for beef cattle, 4 /ha (Jordbruks Verket, 2014: Legislation SJVFS 2010:15)

Operational data

Livestock units

The livestock unit (LU) is a reference unit used to aggregate livestock of different species and age categories on the basis of the nutritional requirement of each type of animal, equivalent to the grazing equivalent of one adult dairy cow producing 3,000 kg of milk per year without additional concentrate feed (Eurostat, 2013). Livestock units are shown in Table 7.5.

Table 7.5. Livestock units (LU) for different categories of animal

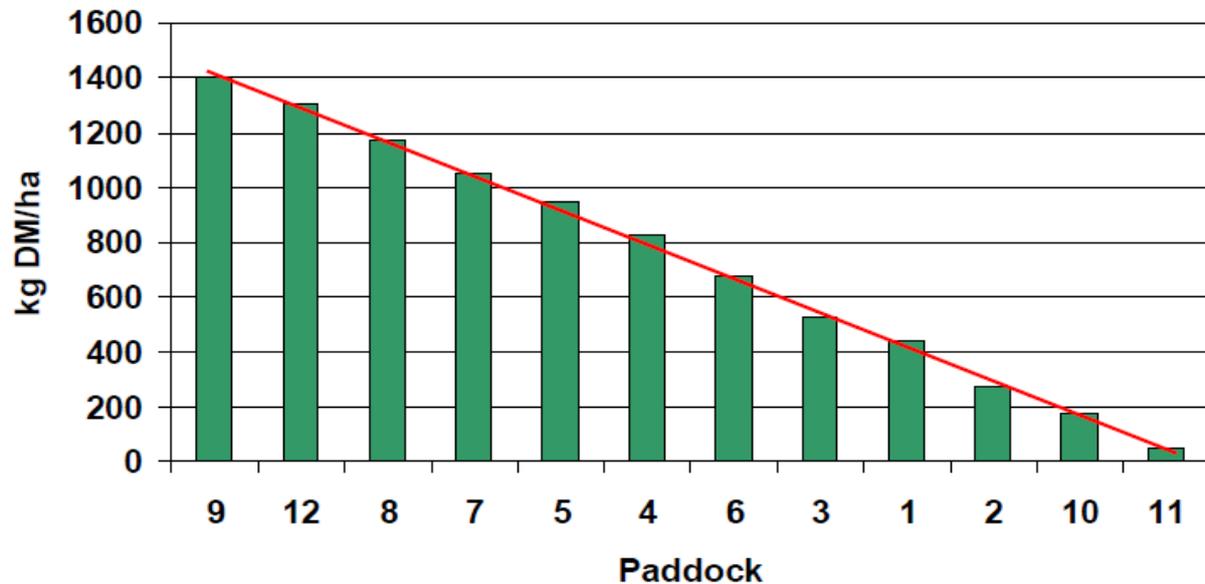
Animal type	Age category	LU
Bovine animals	Under 1 year old	0.40
	1 but less than 2 years old	0.70
	Male, 2 years old and over	1.00
	Heifers, 2 years old and over	0.80
	Dairy cows	1.00
	Other cows, 2 years old and over	0.80
Sheep and goats	All	0.10
Equidae	All	0.80
Pigs	Piglets having a live-weight of under 20 kg	0.027
	Breeding sows weighing 50 kg and over	0.50
	Other pigs	0.30
Poultry	Broilers	0.007
	Laying hens	0.014
	Ostriches	0.350
	Other poultry	0.030
Rabbits, breeding females		0.020
<i>Source: Eurostat (2013)</i>		

Managing stocking rate with grass growth (Source: EBLEX, 2013)

It is best practice to apply the ‘grass wedge’ management tool. A grass wedge is a visual appreciation of the distribution of the grass on the farm, and when used with a target line, is now established as the most valuable tool to optimise mid-season grassland management.

Ideally, all paddocks should be at different stages of grass growth at any one point in time. This means farmers can offer stock pasture of the highest quality every time they move to a new paddock.

This optimises sward utilisation. Creating a grazing wedge, where paddocks are at different stages of regrowth, can only be achieved by walking the fields regularly and recording current sward yields. These are then plotted into a bar graph with the largest cover first and the smallest last (Figure 7.7). The demand line is then plotted which will highlight any surplus or shortfall in grazing in the next few days. There are software packages available to do this.



Source: Hennessey (2013)

Figure 7.7. Depicts the ideal grass wedge where each paddock’s grass cover in kg DM/ha is aligned to the calculated target (red line).

Grass height monitoring

Grass height monitoring is important during the growing season to judge feed volume – allowing decisions about when to graze a paddock or to conserve it for silage. Height is negatively correlated related with grass-N content. Once a certain height is attained, the grass is no longer palatable or efficient for grazing purposes or silage. Traditionally a rising plate meter is used (Figure 7.8). An electronic rising plate meter records total height and number of measurements and calculates average height and average cover³³. A rising plate meter (RPM) measures both height and density of a sward. The average (of 50 readings) height of a paddock is measured in *compressed centimetres* and then converted into kg of dry matter per ha via an equation. The method generally used in the UK is: $(\text{Mean RPM} \times 125) + 640 = \text{kg DM/ha}$ ³⁴

³³ Further information can be found at:

<http://www.dairyco.org.uk/technical-information/grassland-management/pasture-walking/>

However, for quicker accurate assessment a pasture meter has been developed in New Zealand that is mounted on the back of a quad bike:

<http://www.thefreelibrary.com/Changing+places%3B+ADVERTISING+FEATURE.-a0224454573>

Other grassland management tools are available at:

<http://www.interregdairyman.eu/tools/grassland-management/>

³⁴ More information can be found online at: <http://www.dairyco.org.uk/technical-information/grassland-management/sward-assessment/mechanical-plate-meters/>



Figure 7.8. Rising plate meter for grass height measurement

The Grassland Development Centre at IBERS, Aberystwyth University, has developed a new mobile phone application called FarmGRAZE. The app has been launched to help livestock producers improve grass efficiency and cut costs by calculating grazing availability. Using the app allows producers to input field information by measuring the sward height in either cm's or kg DM/ha. Producers can then specify stock class, grazing systems and supplementary feed to accurately calculate grazing wedges and averages. Table 7.6 lists different management regimes for pasture annual yield and ME and Tried and Tested (2013).

Soil drainage limitations

Soil drainage may limit the duration of grazing and the opportunity to responsibly manage mob grazing. Turning animals out earlier or later in the year may be physically constrained by poorly-drained soils (Lalor & Schulte, 2008), which are typical of many beef, sheep and dairy farming areas.

Applicability

This BEMP is applicable to all farms with intensively managed grazing livestock, in particular beef, dairy and sheep farms. Strip grazing is suited to beef and dairy cattle.

Table 7.6. Differing management regimes for pasture annual yield and Metabolisable Energy (ME)

Visual check	Description
	<p>Close control</p> <ul style="list-style-type: none"> • 250 kg N/ha from inorganic fertiliser (or clover-rich swards); • Grazing system controlled using a plate meter, achieving 1500 kg grass DM/ha as a residual target regularly; • Utilising 90% of this and maintaining a grass ME content through the season of around 12 MJ ME/kg DM. <p>Assume 140,400 MJ grass energy used /ha.</p>
	<p>Moderate control</p> <ul style="list-style-type: none"> • 150–250kg N/ha from inorganic fertiliser (or clover-rich swards); • Grazing controlled but no measurements taken; • Utilising 75% of this and maintaining a grass ME content through the season of around 11 MJ ME/kg DM. <p>Assume 90,750 MJ grass energy used /ha.</p>
	<p>Low input grazing with good control</p> <ul style="list-style-type: none"> • Minimal inorganic N input and clover; • Keep on top of grazing through the season; • Utilising 75% of this and maintaining a grass ME content through the season of around 10.5 MJ ME/kg DM. <p>Assume 78,750 MJ grass energy used /ha.</p>
	<p>Low input grazing with lax control and rough grazing</p> <ul style="list-style-type: none"> • Minimal inorganic N input and clover; • Non-productive species in the sward; • No grazing control; • Utilising 55% of this and maintaining a grass ME content through the season of around 9.5 MJ ME/kg DM. <p>Assume 44,400 MJ grass energy used /ha.</p>
	<p>Lax control</p> <ul style="list-style-type: none"> • Some inorganic N applied to grazed grass (or some clover content); • Grazing not controlled; • Utilising 55% of this and maintaining a grass ME content through the season of around 10.5 MJ ME/kg DM. <p>Assume 46,200 MJ grass energy used / ha.</p>

NB: ME: metabolisable energy; MJ: megajoules.
 Source: Tried and Tested (2013)

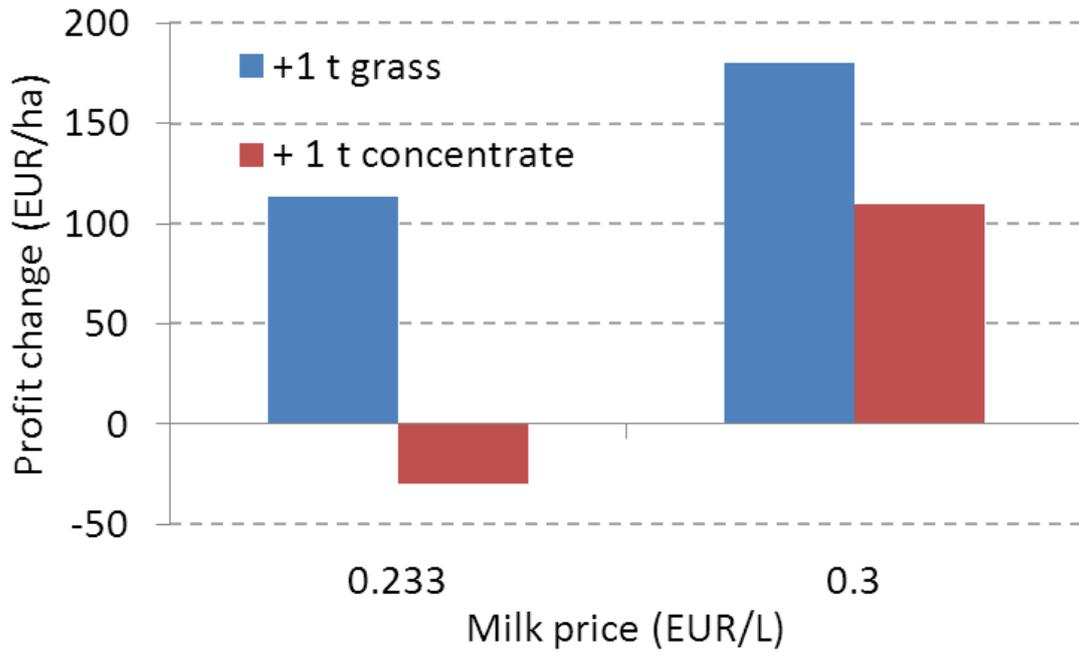
Cover - kg DM/ha	
1500 4-5cm (sward height)	 
2000	 
2500 (leaves are starting to bend over)	 
3000	 

Source: EBLEX (2013), adapted from DairyCo

Figure 7.9. Visual 'ready reckoner' for assessing kg DM of grass /ha.

Economics

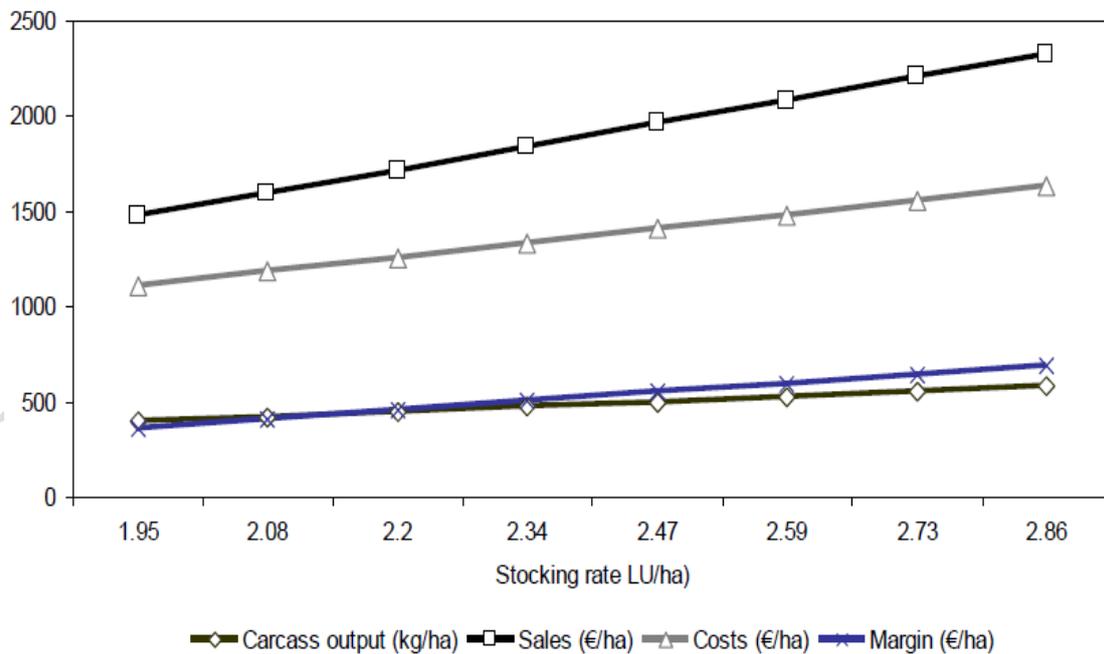
For every additional tonne of grass utilised per hectare on a typical Irish dairy farm, French et al. (2010) estimated between 113 € and 180 €/ha per year additional profits depending on milk price (Figure 7.10). Notably, the profitability of grass is considerably greater than concentrate feed, so that maximising grass utilisation is highly advantageous economically.



Source: French et al. (2010)

Figure 7.10. Additional profit margin from milk sales at different prices when dairy cows fed additional one tonne per hectare grass or concentrate feed

With respect to extended grazing in Ireland, Teagasc (2012) reports a saving of 0.008 €/kg carcass per day for suckler beef and 3.24 €/dairy cow (Figure 7.11).



Source: Clarke et al. (2012)

Figure 7.11. Effect of stocking rate on output and profitability in Ireland

For highly managed pasture on e.g. dairy farms, careful grass height monitoring can lead to 20 % better grass uptake efficiency³⁵. In the Netherlands, dairy farmers are paid 1 Eurocent per litre of milk for each grazing day the cow receives.

Driving forces for implementation

- Reduced supplementary feed costs
- Reduced exposure to price volatility of supplementary feeds
- Improved farm self-sufficiency
- In Sweden grazing is mandatory for all dairy farms. This is regulated via the Swedish Animal Welfare Law since 1987. Furthermore, grazing is mandatory for organic farms in Sweden and Denmark.
- In the Netherlands legislation on ammonia emission and subsidies for new housing are more favourable for dairy farms that apply grazing compared to non-grazers (Reijs et al., 2013).

Reference literature

- Clarke, A., Crosson, P., Brennan, P., 2012. *An assessment of greenhouse gas emissions and economics of grass based suckler beef production systems*. 8th International Conference on Life Cycle Assessment in the Agri-Food Sector, Saint-Malo, France. 4 October 2012.
- Crosson, P., 2012. Mitigating GHG emissions from beef production systems. The Carbon Navigator. 'National Agri-Environment Conference, 'Sustainable Pathways to Food Harvest 2020' Farmleigh, Dublin, Wednesday, 5 December 2012. http://www.teagasc.ie/publications/2012/1637/Agri_Environment_Conference_Proceedings_2012.pdf accessed July 2013.
- DairyCo, 2011. "Grass+ (Section 2): Calculating the cost of your feeds", accessed July 2013: <http://www.dairyco.org.uk/resources-library/technical-information/grass-management/grassplus-section-2-calculating-the-cost-of-your-feeds/#.Uzq2-FOm5ZI> accessed March 2014.
- EBLEX, 2013. *Beef and sheep BRP Manual: 8. Planning grazing strategies for Better Returns*. EBLEX, AHDB, Kenilworth. UK. 22pp.
- Eurostat, 2013. Glossary: livestock unit. Webpage accessed July 2013: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:LSU
- French, P., O'Donovan, M, Horan, B., Dillon, P., Shalloo, L., 2010. *How Far Can We Go On Stocking Rate?* Teagasc, Moorepark, Co. Cork, Ireland. <http://www.mentermon.com/pasture-meter.htm>
- Hennessey, D. 2013. Guidelines and tools to get the most from grazing in Ireland. http://www.europeangrassland.org/fileadmin/media/pdf/working_groups/Guidelines_and_tools_to_get_the_most_from_grazing_in_Ireland_Deirdre_Hennessey.pdf
- IPCC, 2006. *Guidelines for national greenhouse gas inventories. Agriculture, forestry and other land use, vol. 4*. Intergovernmental Panel on Climate Change. IGES, Hayama, Kanagawa, Japan.
- Jordbruks Verket, 2014. "Enklare tillsammans: När dina nötkreatur är ute eller på bête", accessed July 2013: <https://www.jordbruksverket.se/amnesomraden/djur/olikaslagsdjur/notkreatur/utevistelseochbete-sgang.4.4b00b7db11efe58e66b8000308.html>
- EC, 2011. *Is the livestock's shadow so long?* Future of global food and farming, 30 March 2011, Brussels.
- Klimatmärkning för mät, 2010. *Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010*. Sweden: Klimatmärkning för mät.

³⁵ (<http://www.mentermon.com/pasture-meter.htm>)

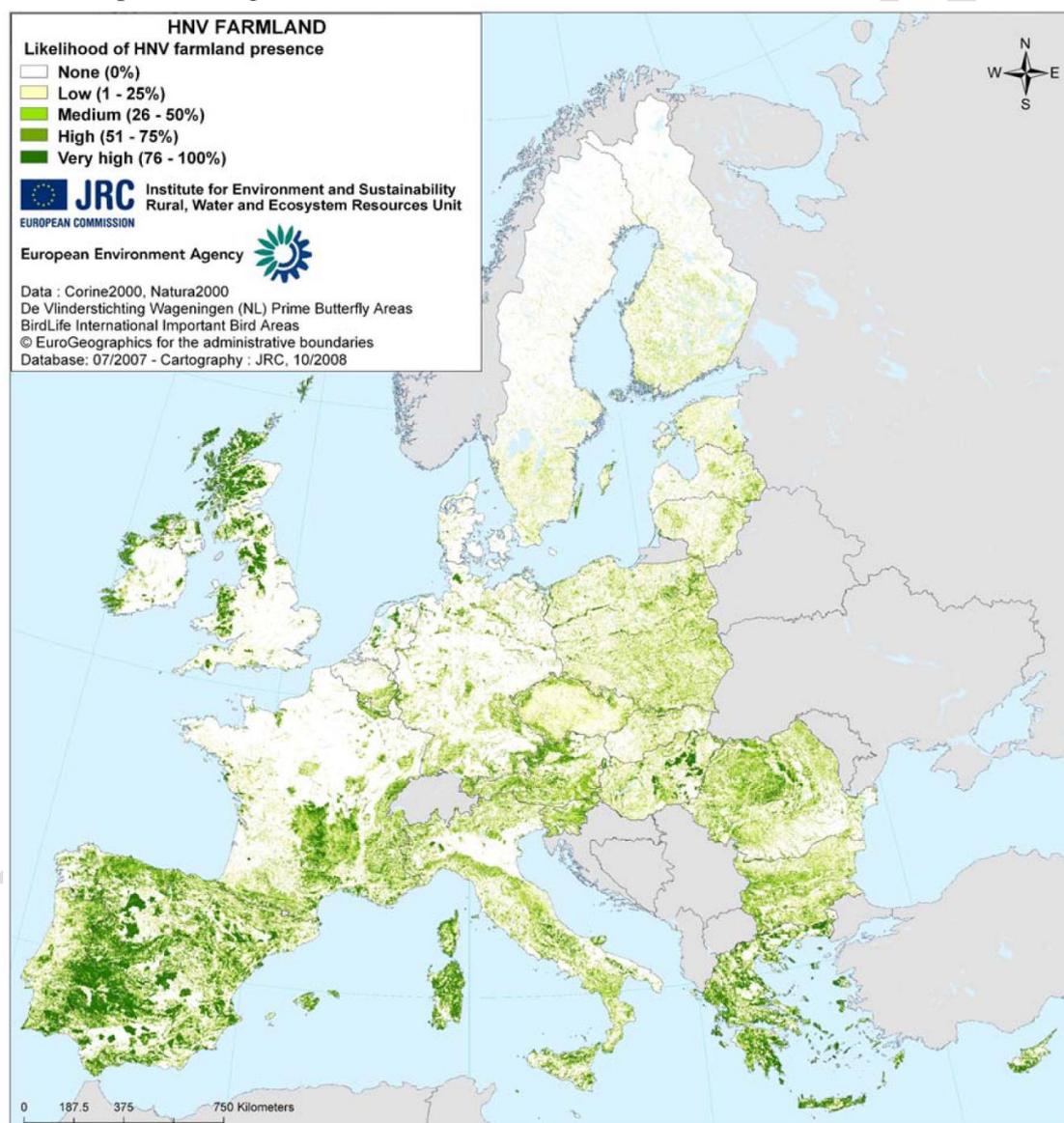
- Lalor, S.T.J. and Schulte. R.P.O., 2008. Low-ammonia-emission application methods can increase the opportunity for application of cattle slurry to grassland in spring in Ireland. *Grass and Forage Science* 63: 531-544.
- Martin, C., Morgavi, D.P. and Doreau, M., 2010. Methane mitigation in ruminants: from microbe to the farm scale. *Animal* 4, 351-365.
- Misselbrook, T.H., Gilhespy, S.L., Cardenas, L.M. (Eds.) (2012). *Inventory of Ammonia Emissions from UK Agriculture 2011*. DEFRA, London.
- Organic Centre Wales (OCW), 2011. *Fact sheet H1. Measuring grass*. IBERS, Aberystwyth University, Wales. 2 pp. http://www.organiccentrewales.org.uk/uploads/h1_measuringgrass2011eng.pdf
- Reijs, J.W., C.H.G. Daatselaar, J.F.M. Helming, J. Jager and A.C.G. Beldman. 2013. Grazing dairy cows in North-West Europe; Economic farm performance and future developments with emphasis on the Dutch situation. LEI Report 2013-001, Wageningen UR, The Hague, Netherlands. 124 pp.
- Sonesson, U., Cederberg, C., Berglund, M. (2009). *Greenhouse gas emissions in animal feed production. Decision support for climate certification*. Sweden: Klimatmärkning för mat, Sweden.
- Teagasc, 2011a. *Sectoral Roadmap: Suckler Beef*. Accessed July 2013: www.teagasc.ie/publications/2011/767/Roadmap_SucklerBeef.pdf
- Teagasc, 2011b. National Farm Survey Results 2010 – Dairy Enterprise. Teagasc. Accessed July 2013: www.teagasc.ie/publications/2011/1018/DairyEnterpriseFactsheet.pdf
- Teagasc, 2012. *A Marginal Abatement Cost Curve for Irish Agriculture. Teagasc submission to the National Climate Policy Development Consultation. Appendix B*. Teagasc, Carlow.
- TFRN, 2011. *Draft Guidance document for preventing and abating ammonia emissions from agricultural sources*. WGSR Informal document no. 20. 112 pp.
- Tried & Tested, 2013. “Feed planning for cattle and sheep”, 28 pp. Accessed June 2013: www.nutrientmanagement.org
- Webb, J., Misselbrook, T.H., 2004. A mass-flow model of ammonia emissions from UK livestock production. *Atmospheric Environment* 38, 2163–2176.

7.2 Managing high nature value grassland

Introduction

The term High Nature Value (HNV) farming recognises that certain types of farming – typically low intensity, low input farming systems, often with high structural diversity – are extremely valuable for biodiversity.

Extent of HNV land: In the 27 EU Member States, it is thought that there are approximately 74 million hectares of HNV farmland, accounting for approximately 30% of the total Utilised Agricultural Area in the EU. Extensive swathes of HNV farmland are found in the central and eastern Member States and in the Mediterranean basin (IEEP, 2010). The likelihood of HNV farmland presence is depicted in Figure 7.12.



Source: Paracchini et al. (2008)

Figure 7.12. Presence of HNV farmland in Europe – degrees of likelihood

Semi-natural pastures and meadows consist of unsown vegetation that is maintained by livestock grazing and/or mowing, and that has not been substantially modified by intensive fertilisation,

drainage or herbicide use (EFNCP, 2014). They are typified by extensive farming using traditional breeds of livestock, and have a relatively low productivity compared with intensively managed grasslands. They are central to the concept of HNV farming.

Semi-natural pastures include not only grasslands but also other vegetation communities used for grazing and browsing, such as heathlands, scrublands and wood pastures. Overall, these various semi-natural communities make up 20% of the habitats listed on Annex 1 of the Habitats Directive, and all require continued grazing and/or mowing for their maintenance (EFNCP, 2014).

Description

Within this BEMP, the following measures are discussed³⁶:

- Match grazing intensity to biodiversity needs
- Optimise mowing (cut 'n carry) in consideration of biodiversity
- Case Study 1: Mts. Menkveld & Wijnbergen farms, Netherlands: an example of integrating 'nature land' into a highly efficient dairy system:
- Case Study 2: Dehesa: an example of an HNV grazing system, South Spain:
- Case study 3: Haymilk in Austria

In this BEMP it should be mentioned that the operational data section is incorporated under the enclosed case studies because of the diversity of the agriculture sector, the various farming systems and the various parameters, which influence the measure that each farmer should take into account in his farm. Furthermore this BEMP is also strongly related to BEMP 3.4 (Landscape scale biodiversity management).

Model for grazing, mowing and biodiversity

In Germany, a free software tool 'Ecopay' has been designed to provide ecologically effective and cost-effective payments for land use measures to conserve endangered species and habitats in agricultural landscapes. Informed payments are made through agri-environment measures to maximise impact on biodiversity targets at minimum cost. In Ecopay 1.0 the user can select as conservation goals 15 endangered bird species, 15 endangered butterfly species and 7 rare grassland habitats types. Altogether Ecopay 1.0 includes several hundred grassland conservation measures which include different mowing and grazing regimes as well as regimes with combinations of mowing and grazing. These regimes differ in frequency and time of land use as well as N-fertilizer inputs, grazing period, livestock density and type of livestock (DSS-Ecopay, 2014).

Grazing for biodiversity

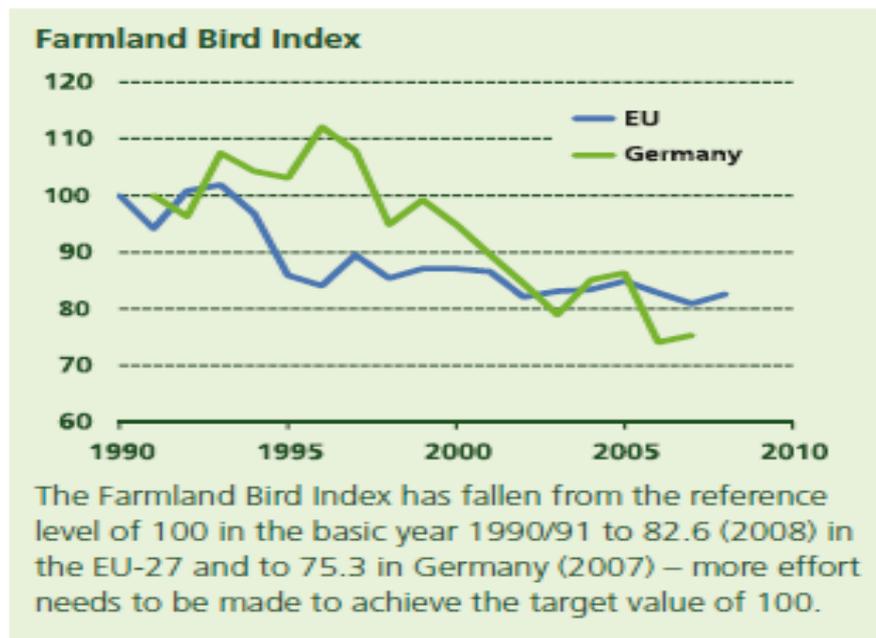
In the absence of reliable inventories of semi-natural vegetation, very low livestock densities per hectare of forage (e.g. < 0.2 LU/ha, although the figure will depend on the area) are themselves a strong indication of predominantly semi-natural forage, and thus of HNV farmland (EFNCP, 2014).

The Rare Breeds Survival Trust (RBST)'s Grazing Animal Project (GAP) in UK has produced 'The Breed Profiles Handbook: A Guide to the Selection of Livestock Breeds for Grazing Wildlife Sites' (Grazing Animals Project, 2009a) with comprehensive information on breed characteristics. Cattle display generalised grazing behaviour which is good for maintaining species diversity in herb-rich swards, compared with sheep that are highly selective grazing behaviour. One aim of this project is to produce best practice information on the sustainable management of heathland (an example of this is seen in Figure 7.13), working together with farmers and graziers (Grazing Animals Project, 2009b). In addition, where such projects are in popular public footfall areas, information boards (Figure 7.14) add to the value of the visit and raise awareness.

³⁶ The case study in BEMP 3.4 is also relevant for this BEMP and the reader can also take it into account.

German organisation DVL (German Association for Landcare) recognises the need for the retention of extensively grazed grassland and argues “agriculture has a major role to play in achieving European targets for the protection of biodiversity and environmental resources.” The extensive use of grassland as near-natural grazing systems could make a considerable contribution to the protection of species diversity, water quality, soil health and climate.

The Voluntary Initiative (2009) also uses Farmland Bird Index as a measure of farm environmental best practice. Bird populations are considered to be a good indicator of the broad state of wildlife because birds occupy a wide range of habitats, they tend to be near or at the top of food chains and there is considerable long-term data on changes in bird populations, which helps in the interpretation of shorter term fluctuations (Figure 7.15).



Source: DVL (2011)

Figure 7.15. Farmland bird index showing gradual declines from original baseline (1990)

Mowing for biodiversity

In most cases, delaying the first mowing date in European meadows has either positive or neutral effects on plant and invertebrate biodiversity (Humbert et al., 2012). Some agri-environmental schemes set the date of first mowing for example not before mid-May.

At the landscape scale, creating a mosaic of different mowing regimes will increase species diversity, as there is no single appropriate mowing time that suits all organisms. In addition to the date of first mowing, a low annual cutting frequency also promotes wild plants and invertebrates.

Haylage

Mowing for haylage has less negative impact on biodiversity than for silage as it is cut later and fewer times. Haylage has lower water content than silage and this reduces potential for pollution from effluent. Haylage has a lower metabolisable energy (ME) than silage and indigenous traditional breeds of cows have greater ability to convert low quality forage to meat production compared with faster-growing, leaner continental breeds.

Nevertheless the farming practices vary for different systems of high nature value farms. Therefore the farming practices that a farmer is important to follow are listed in the bullet points below (Keenleyside et al., 2014):

- Semi-natural grasslands and other semi-natural habitats used for grazing and browsing:
 - Grazing with a mixture of stock types including local breeds appropriate to maintain habitat

- Seasonal grazing
- Shepherding on open grazing, and folding where appropriate
- Encourage regeneration of characteristic native tree and shrub species
- Adjust the grazing intensity to the habitat, maintain structural and floristic diversity, including shrubs and trees were present
- Arable crops:
 - Minimise the use of synthetic fertilisers and apply manure on farm
 - Fallow with spontaneous vegetation
 - Apply manual mowing
 - Apply grazing after harvest
 - Spring sowing of crops
- Permanent crops:
 - Crops grown on terraces
 - Mixed crops, local varieties and old trees
 - Grazed semi-natural vegetation under and between trees
 - Low input of manufactured fertilisers and crop protection products
 - Protection from harmful browsing and from damage by machinery

Achieved environmental benefits

The main environmental benefits are enhanced ecosystem services in aggregate, including a wide range of services listed in section 3.4. These include increased pollination, water purification, carbon sequestration, increased wildlife and biodiversity.

Appropriate environmental performance indicators³⁷

Management indicators

- Match stocking rate to biodiversity needs
- Optimise timing of mowing for biodiversity
- Replace silage with haylage
- Postpone mowing until fledglings have left the nests of ground-nesting birds
- Species frequency and diversity (no. and no./m²)

Performance indicators

- Livestock Units (LU) per ha or per ha of Utilisable Agricultural Area (UAA); in the absence of reliable inventories of semi-natural vegetation, very low livestock densities per hectare of forage (e.g. < 0.2 LU/ha, although the figure will depend on the area) are themselves a strong indication of predominantly semi-natural forage, and thus of HNV farmland
- For land under arable and permanent crops, a combination of low nitrogen and biocide inputs per hectare may be considered a good indicator (EFNCP, 2014)
- Higher Level Stewardship requirements could form a basis for BEMP; IEEP have undertaken a review of Lower Level Stewardship Measures
- Farmland Bird Index recommended by DEFRA (2012) and The Voluntary Initiative (2009)
- Percentage (%) use of rotational grazing and managing pastures to leave more stubble and forage residue; therefore the beneficial insect and soil microbe populations will benefit some wildlife species
- Measuring cutting frequency as well as the date of the first cut

³⁷ BIOBIO (2013) proposed several indicators on biodiversity which are listed: i. Area of HNV land receiving N fertiliser, ii. N input, iii. Pesticide use, iv. Average stocking rate (LU/UAA), v. Grazing intensity (LU/ha), vi. Mowing time and vii. Mowing frequency

Cross media effects

When HNV land reaches the stage where it is no longer economically viable for the farmer to remain, it leads to land abandonment, rank vegetation and scrub develops with no agronomic or biodiversity value. If mowing and/or grazing meadows is carried out too infrequently, this will lead to weed and shrub invasion, lowering the biodiversity of grassland species.

Applicability

Extensively managed HNV grassland is applicable to marginal land e.g. alpine, upland, moorland, coastal, bog, SSSI, Natura sites and SACs.

Economics

Value-added branding. Conservation grazed products have the potential to be branded and achieve high-end value e.g. The Anglesey Wildlife Friendly Produce (AWFP) brand has been developed with Anglesey Grazing Animal Project farmers to promote locally-sourced food and to benefit the island's economy. The AWFP is AGAP Certified, which means that the beef and lamb comes exclusively from traditional breeds and crosses, born and raised on the island. The certificate shows that all produce is from animals whose grazing has been managed for the benefit of wildlife. It complies with strict criteria, which have been designed to reflect its high conservation and welfare standards (AGAP, 2010).



Driving force for implementation

- Habitats Directive
- Natura 2000
- SSSI and SAC sites
- Birds Directive
- AES payment

Reference organisations

- Mts. Menkveld & Wijnbergen farms, Netherlands
- Upper Booth Farm, England.
- Gerardo Moreno, University of Extramadura, Spain gmoreno@unex.es
- <http://www.jamon.com/>

Reference literature

- Anglesey Grazing Animals Partnership (AGAP) 2010. "Homepage: AGAP Quality Mark", available online: <http://www.agap-ynysmon.co.uk/anglesey-wildlife-friendly-produce.php>, accessed January 2013.
- BIOBIO 2013. Indicators for biodiversity in organic and low-input farming systems. Project reference: 227161 Funded under: FP7-KBBE. Available online: http://cordis.europa.eu/result/rcn/54412_en.html, accessed December 2014.
- DEFRA 2012. Green Food Wheat Sub Group Report: Themes, Tensions and Recommendations. DEFRA, London.
- DSS-Ecopay 2014. "Software information". Available online: <http://www.inf.fu-berlin.de/DSS-Ecopay/index.html>, accessed on January 2013.
- European Forum on Nature Conservation and Pastoralism (EFNCP) 2014. "High Nature Value farming indicators", available online: <http://www.efnecp.org/policy/indicators-high-nature-value-farming>, accessed on January 2014.

- German Association for Landcare (DVL) 2011. *Extensive grazing: Sustainable nature conservation on pastures in the EU, the German Federation and its federal states*, available online: http://www.efncp.org/download/Policy_paper_Beweidung_EN.pdf, accessed on January 2013:
- Grazing Animals Project 2009a. “The Breed Profiles Handbook”, available online: http://www.grazinganimalsproject.org.uk/breed_profiles_handbook.html, accessed on January 2013
- Grazing Animals Project 2009b. “Map of UK Conservation Grazing Schemes”, available online: http://www.grazinganimalsproject.org.uk/gap_site/cornwall_coastal_heaths.html, accessed on January 2013.
- High Nature Value Farming (HNV) 2014. “Farming intensity and biodiversity”, available online: <http://www.high-nature-value-farming.eu/biodiversity/farming-intensity>, accessed January 2013.
- Humbert J. et al. 2012. Does delaying the first mowing date benefit biodiversity in meadowland? *Environmental Evidence* 2012, 1:9, doi:10.1186/2047-2382-1-9.
- Institute for European Environmental Policy (IEEP), 2010. “Agriculture and Land Management”, available online: <http://www.ieep.eu/work-areas/agriculture-and-land-management/high-nature-value-farming/>, accessed January 2013.
- Keenleyside C, Beaufoy G, Tucker G, Jones G. 2014. *High Nature Value farming throughout EU-27 and its financial support under the CAP*. Report Prepared for DG Environment, Contract No ENV B.1/ETU/2012/0035, Institute for European Environmental Policy, London.
- Paracchini, M.A. et al., 2008. *High Nature Value Farmland in Europe. An estimate of the distribution patterns on the basis of land cover and biodiversity data*. JRC Scientific and Technical Reports, Luxembourg: Office for Official Publications of the European Communities. 102pp.
- Poláková, J, Tucker, G, Hart, K, Dwyer, J, Rayment, M. 2011. *Addressing biodiversity and habitat preservation through Measures applied under the Common Agricultural Policy*. Report Prepared for DG Agriculture and Rural Development, Contract No. 30-CE-0388497/00-44. Institute for European Environmental Policy: London.
- The Voluntary Initiative, 2009. “Promoting Responsible Pesticide Use: PowerPoint reference materials”, available online: [www.voluntaryinitiative.org.uk/ Attachments/Resources/1267_S4.ppt](http://www.voluntaryinitiative.org.uk/Attachments/Resources/1267_S4.ppt), accessed on January 2014.

7.2.1 Case studies

Case Study 1 – Mts. Menkveld & Wijnbergen farms, Netherlands: an example of integrating ‘nature land’ into a highly efficient dairy system:

This efficient and intensively managed dairy farm has 160 milking cows on 84 ha producing 9286 kg milk/cow/y and 19,253 kg milk/ha supplemented with 20.4 kg concentrate/cow/y. A small parcel of land lies adjacent to a navigable river that is considered ‘nature land’ and produces a low quality rough forage which the farmer uses to top up dry matter content of daily rations. By incorporating this forage into his farm management plan, the farmer acknowledges its contribution to increase in gross balance whilst at the same time, mowing ensures biodiversity of plant and associated species is maintained.

Case Study 2 – Dehesa: an example of an HNV grazing system, South Spain:

Dehesa is extensive grazing system in Spain where animals (pigs, cattle, goats, sheep, and horses) graze in a landscape mosaic of woodland (holm oak and cork trees bearing acorns), cereals and semi-natural grasslands. It plays an essential role for birds from Northern and Central Europe that winter in S.W. Spain as well as many native Spanish birds, such as the nearly extinct Spanish imperial eagle. Dehesa covers almost five million acres of western Spain and Portugal, formerly oak forest, now thinned and managed. Each tree takes between 30 and 40 years to grow to maturity. Acorns are the basis of the Ibérico pig's diet, although it also feeds on the pastures, cereal stubble and wild legumes, making a contribution to the ecological balance of its natural habitat (see <http://www.jamon.com/pigraising.html>).

It is highly advantageous when both holm and cork oak are present because their differing phenology results in an extended acorn season (Montanera or Panage). Apart from manurial returns from grazing animals, additional nutrients are rarely applied and plots are cultivated every four years on average (G. Moreno, 2013).



Iberico pigs grazing on acorns (Photos: Gerardo Morena)



Dehesa landscape with scattered oaks and cereal intercropping (Photo: Gerardo Morena).



Dehesa with oak and cereal intercropping. One plot is cultivated in autumn and other one is ploughed in spring to be cultivated the next autumn (Photo: Gerardo Morena).



Dehesa with oak and legume-rich semi-natural pasture (Photo: Gerardo Morena).

The Ibérico pig is a rare breed, found only in Spain and its acorn diet contributes to its rich and nutty flavour. The most common crossbreed is between Retintos or Lampiños Ibérico pigs and Duroc-Jersey white pigs. Breeders are careful to keep the proportion of Ibérico stock above 75%, because that is the minimum required by the four Denominations of Origin for Ibérico pigs (<http://www.jamon.com/pigbreeds.html>).

Case study 3: Haymilk in Austria

The production of haymilk is the most original form of dairy farming. For centuries the feeding has been adapted to the cycle of the seasons; during summer the cows get fresh grasses and herbs from the meadows and mountain pastures. To produce feed for the colder season the farmers mow the grass, dry it in the sun and then store it in barns for wintertime. Silage feed (fermented grass and fermented corn) is strictly forbidden.

Hay production has a lot of positive effects. This extensive farming practice preserves important resources such as water or grain. Haymilk cows get their essential nutrients from grass and hay, directly from the meadows. They don't need to be fed with grain, soy or corn which could also be consumed by humans. Besides this hay farming positively affects nature and the environment:

- Haymilk supports biodiversity:
8,000 milk farmers cultivate about 112,000 ha of grassland and an additional 100,000 ha of mountain pastures during summertime in Austria. Almost 1,000 grasses and herbs grow on these meadows and pastures and this can only be maintained through this sustainable form of farming. Due to the large variety of different plants, fertilisers are hardly necessary. The grazing of the cows causes growth impulses and prevents permanent reseeding. Haymilk farmers allow the meadows to mature until all plants are blooming and the diversity is at its peak to support biodiversity. Therefore hay farmers cut their meadows one or two times less, per summer, than conventional farmers.
- Preventing forest encroachment:
Cultivating the mountain areas prevents forestation and protects the meadows and pastures from scrub encroachment. By keeping the areas clear, many different kinds of plants continue to exist.

Natural disasters such as landslides can also be avoided. E.g. during winter long grasses make ideal sliding ramps for snow slabs. However a short cut meadow keeps the snow better in place.

- Maintaining fertile grounds: A huge variety of plants and herbs exist in areas where haymilk cows graze. This high level of biodiversity is responsible for deep rooted plants. Soil organisms such as earthworms digest dead roots and convert them into valuable humus. Humus absorbs huge amounts of CO₂ in the soil. This is important as it prevents CO₂ from escaping into the atmosphere, which would accelerate global climate change. Additionally humus provides high soil moisture. Therefore haymilk cows contribute to the maintenance of fertile ground and help to reduce climate change.

Economics

CAP payments can have the effect of penalising the preservation or restoration of dehesa where it is regarded there is an excess of trees. Dehesa is barely economically viable, even with CAP payment, and only then if the farmer needs no additional labour and if the total land area is significant (some hundreds of hectares). Despite the high prices Iberico ham commands (up to 400- 500 Euros per ham), farmers consider this is not sufficient (G. Moreno, *pers. comm.*).

Due to the increased interest in Jamón Ibérico, the commercial value of the dehesa has risen dramatically thereby sparing it from development (<http://www.jamon.com/pigraising.html>).

For further case studies, refer to Section 3.4:

- RSBP recognised farmers: <http://www.rspb.org.uk/ourwork/farming/natureoffarming/finalists/>
See Hope Farm, Cambridge.
- LEAF integrated farming case study: <http://www.sustainable-agriculture.org/stuff/Renner%20Presentation.pdf>

7.3 Pasture renovation and legume inclusion in permanent pasture and leys

Description

Within this BEMP, the following measures are discussed:

- Reseeding at appropriate intervals to maintain high yields only under certain circumstances
- Minimum tillage reseeded (over-seeding)
- Select most suitable varieties (e.g. sugar grasses, deep-rooted varieties)
- Include clover, other legumes

The reseeding of permanent pasture rather depends on the type of pasture – whether it forms part of an intensively farmed system or whether it is extensively grazed and mown high nature value grassland managed principally for biodiversity initiatives. In the latter case, reseeded is infrequently undertaken whilst in an efficient and intensive system, a drop in dry matter productivity requires reseeded and this can be down by ploughing out with total reseed or utilising a min-till approach whereby over-seeding of the existing pasture is sufficient. Min-till reduces the soil CO₂ flush associated with disturbance whilst also being less destructive on soil fauna. Table 7.7 lists the management practices that encourage C sequestration and therefore improve soil organic matter.

Table 7.7. Grassland Practices likely to increase soil organic C

On permanent grassland:
<ul style="list-style-type: none"> • Maintaining the sward without reseeded, using over-sowing techniques/minimal cultivation (rather than full cultivation) if there is a perceived need to introduce new seeds • Encouraging greater contributions of legumes, e.g. clovers, in the sward • Avoiding overgrazing and compaction of the soil • Avoiding heavy (more than 50m³/ha) doses of slurry
On grassland leys:
<ul style="list-style-type: none"> • Aiming to maintain long leys rather than short-term leys or move towards permanent swards • Including deeper rolling grass species, e.g. cocksfoot, fescues, and legumes, e.g. red clover and lucerne, in seed mixtures • Incorporating any organic materials during cultivations (particularly if there is no arable land that would take higher priority) • Protecting surfaces on slopes: soil on slopes is particularly vulnerable to loss of organic matter by water erosion on bare surfaces and open swards.
<i>Source: EBLEX (2012)</i>

Reseeding and over-seeding

The best practice in grassland management should consist of two elements: i. to ensure swards and ii. to protect grass for carbon storage. In particular, it is very important to ensure that swards are maintained in optimum condition, because grazed grass remains the cheapest feed available on livestock farms.

On the other hand, over-seeding works best with a management-intensive grazing system. When livestock step on (trample) seeds, they improve soil-to-seed contact, especially in late seeding or when seeds are exposed or they are not enough covered by the soil. Furthermore producers should avoid over-seeding grasses with legumes due to the fact that lightweight grass seeds do not broadcast as far as legumes do, resulting in an uneven stand. Likewise grass seeds get caught in existing residue more easily than legume seeds (Heckman, undated).

For maximum productivity, ryegrasses are considered the best at a target composition of 70+% in the sward. Re-seeding or over-seeding should be actioned when ryegrass falls to 30% (DairyCo, 2012). The species mix used for grassland depends on the use of that pasture (Table 7.8):

Table 7.8. Grass types for targeted pasture usage

Grass variety	Purpose
Italian ryegrass	1-2 y leys
Hybrid ryegrass (Italian x perennial)	3-5 y leys
Perennial ryegrass	Long term ley/permanent pasture
Timothy	Hardy, tolerant of wet and heavy soils
Cocksfoot	Tolerant of drought
White clover small leaf	Tolerant of heavy continuous grazing
White clover, large leaf	Best suited to cutting for silage
<i>Source: BGS & EBLEX (2007)</i>	

Pasture quality can be measured by D-value, with modern ryegrass varieties being significantly higher than weed grasses and yet, weed species increase in content with sward age (Figure 7.16). When the farmers want to make high quality of silage, it is important to the grass quality at harvesting period. This is affected by stage of grass growth but there there is a compromise between high quality and high yield³⁸. Research has shown that one extra unit of D-value will improve live weight gain in beef cattle and lambs by 40 g/head/day and 20 g/head/day, respectively (British Seed Houses, accessed August 2013). Furthermore quality parameters and yield change rapidly during May. In particular, actual data from (Davies and IBERS, 2015) show that grass in early May grass has 25% crude protein and 75% digestibility (the D-value) but the yield is very low, approximately 3 t of dry matter. According to the same author, by the end of that month (May) the grass has only 12% crude protein and a D-value of 60%, whereas the yield increases, which is approximately 8 t of dry matter (see also BEMP 7.4 for D-value). Also, there are some field annual visual assessments that can be made prior to mowing in order to indicate the nutritional value of the grass. In general young and leafy grass can have a D-value of 70% or even higher. As the flowering stage begins, the D-value will drop to the value of 64% or lower and eventually when seed heads begin the D-value will again drop to 60%, or even lower (Davies and IBERS, 2015). Therefore it is preferable to lengthen the life of a field, rather than ploughing and re-seeding. Over-seeding is a simple, effective and low cost way to improve worn leys or old pasture without ploughing and re-seeding. To many farmers, over-seeding has advantages over the plough. It is cheap, quick and is of low risk, with existing grass being retained and improved without loss of forage or time. For worn-out pastures, over-seeding or slot-seeding with high sugar grasses and clover can improve productivity and therefore also reduce emissions. High sugar grasses can have positive effect on dietary reduction of N excretion (Section 8.3).

³⁸ It should be mentioned that with high producing livestock, quality should never be compromised for yield (more information available: <http://www.silageadvice.com/library/articles/grass-quality-not-yield-key-silage-making>)

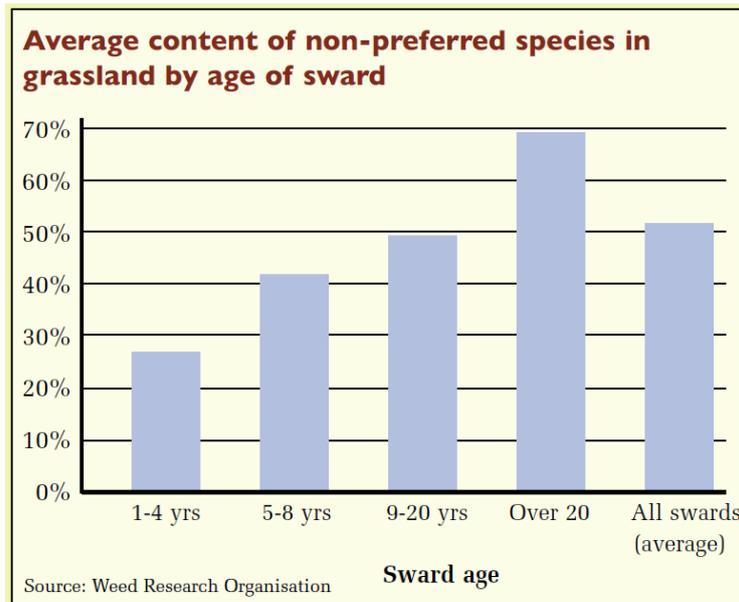


Figure 7.16. Weed species content in different aged pastures (source: Weed Research Organisation cited in British Seed Houses, 2012)

Select most suitable varieties

Finn et al. (2013) found that, in 30 sites throughout Europe, growing a mix of four species [a fast-establishing non-nitrogen fixing grass (such as ryegrass), a fast-establishing nitrogen-fixing legume (such as red clover), a temporally persistent non-fixing grass (e.g. cocksfoot) and a temporally persistent nitrogen-fixing legume (e.g. white clover)] resulted in greater yields compared with monocultures, regardless of soil type, soil fertility and climate. In addition, the percentage of weeds in the plots with four-species mixtures remained consistently low.

The ideal grass is typically ryegrass, as it has good nitrogen-use efficiency. This means it can convert the nitrates produced by the clover successfully into plant yield. Grasses, such as bent, fescue, meadow grass and Yorkshire fog have lower nitrogen-use efficiency and so do not make good companion grasses if production is the main objective (DairyCo, 2011).

Dry matter intakes of beef cattle fed high sugar grass (HSG) increased by around 25%, compared with those fed the control variety. Greater intake was achieved because the HSG variety was highly palatable. Animals grazing HSG recorded average daily live-weight gains of 0.997 kg/head per day, which was 20% higher than the gain of cattle fed the recommended control variety. This bonus from HSG was the result of higher forage intakes and greater efficiency of grass utilisation (Germinal seeds HSG, 2012)

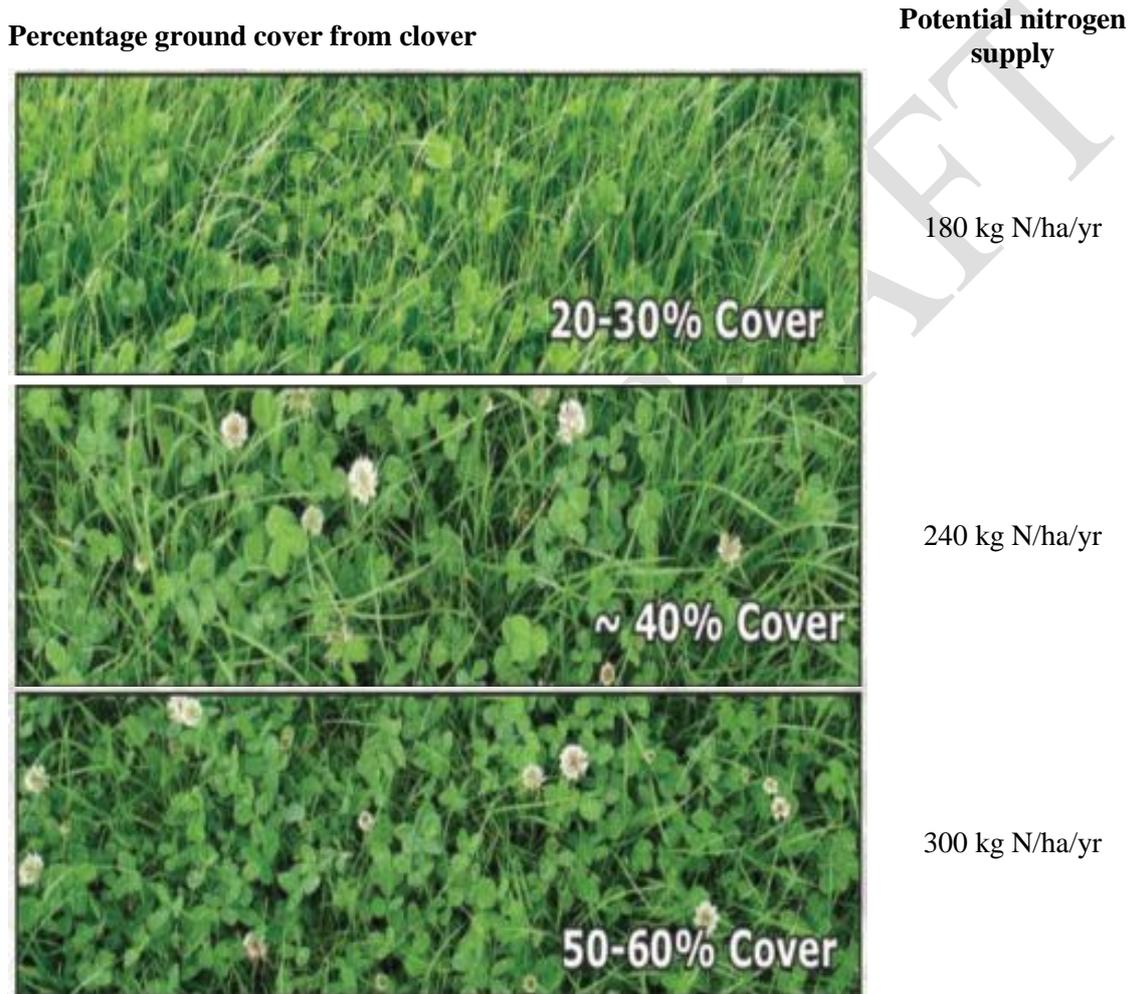
The cost of production per litre of milk or kg of live weight gain is a major consideration for all livestock producers. One of the best ways to improve efficiency is to produce more feed on the farm, rather than buying it in. White and red clovers provide a good source of protein in ruminant diets, both when grazed and conserved and have high intake characteristics and improve pasture D-values. There is the added benefit of nitrogen fixation by the clover plant, so less artificial nitrogen fertiliser is required for grass growth. Clover-rich swards fit well into forage or arable rotations and can benefit soil fertility and structure (DairyCo, 2011).

Yield benefits of grass-clover mixtures are equivalent fertiliser N inputs of 150 to 350 kg/ha, and productive grass-clover mixtures can fix 100 to 380 kg N per hectare symbiotically from the atmosphere. (Peyraud et al, 2009). Switzerland is unusual in mainland Europe in that it has seen an increase in forage legumes and has developed excellent grass-clover mixes as an exemplary

partnership between industry, extension and research. The seed mix is reviewed and published every 4 years and receives the Swiss Grassland Society certificate.

55 MJ are required to produce, transport and spread 1 kg of mineral N while legumes only require solar energy to fix N from the air. In addition to reducing fertiliser nitrogen requirements, the incorporation of legumes such as white clover into grassland swards can also reduce emissions by increasing DM yield for a given level of N fertiliser thus increasing animal productivity and reducing enteric fermentation emissions per litre milk, for example (see also BEMP 6.4).

Assessing nitrogen supply from clover:



Source: DEFRA, 2010.

Figure 7.17. Percentage ground cover from clover and the potential nitrogen supply

The Dairyman Project (Figure 7.17) has developed clover calculator cards (Interreg Grassland website);

BERAS has developed a legume estimator trainer tool (Stein-Bachinger et al., 2013) and has prepared a compendium of legume proportions in arable forage as well as permanent grassland.

Other legumes used in leys:

- Red clover (higher in protein than white clover)
- Lucerne
- Lotus

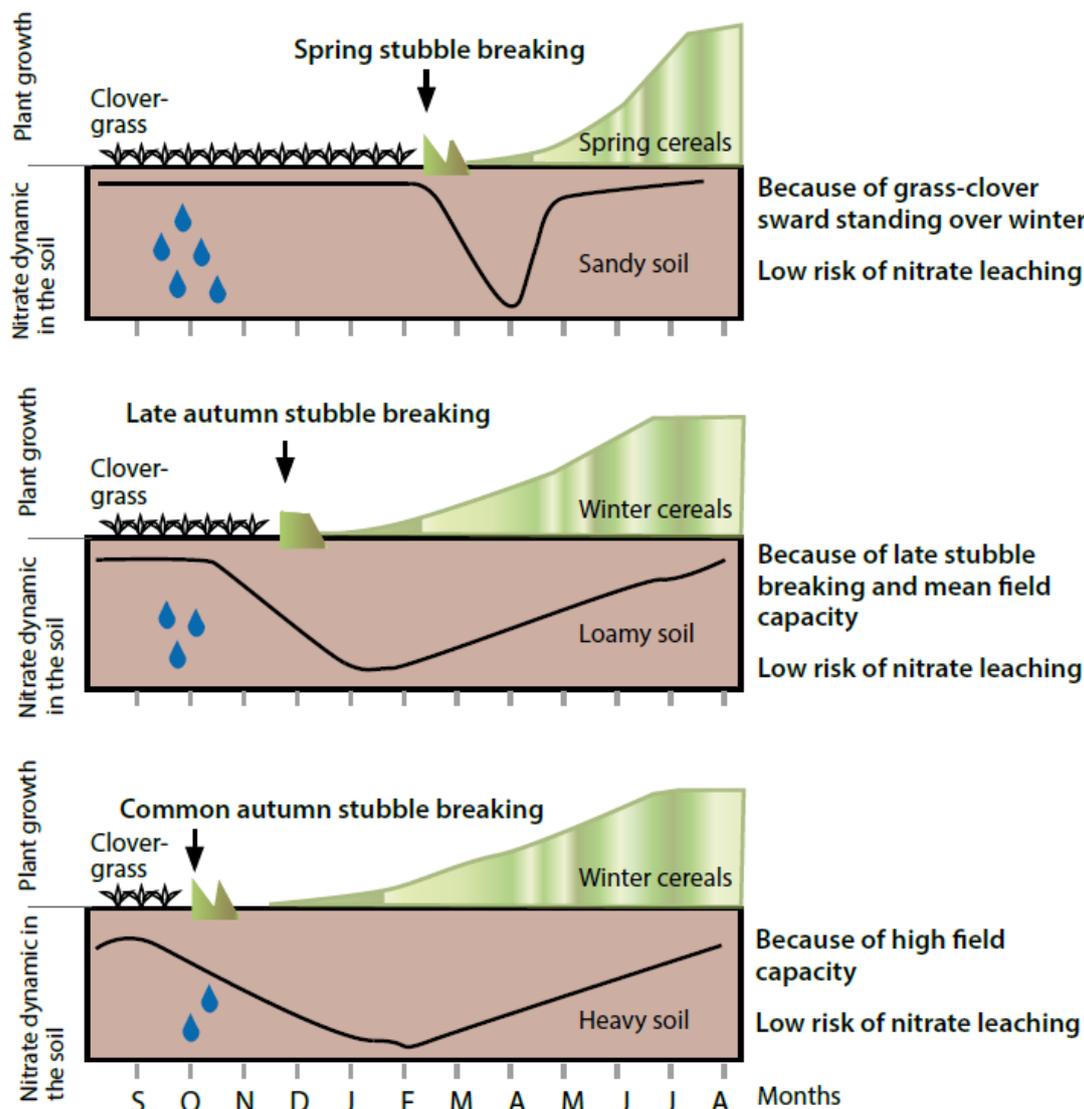
- Medic
- Sulla
- Sainfoin.

Figure 7.18 illustrates different strategies of ploughing grass-clover to avoid nitrate leaching (Stein-Bachinger et al. 2013, citing Faßbender et al. 1993).

Achieved environmental benefits

Benefits of legume inclusion (Dairy Co, 2011):

- Less N fertiliser usage and therefore reduced potential for nitrate-N leached and soil N₂O flux as well as avoided energy consumption and GHG emissions from fertiliser production.
- For every 1 kg of mineral N replaced by BNF, 55 MJ and approximately 6 kg CO₂e is saved.
- Clover increases the crude protein content of first cut silage by 1% for every 10% increase in the amount of clover in the sward.



Source: Stein-Bachinger et al. (2013), citing Faßbender et al. (1993)

Figure 7.18. Schematic description of the N content in the soil of different soil types after site-adapted ploughing of clover-grass.

Appropriate environmental performance indicators

Management indicators

- Practice min-till techniques for re-seeding permanent pasture wherever possible to maintain high yields
- Update seeding mixes to include new varieties when reseeded
- Include clover in leys and permanent pasture and reduce fertiliser N according to BNF
- Plan for N-release following ploughing under of short-term leys
- D-value of pasture
- Live weight gain

Performance indicators

- Actual or avoided fertiliser N application, kg N/ha/y
- Nitrogen use efficiency (%)
- Phosphorus surplus (kg/ha/yr)
- % seed by weight in ley mix as legume
- % field cover as legume
- % non-preferred species in sward
- % percentage difference in plant species diversity in pastures (because forage yields increase might reduce biodiversity because of reduction of weeds in pasture)

Cross-media effects

Clover in conserved forage reduces enteric fermentation but can increase urine-N excreted unless balanced with high C (starch) forage e.g. maize or with high sugar grasses.

Klimatmärkning för mät (2010) noted that when leys and green manures are ploughed under, large amounts of soluble nitrogen can be produced and this can lead to high emissions of climate gases. However, there are no requirements on the time for ploughing under ley/green manure since the choice of effective measures varies within the country and between farms. The producer should be able to show that account has been taken of the large amounts of nutrients released into the soil after break-up of leys, particularly at times when the crop cannot take up nutrients.

Moreover, the biodiversity promotion may result to negative effects. For instance, diversification could be promoted based on sowing exogenous species, which eventually destabilises the land.

Operational data

Farmers should take into consideration the following principles:

- Forage containing clover can be more difficult to conserve well.
- N fertiliser can inhibit BNF, so apply at less than 50 kg N/ha if necessary
- Over-seeding is done in summer when soil moisture level is sufficient. It is best to roll the field prior to over-seeding or to graze sheep for just a few days to achieve the same effect. Grazing can commence within five weeks (cattle preferred to sheep because of grazing height) but the pasture should not be cut in its first year.
- Higher percentages of ryegrass in the grass mix can increase yields, with data for Ireland showing an increase in yield from 9.7 t DM/ha/y at 10% ryegrass to 12.7 t DM/ha/y at 100% ryegrass, with a more than doubling in spring grass yield enabling earlier grazing (French et al., 2010).
- Over-seeding can improve productivity the following season by up to 40% and is useful where (EBLEX, 2013):
 - ploughing is not preferred option (or environmental restrictions prevent it);
 - there are gaps in the sward, e.g. after poaching;

- soil structure is good and the sward is needed to carry stock;
- more ryegrass or newer varieties are wanted and/or clover needs to be introduced.

Clover variety should reflect the type of livestock. In particular; small-leaved suits continuous, hard sheep grazing; medium-leaved suits frequent cutting and rotational grazing; large-leaved suits cutting and rotational cattle grazing (EBLEX, 2013).

Klimatmärkning för mät (2010) emphasised that, when fertilising mixed leys, the Swedish Board of Agriculture guidelines for reduced fertilisation of mixed leys in relation to clover fraction (i.e. a reduction in fertiliser comparable to the estimated BNF), including manure, must be observed.

Applicability

This BEMP is applicable to all systems, and is more prevalent in the following situations:

- Organic systems
- Low-input systems
- Livestock systems
- Break cropping in arable systems

Economics

Seed mixes are usually more expensive but 20-30% clover cover in a ley has a FRV equivalent to 180 kg N /ha (or 210 €/ha).

As grass varieties are constantly improved, re-seeding a five-year-old ley can produce an extra £1,144 (1,346 €/ha) (of feed, based on summer 2012 prices: feed wheat £160 (188 €/t); soya £380 (447 €/t) and a starting yield of 8.5 t DM/ha (EBLEX, 2013).

Costings (EBLEX, 2013):

A full re-seed, including ploughing, costs £375 (440 €/ha)

Direct drilling costs £320 (375 €/ha)

Over-seeding costs £175–200 (205–235 €/ha)

Driving forces for implementation

- Reduced fertiliser costs
- Improved N use efficiency
- Improved crude protein content of ley
- Reduced carbon footprint

Reference organisations

- BERAS, Baltic States
- British Seed Houses
- DairyCo, UK
- Defra, UK
- EBLEX, UK
- Interreg, pan-Europe
- Swedish Agriculture Board
- Swiss Grassland Society

Reference literature

- BGS & EBLEX, 2007. “Silage Decisions: Get the Factsheets”, accessed August 2013: www.silagedecisions.co.uk/factsheets.html?answers=131331220123312

- British Seed Houses, 2012. [www.britishseedhouses.com/files/Pacemaker King Crop 2012 FINAL LORES.pdf](http://www.britishseedhouses.com/files/Pacemaker_King_Crop_2012_FINAL_LORES.pdf) accessed August 2013.
- DairyCo, 2011. *Muck and slurry on clover swards*. Publ. DairyCo/ADHB, Warwickshire, England. 16 pp.
- DairyCo, 2012. “Feeding+ (Section 5) – Managing your forage feeds”: www.dairyco.org.uk/resources-library/technical-information/feeding/feedingplus-section-5-managing-your-forage-feeds, accessed July 2013.
- Davies D., IBERS, 2015. Grass quality not yield key to silage making, available online at: <http://www.silageadvice.com/library/articles/grass-quality-not-yield-key-silage-making>, accessed April 2015.
- DEFRA, 2010. *Fertiliser Manual (RB209)*. 8th edition. Publ. TSO, Norwich, England. 253 pp.
- EBLEX, 2012. *Down to earth. Beef and sheep Road map – Phase 3*. BRP. Publ. AHDB, Warwickshire, England.
- EBLEX, 2013. “Planning grazing for better returns”, accessed Aug 2013, <http://www.eblex.org.uk/wp/wp-content/uploads/2013/06/Manual-8-Planning-grazing-strategies-200313.pdf>
- Faßbender, K., Heß, J., Franken, H., 1993. “Sommerweizen, grundwasserschonende: Alternative zu Winterweizen auf leichten Böden”, in: Zerger, U. (Hrsg.): *Forschung im Ökologischen Landbau. Tagungsband zur 2. Wissenschaftstagung zum Ökologischen Landbau*, pp 139-144.
- Finn, J. A., Kirwan, L., Connolly, J., et al. 2013. Ecosystem function enhanced by combining four functional types of plant species in intensively managed grassland mixtures: a 3-year continental-scale field experiment. *Journal of Applied Ecology* **50**: 365-375. Doi: 10.1111/1365-2664.12041
- French, P., O’Donovan, M, Horan, B., Dillon, P., Shalloo, L., 2010. *How Far Can We Go On Stocking Rate?* Teagasc, Moorepark, Co. Cork, Ireland.
- Germinal Seeds HSG, 2012. [http://www.germinalseeds.co.uk/files/Aber HSG 2012 FINAL LORES-270911.pdf](http://www.germinalseeds.co.uk/files/Aber_HSG_2012_FINAL_LORES-270911.pdf)
- Heckman undated. Improving grass pastures and hayfields by overseeding legumes, available online: <http://www.agry.purdue.edu/ext/forages/Hoos-Your/Fall2003/Improving.pdf>, accessed January 2015.
- Interreg Grassland website <http://www.interregdairyman.eu/en/dairyman/Tools/Grassland-Management.htm> <http://www.interregdairyman.eu/tools/grassland-management/> accessed July 2013.
- Klimatmärkning för mät., 2010. *Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010*. Sweden: Klimatmärkning för mät.
- Peyraud et al, 2009. *Irish Journal of Agricultural and Food Research* **48**: 115–135.
- Stein-Bachinger, K., Reckling, M. & Granstedt, A., 2013. *Ecological Recycling Agriculture - Farming Guidelines*, Vol. 1. Järna, Sweden. ISBN 978-3-00-042440-3, www.beras.eu. 136 pp.

7.4 Efficient Silage Production

Description

Within this BEMP the following measures are discussed:

- Cross refer to Section 7.3 regarding maximising grass growth efficiency
- Harvest timing and method to maximise quality
- Adequate wrapping and storage to minimise % DM losses and spoilage

This BEMP focuses on intensive systems producing silage. Haylage is more typical of extensive systems and HNV grasslands and is discussed in Section 7.2.

Maximising quality in silage

It is considered best practice to produce the highest quality, well-fermented grass silage as possible, as it has been shown to pay significant dividends throughout the winter, and reducing concentrate feed requirements by up to 2kg/head/day (DairyCo, 2012). To optimise ruminant performance, it is essential to maximise output from forage by applying good growing, preservation and storage techniques. Grass, maize, and whole crop cereal silages form the basis of most winter feeding programmes but can show wide variations in quality both between farms and also within the same farm. This can significantly affect animal performance. This BEMP primarily focuses on grass silage, but aspects are also relevant to other types of silage. Silage storage in clamps is addressed in Section 3.3 with respect to leachate management.

One of the most important principles in producing high quality silage is to cut pastures early, when they are at a late vegetative to early reproductive stage of growth. Although delaying cutting often produces a higher silage yield, silage quality from early cutting is usually higher. Pasture regrowth is also usually greater, which means that total production from the pasture (as both silage and regrowth) is also higher.

- Improve pasture utilisation by timing silage cuts to remove surplus pasture.
- Maximise total forage production during the period of peak pasture growth.
- Maximise the quality of both the silage and grazed pasture.

The stage of growth at which pasture is cut will have a greater impact on the feeding value of the silage than any other factor under the farmer's control (EBLEX, 2011).

The first cut (usually of three during summer) of grass in late May is the most important. Growth at this time of year is vigorous and the grass is rich in energy as it produces leaf rather than going to seed. As a rule, D-value (measure of digestibility) falls by 0.5 units a day from when the grass starts to push up flowering stems. When grass is cut for silage at a high D-value of 70 – 72, it is best used to finish beef cattle, whilst over-wintering dry suckler cows are better fed on lower quality silage with a D-value of ca. 60-65 (Davies and IBERS, 2015).

There is a trade-off between digestibility and yield to make when deciding when to cut silage; cutting at a higher D-value means a smaller yield. It is vital to have sufficient silage to meet animal demand through the desired feeding period, as buying in bulk feeds (including straw) can be more expensive than making a high yield of a lower quality silage and balancing it with concentrates (EBLEX, 2011). Benchmark values for key silage quality properties are given in Table 7.9.

Table 7.9. Silage quality indicators

	Good	Moderate	Poor
D-value	70	65	60
% of ear emergence	25%	50%	100%

	Good	Moderate	Poor
Energy ME (MJ/kg DM)	11.5	10.5	9.5
Crude protein content (%)	16	12	10
Ammonia N as proportion of total N (g/kg)	50	100	150
% DM (clamp silage)	28-30	25	20
Feed to:	Finishing stock, ewes carrying multiples	Growing cattle, autumn calving suckler cows, ewes carrying singles	Dry stock, spring calving suckler cows
<i>NB:</i> D-value = measure of feed digestibility			
<i>Source:</i> EBLEX (2011)			

Wet silages result in reduced total DM intakes and cause balling and physical separation of mixed rations whereas very dry forages may lead to greater sorting and increased risk of acidosis.

The difference in ME between the poorest silage and the average can equate to around 5 litres of milk (Tried & Tested, 2013). ME is directly related to grass D-value ($ME = 0.16 * D$). Second cut silages tend to have lower digestibility and ME than first cut.

Silage analysis

Given that forage represents a large proportion of dry matter intake in winter, it is important that laboratory silage analysis should be undertaken.

Dry matter, ME, CP and pH values can all be estimated on-farm. The dry matter of conserved forages of less than 30% can be estimated by squeezing a handful of silage. The dry matter in drier chopped silages can be estimated by taking a handful of silage and compressing it tightly for half a minute, before suddenly releasing and noting the effect on the silage 'ball' (Table 7.10) (EBLEX, 2011).

Table 7.10. On-farm estimate of silage DM.

Amount of squeezing	DM%
Juice easily expressed by hand	< 20
Juice expressed with some difficulty	20-25
Little or no juice expressed but hands moist	> 25
Ball' shape	DM%
Ball retains its shape and some free juice expressed	< 25
Ball retains its shape but no free juice expressed	25-30
Ball slowly falls apart	30-40
Ball rapidly falls apart	> 40
<i>Source:</i> EBLEX (2011)	

Estimate metabolisable energy and crude protein in ryegrass-based swards by looking at the leaf and stem content (Table 7.11).

Table 7.11. On-farm estimate of silage Metabolisable Energy and crude protein.

Leaf and stem content	ME (MJ/kg DM)	CP (%)
Very leafy, no stem visible	12	18
Leafy, some stem present	11	16

Leaf and stem content	ME (MJ/kg DM)	CP (%)
Leafy with some flowering stems	10	14
Moderately leafy with large numbers of flowering stems	9	12
Stemmy, grasses at flowering stage	8	10
Stemmy, grasses at post-flowering stage	7	8
<i>Source: EBLEX (2011)</i>		

Estimate silage pH by mixing a 1:9 silage water sludge and dipping with pH paper.

Silage additives

The main reason for using silage additives is to ensure a good fermentation and minimise ensiling losses. These are available as live bacteria or as acid. The effects of additives on silage quality have been extensively studied and responses have been generally positive. Whilst these are increasingly used routinely on silages to be fed to dairy cattle, relatively few silages made for feeding to sheep are treated with additive, especially silage bales. Additives are recognised as insurance against difficult weather but there is now plenty of evidence to support both the economic and production benefits of using a silage additive (OCW, 2011).

Silage storage

Maximise efficiency of home-grown grass by minimising %DM loss (big bale better than clamp) but, bales more likely to be broached by birds and rodents, resulting in wastage.

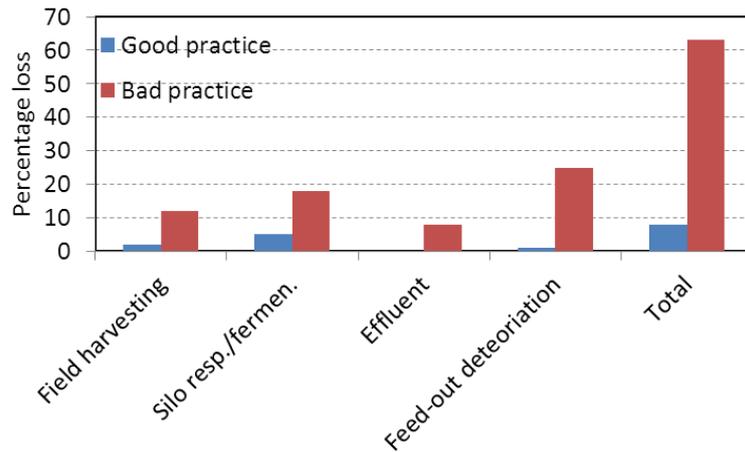
Silage wrapping

From: Silage Decisions factsheet on silage wrap website, accessed Sept 2013.

- Silage at 22% dry matter released 28 litres/t of effluent when it had four layers of wrap and 11 litres with six layers. (IGER, Aberystwyth University)
- With four layers of wrap, wastage was almost 9% compared with 1% in those with six or more layers. More layers also maintained higher energy content and D-value. (CEDAR, Reading University)
- A decrease in mould from 1.75% to 0.75% when comparing four versus six layers of wrap and a predicted increase in cattle daily live-weight gain from 0.62 to 0.65 kg, respectively. This 5.4 kg in extra gain over winter would be worth more than double the cost of extra wrap. (IGER, Aberystwyth University).

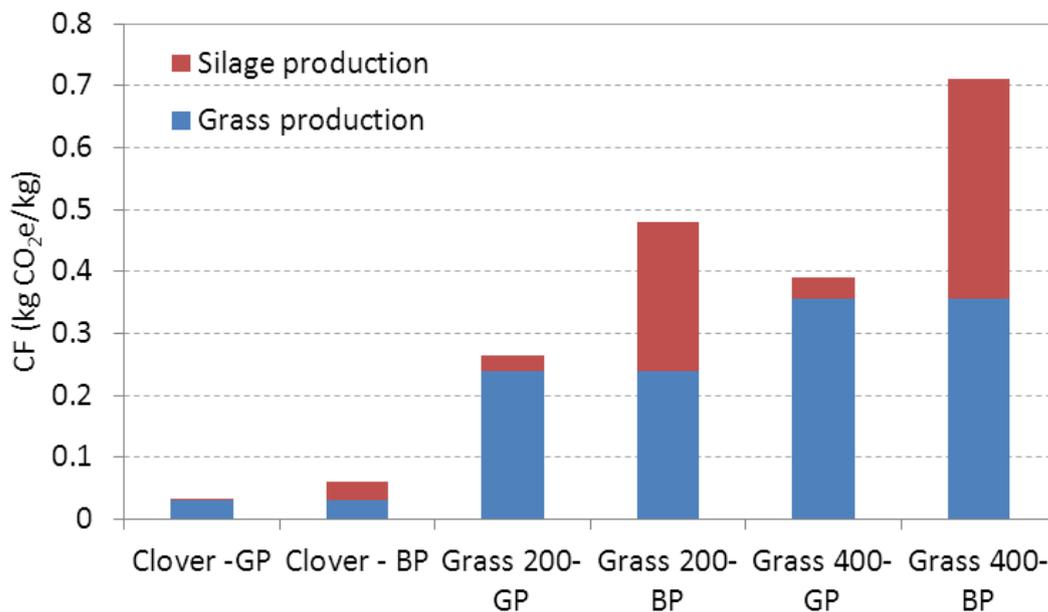
Achieved environmental benefits

- Reduced reliance on concentrate feed by 2kg/dairy cow/day is achievable with good silage, thus lower C footprint (CF)
- An average silage ME equates to an extra 5 l milk/cow/day cf. that of poor silage
- Improved fertiliser use efficiency (less wastage if silage is of good quality (Figure 7.19)
- Reduced CF per unit of N input through best practice silage management (Figure 7.20)



Source: ATP (2013), based on data from IGER-Dow (2008)

Figure 7.19. Best practice and poor performance silage dry matter losses throughout the ensiling-storage-feed-out process



Source: ATP (2013), derived from data in Andrews et al. (2007) and IGER-Dow (2008)

Figure 7.20. Life cycle carbon footprint of silage at feed-out, based on grass production fertilised with clover only, 200- or 400- kg fertiliser N, and with good practice (GP) or bad practice (BP) in silage management.

Appropriate environmental performance indicators

Management Indicators

- Maximise efficiency of grass production (timely pasture renewal, include legume, D-value)
- Optimise harvest timing and method to maximise quality
- Send silage samples to lab for analysis of pH, ammonia-N, volatile fatty acids, D-value, ME, crude protein, sugars, intake potential. Estimate ME, CP, DM and pH on-farm.
- Minimise storage and feed-out losses through careful wrapping

Performance indicators

- Feed conversion efficiency = kg feed DM eaten per kg of meat liveweight or litres of milk produced per kg of dry matter intake. Typical figures: Meat production – 5.5 to 6.5 kg DM eaten

per kg live-weight gain. Milk production – 1 to 2 litres produced per kg DM (Tried & Tested, 2013).

- % DM loss post-ensiling

Cross-media effects

Clamps of poor (low %DM e.g. 18%) silage can yield 100 L effluent /tonne/day which is highly polluting and must be collected.

The environmental efficiency associated with maximisation of silage feed-out is associated with almost no negative environmental effects.

The superior performance of wrapped bales compared with clamps for silage storage outweighs the environmental burden associated with the production and disposal of the additional plastic sheeting required: 1.3 kg plastic film per tonne silage for wrapped bales compared with 0.16 kg plastic film per tonne of clamp silage (DEFRA, 2006).

Clamp sheet plastic can be re-used the next year for non-critical areas e.g. the clamp shoulder or as a groundsheet elsewhere.

Responsible disposal of the plastic film, following reuse where possible, can minimise the risk of harm to wildlife that can arise from plastic litter (Figure 7.21) (DEFRA, 2013).



Source: Westcountry Rivers Trust (2007)

Figure 7.21. Unsightly silage plastic needs careful waste management.

Operational data

Best practice for silage making:

- Rapid field wilting, no more than 24 hours for grass and 48 hours for legumes such as lucerne and red clover;
- Spread the forage in as wide a swath as possible as quickly as possible and definitely within 1 hour of cutting;
- Consider adding an additive to control the fermentation and reduce in-silo losses (Source: IGER-Dow, 2008)

Best practice for silage conservation

The approximate amount of plastic sheet required for clamp silos is 0.16 kg per tonne of silage; for wrapped bales it is 1.3 kg of film per tonne silage. If bales are used because a clamp is no longer serviceable without maintenance, it may be worth financing its upkeep as a cheaper alternative to baling. Square bales take more wrap than cylindrical bales (Table 7.12) (DEFRA, 2013).

Wait 6 weeks after baling or clamping to sample silage for lab or on-farm analysis and ensure samples are representative for all the harvest.

Silage effluent

Effluent must be collected and can be spread on to land but should be diluted 1:1 with water to reduce the risk of pollution and sward scorch. Aim for a rate of between 25–30 m³/ha (EBLEX, 2011).

Wrapping (EBLEX, 2011)

- Maintain wrapper
- Wrap within two to three hours of baling
- Remove field-wrapped bales to the storage area without delay to avoid damage from birds;
- Use high quality film with 55–70% pre-stretching.
- Use six layers of wrap
- Consider green or white wrap to reduce heat at bale surface
- Handle and store to avoid damage to wrap.

Stacking

Guidance from EBLEX (2011):

- Use level site accessible during winter
- Follow HSE guidance
- <25% DM one bale high, 25–35% DM two bales high, >35% DM three bales high
- place best quality silage within the stack;
- Stack more than 10 m away from watercourse;
- Net and bait stack to prevent bird and rodent damage.

Table 7.12. Operational pros and cons of clamps versus big bales of silage

Pros	Cons
Big Bales	
Low aerobic spoilage	Not suitable for very wet silage
Flexibility to cut at optimum cutting date for each field	Labour intensive at feeding out
Can target quality to livestock needs	Risk of variability between bales
Good for storing surplus grass, especially cuts taken in autumn	Prone to damage; mechanical, birds, vermin
Clamp	
Consistent quality for each cut	Higher DM losses than bale (25% vs. 8%)
Suitable for a range of dry matters up to 40%	Heating/mould development at face at feed out

Source: EBLEX (2011)

Best Practice to reducing DM losses are:

- Rapid field wilting, no more than 24 hours for grass and 48 hours for legumes such as lucerne and red clover;
- Spread the forage in as wide a swath as possible as quickly as possible and definitely within 1 hour of cutting;
- Add an additive to control the fermentation and reduce in-silo losses;
- Compact and seal either the clamp or bale well and quickly. Use six layers of quality silage wrap film on the bale;

- Maintain the silage storage area to reduce damage to bales and clamp and so reduce the risk of air (oxygen gaining access to the silage);
- Consider a good way to feed the silage to minimise wastage either through aerobic spoilage or by the animals during feeding.

Applicability

All farms where silage is produced.

Economics

Clamp has large capital layout (Table 7.13). Loss of %DM is lower in bales than clamps (8% vs. 25%, IGER-Dow, 2008), representing a cost to European farmers estimated at € 3.1 billion.

Table 7.13. Economic pros and cons of clamps versus big bales of silage

Pros	Cons
Big Bales	
Low DM loss (< 5-10%) during production and storage	Plastic disposal: high cost of compliance with Waste Regulations
Limited capital investment, low transport and storage costs	High unit costs
Clamp	
Large scale operation allows speedy harvest	Depreciation cost of clamp
<i>Adapted from: EBLEX (2011)</i>	

Driving forces for implementation

- Waste Regulations
- Reduced concentrate feed costs
- Pollution prevention
- Water Framework Directive

Reference literature

- Andrews, M., Scholefield, D., Abberton, M.T., McKenzie, B.A., Hodge, S., Raven, J.A., 2007. Use of white clover as an alternative to nitrogen fertiliser for dairy pastures in nitrate vulnerable zones in the UK: productivity, environmental impact and economic considerations. *Annals of Applied Biology*, 151, 11-23.
- Bangor ATP, 2013. Material for the Carbon Footprinting and Life Cycle Assessment course, School of Environment, natural Resources and Geography, Bangor.
- BGS & EBLEX, undated. "Silage Decisions Factsheet: Silage Wrap", accessed Sept 2013: www.silagedecisions.co.uk/pdfs/silage%20wrap%20factsheet.pdf
- DairyCo, 2012. "Feeding+ (Section 5) – Managing your forage feeds" (published 12 July), accessed July 2013: www.dairyco.org.uk/resources-library/technical-information/feeding/feedingplus-section-5-managing-your-forage-feeds/
- Davies D., IBERS, 2015. Grass quality not yield key to silage making, available online at: <http://www.silageadvice.com/library/articles/grass-quality-not-yield-key-silage-making>, accessed April 2015.
- DEFRA, 2006. <http://archive.defra.gov.uk/environment/waste/topics/farm/documents/waste-minimisation.pdf> accessed March 2014.
- DEFRA, 2013. "Minimising farm waste: composting and recycling", accessed Aug 2013: <https://www.gov.uk/minimising-farm-waste-composting-and-recycling>

- EBLEX, 2011. *Best practice manual for making silage*. Downloaded July 2013: <http://www.eblex.org.uk/wp/wp-content/uploads/2013/06/Manual-5-makinggrassilageforbetterreturns070211.pdf>
- IGER-Dow, 2008. Assessing on-farm dry-matter losses in silage making stages. EUR 003-09101 0508/PN.
- Organic Centre Wales (OCW), 2011. Factsheet H2: Grass silage quality. Aberystwyth University. 2 pp.
- Tried & Tested, 2013. “Feed planning for cattle and sheep”, 28 pp. Accessed June 2013: www.nutrientmanagement.org
- Westcountry Rivers Trust, 2007. *Best Practice Information sheets IS1.4.1 Silage plastics*. Accessed Jan 2014 from <http://adlib.everysite.co.uk/adlib/defra/content.aspx?doc=245926&id=246011>

FINAL DRAFT

8 Animal husbandry

Introduction

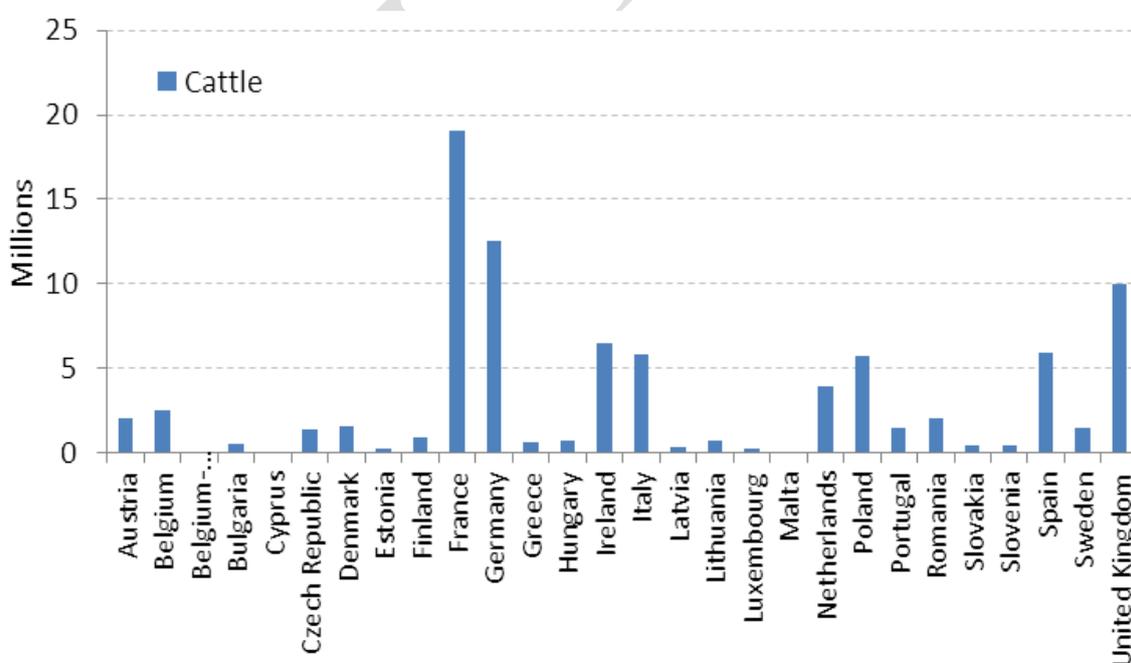
This section is relevant to livestock farms and covers seven BEMPs, namely:

1. Locally productive breeds/hybrids;
2. Nutrient budgeting on livestock farms;
3. Dietary reduction of nutrient excretion;
4. Dietary reduction of enteric fermentation;
5. Green procurement of feed;
6. Maintain herd health;
7. Herd profile management.

The focus here is mainly on ruminants as non-ruminants are comprehensively covered in the Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (EC, 2003), in the draft Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (EC, 2013) and in the Draft Guidance Document for preventing and abating ammonia emissions from agricultural sources (TFRN, 2011).

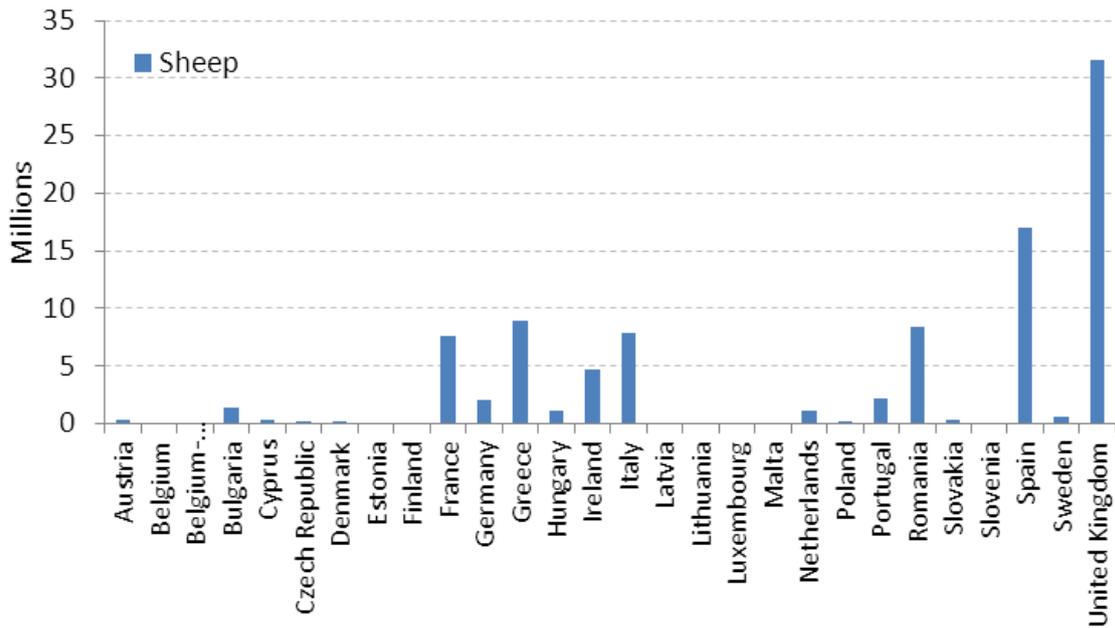
Source: **FAOStat (2013)**

Figure 8.1 displays numbers of cattle and sheep (Figure 8.2) across EU member states, highlighting the importance of France, Germany, Ireland, Italy, Netherlands, Poland, Spain and the UK for cattle rearing, and France, Greece, Ireland, Italy, Romania, Spain and the UK for sheep rearing.



Source: FAOStat (2013)

Figure 8.1. Numbers of cattle across EU member states in 2011



Source: FAOStat (2013)

Figure 8.2. Numbers of cattle (top) and sheep (below) across EU member states in 2011

Regarding pig rearing (Figure 8.3), Denmark, France, Germany, Italy, Netherlands, Poland and Spain are particularly important member states, whilst chicken rearing is important across a wider number of member states (Figure 8.4).

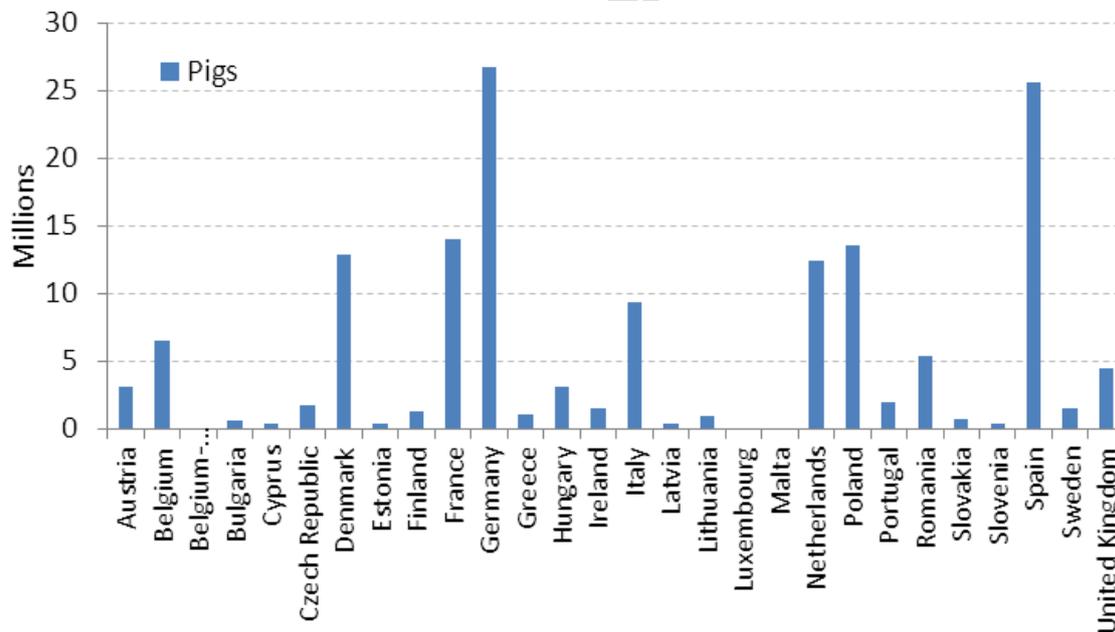
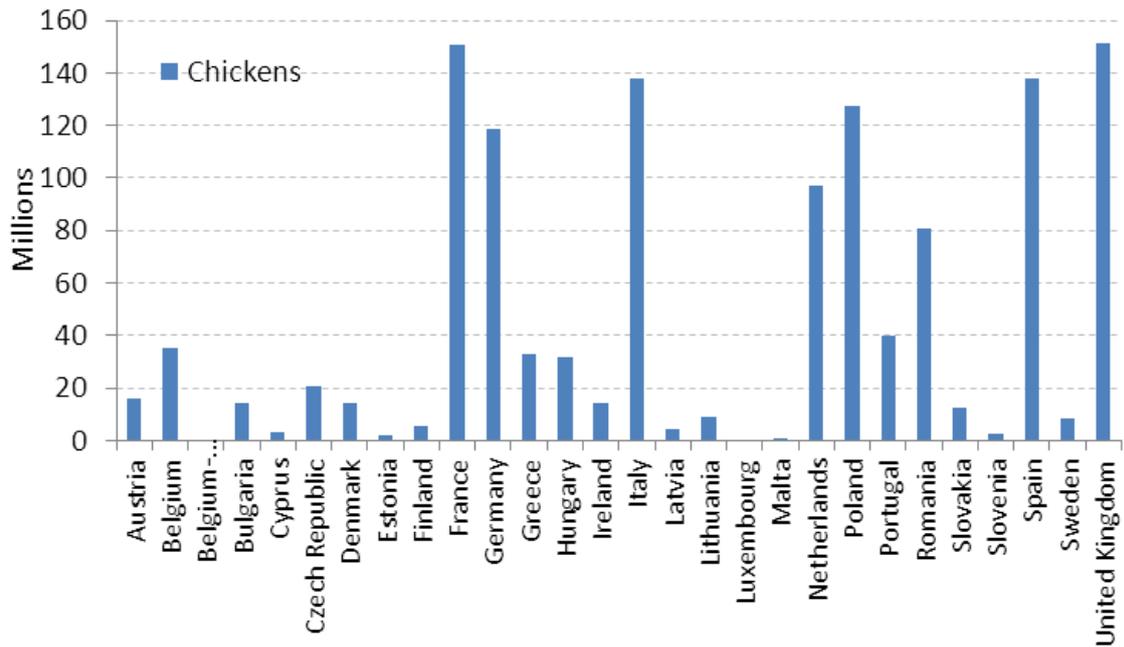


Figure 8.3. Numbers of pigs across EU member states in 2011

Source: FAOStat (2013)



Source: FAO Stat (2013)

Figure 8.4. Numbers of chickens across EU member states in 2011

The carbon footprint of animal husbandry can be reduced by:

- Achieving optimum daily live-weight gains
- Achieving the animal's optimal finishing weight as early as possible
- Feeding a high quality ration, rich in high Metabolisable Energy (ME) density, and the use of co-products, where possible
- Reducing the reliance on artificial fertiliser
- Low carbon source of protein, such as rapeseed meal rather than soya bean meal (EBLEX, 2012).

The issues associated with livestock include nutrient excretion (N, P) since animals are inefficient in converting nutrients into biomass and in the case of ruminants, enteric fermentation gives rise to methane emissions.

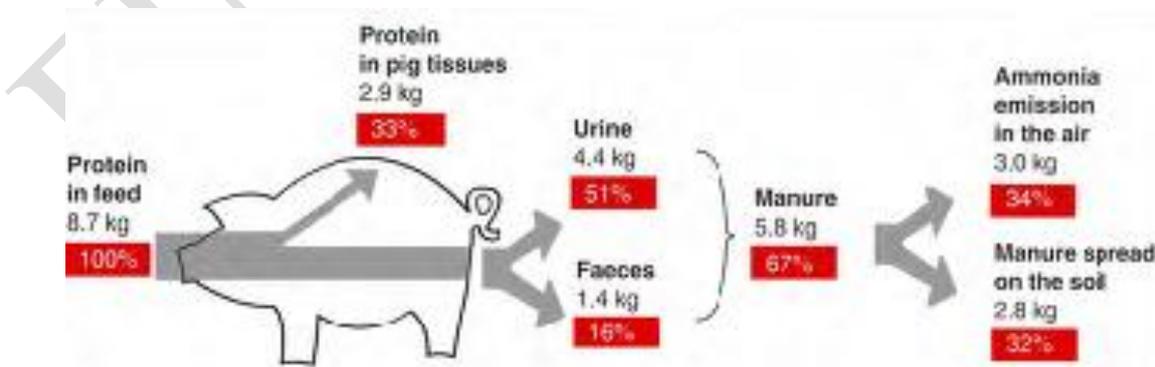


Figure 8.5. Fate of dietary N over the lifetime of a fattening pig slaughtered at 108 kg (EC, 2003)

In intensive livestock rearing, animals metabolise feed and excrete most of the nutrients via manure. In the production of pigs for slaughter the process of nitrogen consumption, utilisation and losses is well understood (Figure 8.5). As intensive livestock farming often coincides with areas of high animal densities e.g. western Flanders in Belgium, southern provinces of Netherlands and Brittany in France, commonly the amount of nutrients in animal manure exceeds agronomic requirements in the locality (EC, 2003).

Relative to ruminants, monogastric animals are minor emitters of GHG. The IPCC (2006) assumes enteric CH₄ emission factors for pigs at about 1.2 to 2.8% of the emission factors for cattle. Recent estimates place GHG emissions from pigs at about 9.5% of the total emissions from livestock (Gerber et al., 2012) and, according to the same authors, the contribution of poultry to the global livestock GHG emissions is around 9.7% (Figure 8.6).

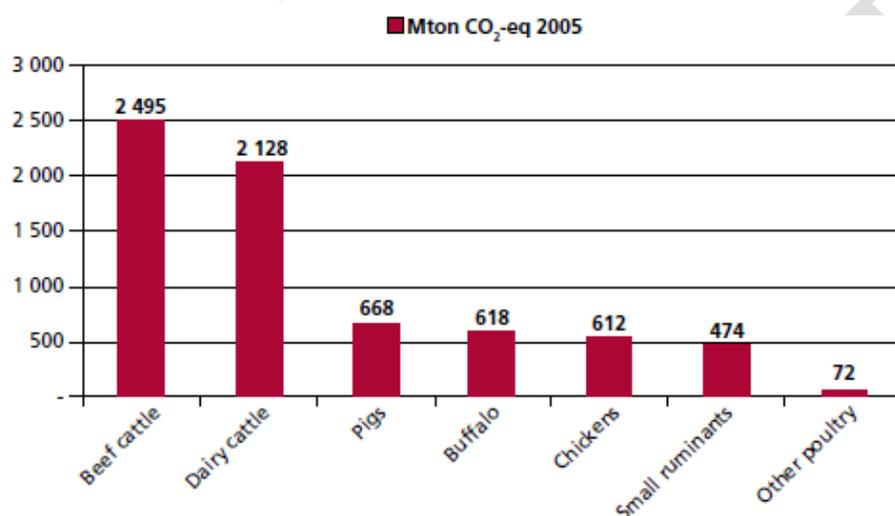


Figure 8.6. Total Global GHG emissions by animal species in 2005 (Gerber et al., 2012; FAO, 2013)

To achieve low GWP farming, the following applies to livestock husbandry (EBLEX, 2012):

- Achieving optimum daily live-weight gains (feed efficiency);
- Achieving the best finishing weight as early as possible (feed efficiency);
- Feeding good quality grass or a high quality ration (with high available ME) where required and the use of co-products where suitable (feed efficiency);
- High output per breeding unit (fertility efficiency).

It is noteworthy that longevity has a lower GWP (Table 8.1 and Table 8.2) saving than either feed or fertility efficiencies (EBLEX, 2009).

Table 8.1. GHG Emission Savings from Beef Production Efficiency Improvements.

Area	Change in physical performance	GWP100 Saving (kg CO ₂ eq/kg meat)
Fertility Efficiency	+ 0.02 calves/cow/Year	0.26
Longevity	+ 1 year productive life	0.07
Feeding Efficiency - genetic improvement	+ 5% lifetime growth rate	0.3
Feeding Efficiency - feed quality improvement	+ 5% forage energy density (ME)	0.31

Source: EBLEX (2009)

Table 8.2. GHG Emission Savings from Sheep Production Efficiency Improvements.

Area	Change in physical performance	GWP100 Saving (kg CO ₂ eq/kg meat)
Fertility Efficiency	+ 0.1 lamb per ewe	0.74
Feeding Efficiency - genetic improvement	+ 2% daily liveweight gain (DLWG)	0.18
Feeding Efficiency - feed quality improvement	+ 5% forage energy density (ME)	0.61

Source: EBLEX (2009)

Reference literature

- EBLEX, 2009. *Change in the wind. The English Beef and Sheep Production Roadmap – Phase 1*. AHDB, Warwick, U.K.
- EBLEX, 2012. *Down to earth. The beef and sheep roadmap – Phase 3*. AHDB, Warwick, U.K.
- FAOStat, 2013. “FAOSTAT – Domains”, accessed July 2013: <http://faostat3.fao.org/faostat-gateway/go/to/download/G1/GU/E>
- FAO, 2013. *Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO₂ emissions*. Editors: Gerber, P.J., Henderson, B. and Makkar, H.P.S. Paper 177. FAO, Rome, 2013.
- Gerber, P. et al., 2012. Greenhouse gas emissions from livestock food chains: a global assessment. Bratislava, EAAP.
- IPCC, 2006. *Guidelines for national greenhouse gas inventories. Agriculture, forestry and other land use, vol. 4*. Intergovernmental Panel on Climate Change. IGES, Hayama, Kanagawa, Japan.
- EC, 2003. *IPPC Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs* (ILS, BREF). July 2003.
- EC, 2013. *IPPC Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs* (BREF, draft 2). August 2013.
- TFRN, 2011. *Draft Guidance Document for preventing and abating ammonia emissions from agricultural sources*. Informal document no. 20. TFRN. Downloaded May 2013: <http://www.clrtap-tfrn.org/documents>

8.1 Locally adapted breeds

Description

Within this BEMP, the following measures are discussed:

- Local breeds/hybrids suited to conditions (extensive systems)
- Productive breeds but resilient to local climatic conditions (intensive systems)
- Cross-breeding, check genetic merit in other spp., e.g. poultry, sheep, etc.

Farmers over time have developed animal breeds that are particularly adapted to local conditions, including social, economic and ecological conditions that incorporate a large degree of intra-specific/within breed genetic diversity. Locally adapted and rare breeds are crucial in maintaining food security, especially in areas with little control over crop growth conditions. They are also a foundation of resilient local food systems. This BEMP also includes the in-situ preservation of rare and traditional breeds.

Breed selection can be for:

- Improving genetic merit to maximise resource efficiency (e.g. Ireland EBI);
- Survival under harsh climatic/arid conditions;
- Grazing of marginal land (e.g. uplands);
- Conservation end-use e.g. on rejuvenating heathland.

For a trait to be considered for inclusion in a breeding objective it must be either economically, socially (e.g., animal welfare) or environmentally important. In the next paragraphs, a distinction between the locally productive breeds and the resource efficiency breeds is done.

8.1.1 Locally productive breeds

According to FAO/IAEA maintaining the diversity of animal genetic resources is essential to satisfy basic human needs for food and livelihood security. Animals can provide meat, milk, eggs, fibre, clothes, resources for shelter, manure for fertilizer and fuel, draught power, etc. Genetic diversity ensures that different species and breeds are able to adapt to extreme conditions of drought, humidity, cold, and heat, making it possible for humans to obtain livelihoods in inhospitable areas.

The Organic Standards (DEFRA, 2006) stated that in order for the farmers to select the appropriate breeds or strains, parameters like the capacity of animals to adapt to local conditions, their vitality and their resistance to disease must be taken into account in advance. In addition, breeds or strains of animals shall be selected to avoid specific diseases or health problems associated with some breeds or strains used in intensive production and preference is to be given to indigenous breeds and strains.

For instance, the advantages of these breeds from a health and welfare perspective in sheep are listed below:

- More likely to utilise lower quality feed;
- More resilient to climatic stress;
- More resistant to local parasites and diseases.

Moreover, local and native breeds represent a unique genetic resource for improving health and performance traits in future. However, these characteristics often have to be balanced with economic efficiency and market requirements. Local breeds, under good production conditions, tend to be less productive than improved breeds (Organivet, undated).

Cattle

EURECa project about self-sustaining local cattle breeds in Europe makes ten recommendations to make local breeds more self-sustaining (Hiemstra et al, 2010).

Globally, about 20% of all breeds or livestock populations are considered to be ‘at risk’ and 9% are already extinct (FAO, 2007). Similar figures³⁹ can be shown for cattle breeds in Europe where at least 130 previously known cattle breeds are already ‘extinct’.

With the increasing demand for animal meat and milk, breeds were intensively selected for food purposes and the development of specialised dairy and beef breeds began. This process started at different periods depending upon the country and region. Intensively selected breeds and their high-input high-output production systems have been very successful and widely disseminated, displacing many native breeds which had not undergone any selection process. Many of the native breeds have survived in areas where high-input high output systems were not established for economic, cultural or environmental reasons.

Upper Booth farm, England – Case Study: Belted Galloway cattle are a hardy breed tolerant of the cold and windy climate and able to digest coarse vegetation on Upper Booth Farm. The farm spans a gradient from 270 to 600 m above sea-level, and a range of upland habitats including moorland grazing at the summit in Derbyshire, NW England. Belted Galloways are also used on remote coastal marginal land in Cornwall, SW England (Figure 8.7).



Figure 8.7. A hardy Belted Galloway herd grazing rough pasture near Gurnard's Head, Cornwall

Poultry

Conservation of local chicken breeds in Turkey and Italy – Case Study: Increased global use of highly productive breeds of farm animals has been associated with loss of genetic diversity in most species, but especially in local poultry species (Özdemir et al., 2013). In the Veneto region of Italy, since 2000, various governmental, non-governmental and private organizations have successfully worked to preserve the genetic diversity of poultry resources. By improving knowledge of biological functions, conservation of typical morphological characteristics, development of selection strategies, control of inbreeding and, finally, valorisation strategies to distribute the breed in local productive systems. This best practice approach is now being rolled-out in Turkey (Özdemir et al., 2013).

Grazing animals

The Rare Breeds Survival Trust (RBST)'s Grazing Animal Project (GAP) in UK has produced an extensive series of leaflets on grazing animal types ‘The Breed Profiles Handbook: A Guide to the

³⁹ For more information visit also: www.fao.org/dad-is

Selection of Livestock Breeds for Grazing Wildlife Sites' with comprehensive information on breed characteristics, e.g. Hardiness, physical attributes and husbandry, grazing characteristics, interaction with the public, marketability, sites where animals are being used with contact details (GAP, 2009). Cattle display generalised grazing behaviour which is good for maintaining species diversity in herb-rich swards, compared with sheep that are highly selective grazing behaviour.

Indigenous traditional breeds of cows on have greater ability to convert low quality forage to meat production compared with faster-growing, leaner continental breeds and Holsteins are of extremely limited use with conservation owing to their weight (700 kg) compared with smaller Jersey or Kerry which are suitable to graze rough, herb-rich land.

The 'Smaller breeds' argument for conservation grazing: The amount of dry matter an animal requires for maintenance purposes is directly correlated to its weight. A large, continental-bred 750 kg cow will need an intake of 15 kg of dry matter whereas a smaller, native-bred cow weighing 450 kg (size partly dictated by breed and calving age) will only require 9 kg of dry matter for maintenance. In this case, five smaller cows could be kept on the same area of land as three larger cows (Chapman, 2012).

Size of Breed and poaching: A study in Ireland comparing the effects of poaching from two dairy cow breeds, the large Holstein Friesian and the smaller Jersey Crossbred (Jersey x Holstein Friesian) found that there was no difference between the two breeds. This was attributed to similar static loading pressures of both breeds: the smaller cows had smaller hooves and, hence, caused similar damage to the soil surface (Dairyman project, accessed Nov. 2013).

8.1.2 Resource efficient breeds

Currently in the UK (2014), livestock production accounts for about 7% of UK GHG emission when expressed as global warming potential in CO₂ equivalents, the second most important source after energy. Particularly potent are N₂O and CH₄ from livestock production (DEFRA, 2008).

Cattle and sheep

Teagasc, in association with the Irish Cattle Breeding Federation (ICBF) and Sheep Ireland, has been making strides in the development of the national genetic evaluations for cattle and sheep in Ireland. For a trait to be considered for inclusion in a breeding objective it must be either economically, socially (e.g. animal welfare) or environmentally important.

Economic Breeding Index (EBI) is a 'single figure profit index' aimed at helping farmers identify the most profitable bulls and cows for breeding dairy herd replacements. It comprises of information on six sub-indexes related to profitable milk production namely: Milk production, Fertility, Calving performance, Beef carcass, Maintenance and Health. Genetic evaluations attempt to disentangle the effects of genes and the environment in order to select animals that have high genetic merit, and not those that perform well simply because they are well managed and fed.

Recent work in Ireland shows an increase of over €3 in profit per cow for every €1 increase in herd EBI (EBI, undated).

An increase in EBI for dairy cattle reduces GHG via: reducing calving interval and replacement rates thus reducing enteric CH₄ emissions per unit of product, increasing milk yield and composition per unit of grass grazed, earlier calving, increasing proportion of grazed grass in diet and reducing culling rates, improving health, reducing health and disease (Schulte et al., 2012).

Best practice is to use Artificial Insemination to breed dairy replacements.

SRUC sheep breeds for multiple births (Vipond 2011):

- 1 kg of lamb sold or retained per 1 kg of ewe to ram;
- 1 kg of lamb produced for every 5 kg of concentrate fed.

In the UK, targets have been set to reduce beef and sheep system emissions by 11% (based on 2008 values) by 2020. On the basis of calculated current emissions levels – which include the CO₂ generated by primary energy use - this means reductions of around 1 kg CO₂ equivalent per kilogram of beef and sheep meat respectively (EBLEX, 2009), which could be used as a benchmark.

Benchmarks of excellence

- 1 kg CO₂e reduction /kg beef produced
- 1 kg CO₂e reduction /kg sheep meat produced

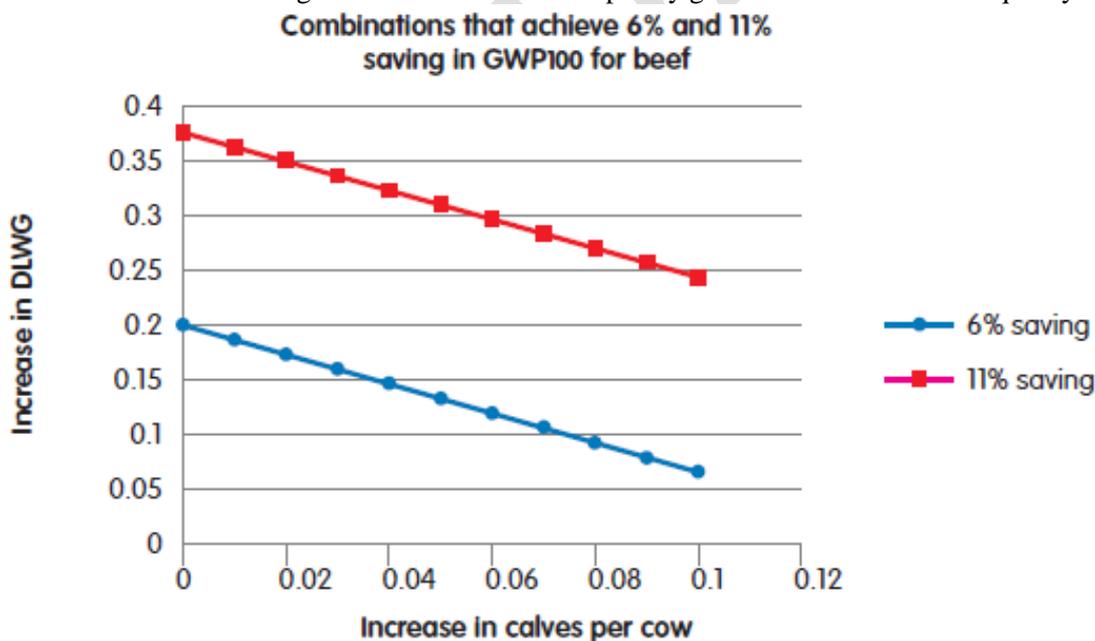
Table 8.3. Annual Beef and sheep System GHG Emission Targets (GWP100 kg CO₂ eq/kg meat)

	2008 Baseline	2929 Target (-11%)
Lowland suckler beef	17.12	15.24
Hill and upland suckler beef	16.98	15.11
Dairy beef	10.97	9.76
Hill flocks	18.44	16.41
Upland flocks	13.82	12.30
Lowland flocks	12.62	11.23

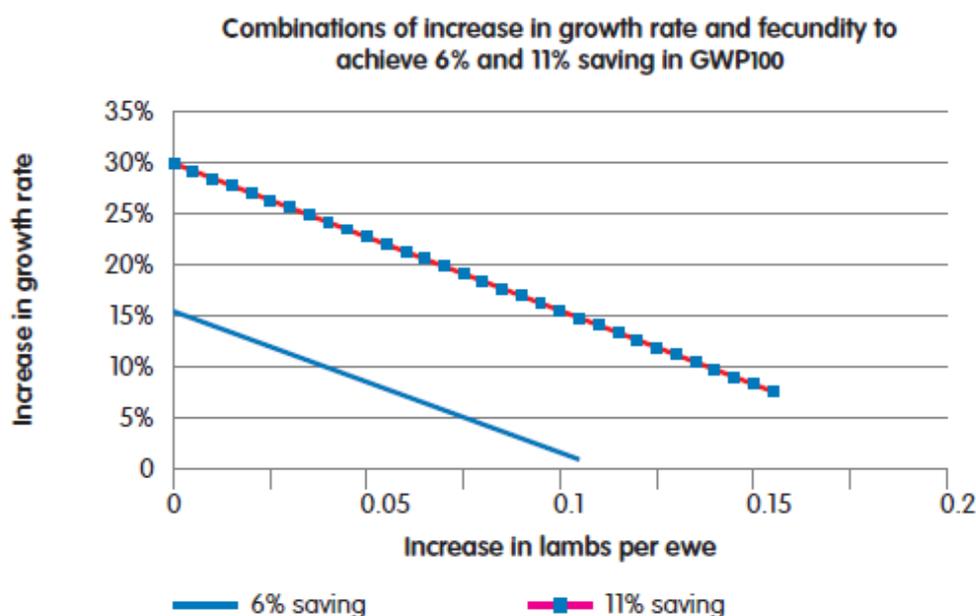
Source: EBLEX (2009)

Achieved environmental benefits

- Increased resource efficiency;
- Reduced GHG (Table 8.4);
- Conservation of diverse habitats and species;
- Productive use of marginal land;
- Avoidance of rank vegetation establishment on poorly grazed or abandoned low quality land.



Source: EBLEX (2009)



Source: EBLEX (2009)

Figure 8.8. Combinations of herd/flock efficiency improvements required to achieve an 11% saving in GWP100 by 2020 for beef systems (above) and sheep systems (below).

Table 8.4. Modelling the impacts of past and likely future genetic changes: Total emissions to air per tonne product for different species and breeds, and proportional changes with genetic changes.

		Kg CH ₄	Kg NH ₃	Kg N ₂ O	GWP(kg CO ₂ -eq)
<i>Layers</i>	² Current (kg)	7.5	28	3.8	3791
	1988 (%)	129.7	136	129	125.2
	2022 (%)	80.4	76.5	80.9	83.2
<i>Broilers</i>	Current (kg)	4.9	23	3.4	3448
	1988 (%) ¹	119.7	110	123	123.4
	2022 (%) ¹	87.1	91.2	79.4	80.9
<i>Turkeys</i>	Current (kg)	5	21.8	5.5	4747
	1988 (%)	99.7	106.3	99.6	99.5
	2022 (%)	92.9	91.5	93.5	93.1
<i>Pigs</i>	Current (kg)	48.8	27.8	2.3	4689
	1988 (%)	116.8	117.6	113.9	115.3
	2022 (%)	90.1	89.6	89	89.3
<i>Dairy</i>	Current (kg)	18.9	3.4	0.6	958
	1988 (%)	124.9	117.3	130.4	115.9
	2022 (%)	87.9	91.5	84.8	92.1
<i>Beef</i>	Current (kg)	264.5	71.4	11.6	14704
	1988 (%)	100.3	100.3	100.3	100.3
	2022 (%)	99.7	99.7	99.7	99.7
<i>Sheep</i>	Current (kg)	300.9	41.3	11.3	15813
	1988 (%)	100.7	100.3	99.9	100.7
	2022 (%)	99.6	99.9	100	99.4

¹ expressed as % change in emissions relative to current levels of emissions per unit product. ²'current' refers to 2007 figures throughout.

Source: DEFRA (2008)

Appropriate environmental performance indicators

Management indicators

- In extensive farm systems, stock local breeds/hybrids.
- In intensive systems, stock breeds/hybrids that are appropriate to local climatic conditions.
- Share of production accounted for by locally adapted and /or rare breeds during the analysed time-frame.

Extensive systems (beef cattle, dairy cattle, sheep, pigs)

- Proportion of land area being grazed for conservation compared with commercial grazing area;
- Biodiversity indicators relevant to the area under grazing management for conservation;
- % animals that are of local or rare genetic origin

Intensive systems (beef cattle, dairy cattle, pigs, poultry)

- kg meat or live weight gain and milk per head per year
- Reduced GHG per unit of saleable product in kg CO₂e/kg product
- Fertility efficiency:
 - *beef fertility efficiency - calving interval 420 d
 - *ewe fertility – 139 lambs / 100 breeding ewes
- Feed conversion efficiency:
 - *beef feed efficiency, live-weight gain – 0.484 kg/d carcass weight
 - *lamb feed efficiency – 23.5 kg lamb carcass / ewe
- Herd health (refer to Section 8.6)
- Improvements on 2007 levels of GWP by 1.5%, 1.0%, 0.8%, and 0.8% per annum for layers, broilers, pigs and dairy cows, respectively (DEFRA, 2008).
- Improvement in EBI;

*These are 2020 targets for England, which are presented in Table 8.5 (EBLEX, 2012).

Table 8.5. Key performance indicators for the beef and sheep industry with 2020 targets

Component	2008	2009	2010	2020 Target
Beef efficiency carcass gain (kg/d)	0.448	0.452	0.456	0.484
Beef fertility calving interval (d)	442	446	440	420
Beef herd output (calves/100 cows calving/y)	84.88	84.30	85.08	87
Age at first calving (mo)	33.7	34.0	33.6	32.0
Cow output (calving/cow/y of life)	0.59	0.61	0.62	0.63
Lamb efficiency (kg lamb carcass produced / ewe)	22.6	22.2	22.1	23.5
Ewe fertility (no. lambs/ 100 breeding ewes)	131	129	129	139

Source: EBLEX (2012)

Cross-media effects

- Animal health is paramount to feed and fertility efficiencies and therefore should be of primary consideration in intensively managed systems.
- Grazing less productive land can constrain economic viability.
- More extensively managed systems can lead to inefficiencies and therefore greater GWP per unit of product.

Operational data

Of the traits examined in this study, those that are most likely to have a beneficial effect on methane emissions through genetic selection or breed substitution are ewe prolificacy, ewe longevity and muscle depth (through its correlated effect on carcass weight) (Hybu Cig Cymru, 2011). Table 8.6 lists the animal strategies offering non-CO₂ GHG mitigation opportunities according to FAO (2013).

Table 8.6. Animal management strategies offering non-CO₂ GHG mitigation opportunities

Category	Potential CH ₄ mitigation ¹	Potential N ₂ O mitigation ¹	Effective ²	Recommended ³
Increased productivity	High ⁴	High ⁴	yes	Yes
Genetic selection	low?	?	yes	yes? ⁵
Animal health	low?	low?	yes	yes
Reduced animal mortality	low?	low?	yes	yes
Reduced age at harvest and reduced days on feed	medium	medium	yes	yes

¹High = >30% mitigating effect; Medium = 10-30%; Low = <10%. Mitigating effect refers to % change over a standard practice i.e. study control that was used for comparison and are based on combination of study data and judgement by authors.
²Determined on the basis of: GHG mitigation potential and/or effect on productivity (no negative effect or improvement is beneficial).
³Based on available research or lack of sufficient research.
⁴Increased productivity will have a powerful mitigating effect on GHG emissions, but the size of the effect will depend on a variety of factors (baseline productivity, type of animal, type of production, feed quality and availability, genetic make-up of herd, etc.).
⁵Uncertain results and requires significant investment.

Source: FAO, (2013)

Applicability

The conservation and continual development of locally productive and resource efficient breeds and hybrids is applicable to pig, beef, dairy, sheep and poultry.

Sheep genetic improvements will see most GWP benefit in lowland flocks with small yet nationally significant benefit in upland sheep in Wales because of high percentage of sheep in uplands in Wales.

Economics

- Improved potential for funding from agri-environment schemes for the use of conservation grazing;
- Value-added pricing of products from animals grazed for conservation end-use : high-end market value;
- Locally productive breeds
- An increase of over €3 in profit per cow for every €1 increase in herd EBI.
- If the potential to increase dairy cow EBI by €65 per cow, Schulte et al. (2012) calculated a marginal abatement potential (IPCC methodology) of 0.596 Mt CO₂e in Ireland, at a cost of - 288 M€.

Driving forces for implementation

Genetic diversity of breeds within the landscape is an best practice to build resilience into the livestock industry for environmental perturbations and trends including drought tolerance, exposure,

weather swings (e.g. temperature variation, flooding), disease, health problems, range of forage quality.

Reference literature

- Chapman, 2012. *Are Mob Grazed Cattle the Perfect Arable Break?* Nuffield Farming Scholarship Trust Report, July 2012. Nuffield, UK. Downloadable from: http://www.nuffieldinternational.org/rep_pdf/1348746792Tom-Chapman-2011-report.pdf
- DEFRA, 2006. Compendium of UK Organic Standards.
- DEFRA, 2008. AC204 Report: *Animal genomics for CH4 and N2O reduction*.
- Dairyman project, 2013. www.interregdairyman.eu/ accessed January 2014.
- EBLEX, 2009. Change in the wind. The English Beef and Sheep Production Roadmap - Phase 1. AHDB, Warwick, U.K.
- EBLEX, 2012. Down to earth. The beef and sheep roadmap - phase three. AHDB, Warwick, U.K.
- Economic Breeding Index, undated. "Understanding the Economic Breeding Index (EBI)", accessed July 2013: http://www.icbf.com/services/herdplus/files/Understanding_EBI.pdf
- FAO, 2007. The State of the World's Animal Genetic Resources. FAO, 2007.
- FAO, 2013. Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO2 emissions. Editors: Gerber, P.J., Henderson, B. and Makkar, H.P.S. Paper 177. FAO, Rome, 2013.
- FAO, 2013b. SAFA Indicators. FAO, Rome, 2013.
- FAOStat, 2013. <http://faostat3.fao.org/faostat-gateway/go/to/download/G1/GU/E>, accessed Jan 2014.
- Grazing Animals Project (GAP), 2009. "The Breed Profiles Handbook", accessed January 2013: http://www.grazinganimalsproject.org.uk/breed_profiles_handbook.html
- Hybu Cig Cymru, 2011. *Modelling the effect of genetic improvement programmes on greenhouse gas emissions in the Welsh sheep industry*, accessed January 2014: <http://hccmpw.org.uk/medialibrary/publications/of%20genetic%20improvement%20programmes%20on%20greenhouse%20gas%20emissions%20in%20the%20Welsh%20sheep%20industry.pdf>
- Hiemstra, S.J., de Haas, Y., Mäki-Tanila, A., and Gandini, G., 2010. *Local cattle breeds in Europe: Development of policies and strategies for self-sustaining breeds*. Wageningen Academic Publishers, the Netherlands. Downloadable from <http://www.regionalcattlebreeds.eu/publications/documents/9789086866977cattlebreeds.pdf>.
- EC, 2003. IPPC Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (ILS, BREF) July 2003.
- Organivet, undated. "Breeds", accessed July 2013: <http://www.organicvet.co.uk/Sheepweb/health/prodweb/breed.htm>
- Özdemir, D., Durmu, S., Özdemir, E., De Marchi, M., Cassandro, M., 2013. Conservation of local chicken breeds of Turkey and Italy: a case study. Italian Journal of Animal Science, Available at: www.aspajournal.it/index.php/ijas/article/view/ijas.2013.e49
- Vipond, 2011. *Ewe efficiency – the driver of profitable sheep systems*. SAC Sheep Breeders Round Table, accessed Aug 2013: http://www.nationalsheep.org.uk/pdf_files/Ewe-efficiency%20E2%80%93the-driver-of-profitable-sheep-systems26032012172844.pdf
- Schulte et al., 2012. *Marginal Abatement Cost Curve for Irish Agriculture, Appendix B: Detailed methodologies for the computation of the marginal abatement cost-abatement potential of individual measures*. Teagasc. Ireland.

8.2 Nutrient Budgeting on livestock farms

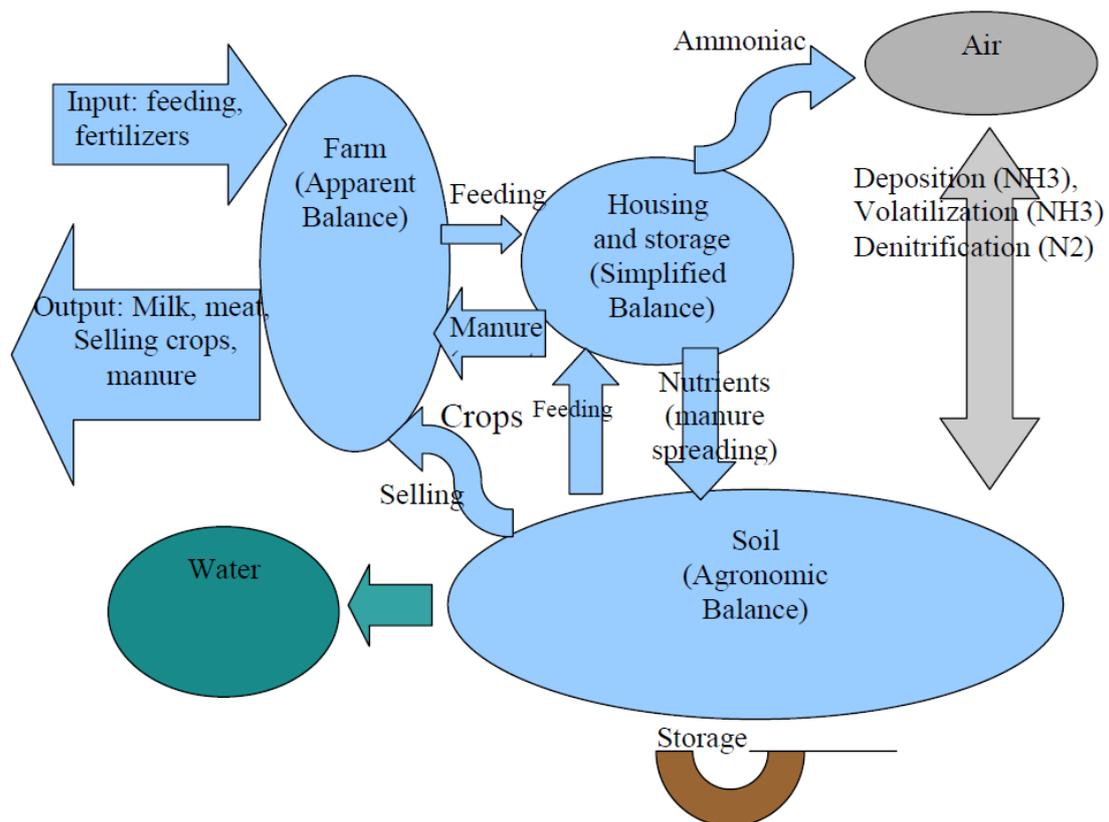
Description

Within this BEMP, the following measures are discussed:

- Nutrient budgets as part of NMP (cross-ref. 5.1);
- Feed nutrient intake (cross ref. 8.3 for N intake) and deposition;
- How to calculate farm surplus and Nitrogen Use Efficiency (NUE) benchmarks;
- Other measures to improve efficiency;
- Case study: NL commercial farm using annual nutrient cycle assessment.

Section 5.1 deals with nutrient budgeting at the field level, understanding environmental and economic optima for crop supply, inputs of nutrients (accounting for organic and mineral) and crop uptake/offtake.

This section looks at nutrient management planning for the whole livestock farm, taking account of all nutrient imports and exports via the farm gate and how nutrient surpluses can be optimised. Pathways of nutrient flow into and out of a livestock farm system are shown in Figure 8.9.



Source: IEEP (2009)

Figure 8.9. Nutrient through-flow for a livestock farming system

Nutrient budgeting is the best practice measure for deciding the nutrient requirement of a farm and involves the judicious balancing of nutrient imports and exports for a farm. A budget requires calculating the macronutrient (N, P, K) and energy intake demand of a livestock unit, recording how much of the nutrient is exported as kg of meat or kg of milk then, considering the land bank area, what is the shortfall in nutrient that has to be imported as feed concentrate.

Table 8.7 shows the estimated potential for reducing N leaching following a tightening of the regulation for overall fertilisation on dairy and pig farms and farms that use considerable amounts of pig manure. Because of the large global warming potential of N₂O, the reduction in N₂O emissions contribute more than 60 % of the aggregated improvement potential in these farms.

Table 8.7. Potential for reduced use of N fertiliser and leaching in dairy and pig production systems in EU-27 following a tightening of the regulation of manure application.

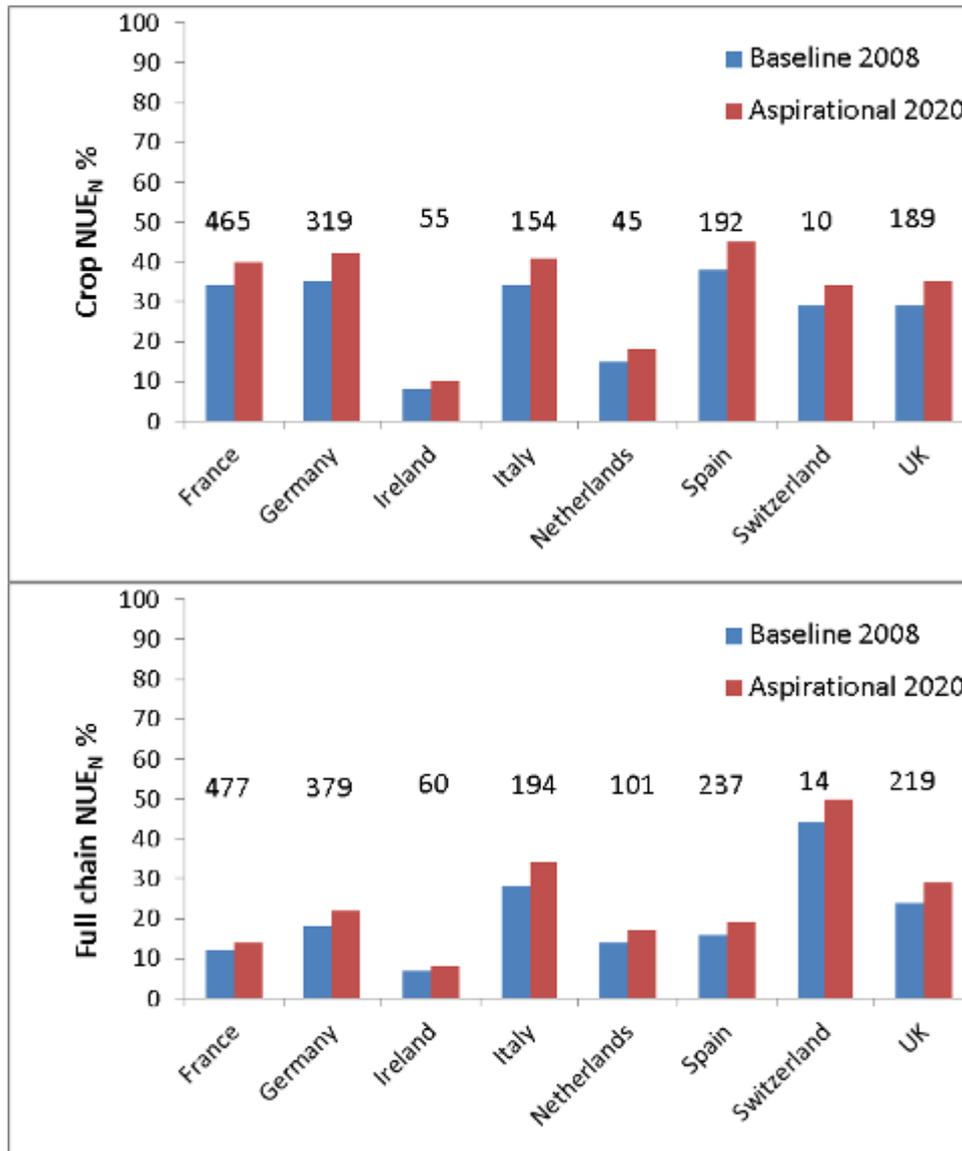
	Fertiliser Tg N/year	Leaching Tg N/year	Leaching Tg nitrate/year	N ₂ O emission Tg/year
Present livestock model (dairy & pigs)	4.12	2.28	10.1	0.365
<i>Potential reduction by limiting total N fertilisation and requiring manure N to be calculated at a utilisation efficiency relative to artificial N of:</i>				
a) 70% in dairy systems	-0.842	-0.842	-3.73	-0.025
b) 75% in pig systems	-0.293	-0.293	-1.3	-0.009
a) and b) combined	-1.14	-1.14	-5.03	-0.034
Note: This assumes high NUEs for manure (60% is more frequently assumed).				
Source: EC (2008)				

Nutrient surplus and use efficiency indicators

Gross nitrogen or phosphorus balance is calculated as the potential surplus of nitrogen or phosphorus on agricultural land (kg/ha/year). Nitrogen use efficiency is the amount of N imported to the farm system (fertilisers, feed and bedding materials: see Section 8.2) that is exported from the farm in products (e.g. cereal grain, straw, animal live weight, milk).

A recent report on NUE at the global scale (Sutton et al., 2013) highlights the importance monitoring NUEs, not only in agriculture but to work towards a “full-chain NUE” on a regional or national basis, and promotes the use of NUE as an indicator to quantify and report on the impacts of practices to improve nutrient consumption on a global scale. For mixed crop-animal farm systems, the N surplus and NUE are calculated as follows (TFRN, 2011):

$\text{SurplusN} = [\text{FertN} + \text{ManureN} + \text{CompostN} + \text{BNF} + \text{Atm.N} + \text{SeedN}] - [\text{CropN}]$
$\text{NUEcrop} = [\text{CropN}] / [\text{FertN} + \text{ManureN} + \text{CompostN} + \text{BNF} + \text{Atm.N} + \text{SeedN}]$
SurplusN = N Surplus at farm level, kg/ha NUEcrop = N use efficiency at farm level, mass/mass ratio (dimensionless) FertN = Amount of fertilizer N imported to the farm, kg/ha ManureN = Amount of manure N imported to the farm, kg/ha CompostN = Amount of compost N imported to the farm, kg/ha BNF= Amount of biologically fixed N ₂ by leguminous crops, kg/ha Atm.N = Amount of N from atmospheric deposition, kg/ha. SeedN = Amount of N imported via seed and plants, kg/ha. CropN = Net amount of N in harvested crop exported from the farm, including residues, kg/ha
Source: TFRN (2011)



Note: The written values show the equivalent total savings per country (ktonne N /year) achieved by the aspirational goals. Full chain NUE is defined as the ratio of nutrients in final products (e.g., human food consumed) to new nutrient inputs (e.g., Haber-Bosch Nr, biological N fixation, NOx formation, mined P and N).

Source: Adapted from: Sutton et al. (2013)

Figure 8.10. Estimated Crop NUEN and Full-chain NUEN per selected country for 2008 (baseline) as compared with an aspirational target for 2020, based on a 20% relative improvement from the 2008 values

Example online Tools for carrying out a nutrient budget:

PLANET <http://www.planet4farmers.co.uk/> provides field-level record keeping, industry standard recommendations allowing for organic manure nutrients, nutrient application plans, and help with carrying out calculations and producing reports to assess and show compliance with the revised NVZ rules (a worked example is given below in ‘Operation data’ section). It can also be used to produce balances and NUE allowing farm standards or benchmarks to be produced. Commercial farms are then scored at 25%, 20%, 15% or 10% above or below the benchmark value for a specific farm system. Benchmarks can be expressed either as kg nutrient/ha or per livestock unit.

MANNER <http://www.adas.co.uk/MANNER/tabid/270/default.aspx> a decision support system that can be used to accurately predict the fertiliser nitrogen value of organic manures on a field specific

basis. It also provides estimates of NH₃ and NO₃ losses, and calculates the amount of applied organic-N that remains available to plants, according to application method and timing and organic composition.

Table 8.8. Farm-gate nutrient balance methodology devised by DEFRA and the Environment Agency in the UK and used in PLANET software

Imports onto farm	Exports from farm
<ul style="list-style-type: none"> • Mineral fertilisers • Livestock feeds (concentrates, fodder and waste products) • Young livestock (including eggs for hatching) • Bedding (straw, wood shavings etc.) • Inorganic fertilisers • Organic manures (including industrial waste) • Biologically fixed nitrogen (clover, lucerne, peas, beans etc.) 	<ul style="list-style-type: none"> • Livestock (including replacements and fallen stock) • Livestock products (milk, eggs, meat and wool) • Crop products (including straw and fodder) • Organic manures (livestock manures, composted green waste etc.)
<p><i>Source:</i> DEFRA (2005)</p>	

Feed materials, e.g. concentrates, represent a significant amount of the N and P imported into a livestock farm; refer to tables on crude protein in Section 8.3.

Ruminants cannot use N and P very efficiently; for every 100kg of N fed to stock, only ca. 15 – 30 kg are retained and available to export as milk and meat. The remaining percentage of N enters ecosystem N cycles (Tried and Tested, 2013).

Best practice measures in soil, grazing management and manure management (see Chapters 5, 7, 8 and 9) are to tighten the N loop to maximise retention in the system and minimise losses to air and water, as follows:

Reduce dietary N and P intakes	Adjust the composition of livestock diets to reduce the total intake of N and P per unit of production.
Adopt phase feeding of livestock	Manage livestock in smaller groups, divided on the basis of their individual feed requirements. Feed groups separately with rations matched to the optimum N and P requirements of the animals within each group.
Reduce the length of the grazing day/grazing season	Reduce the length of time livestock graze in the fields, either by keeping stock inside during the night or by shortening the length of the grazing season.
Extend the grazing season for cattle	Where soil conditions allow, the grazing season is extended (either earlier in the spring or later in the autumn).
<p><i>Source:</i> Newell-Price et al., (2011)</p>	

According to LEAF Marque Global Standard (Version 10) best practice is to:

- Calculate whole farm nutrient budget
- Use recognised nutrient accounting tool
- Account for organic nutrient inputs
- Periodically analyse manures for nutrient content
- Measure N efficiency per tonne of product.

Dutch best practice in nutrient cycling is informed by the BEX tool. BEX is a farm specific assessment which equates to better than ‘good practice’. The success of BEX (Evaluation of farm-

specific Excretion) is reflected in the very high adoption by farmers who are adopting is voluntary best practice. It calculates the farm specific excretion of the herd as feed intake minus the production of milk, calves and additional bodyweight. Most (60 – 70%) Dutch dairy farmers are already using BEX. If N or P₂O₅ excretions are below the national standards, the authorities accept the farm-specific outcome, which reduces the necessity to export manure. In addition, the farmer is informed on the efficiency of feeding, which enables him to optimise feed purchasing. The default national standard requires a full farm ANCA (Annual Nutrient Cycle Assessment).

Achieved environmental benefit

Nutrient surplus and nutrient use efficiency are both indicators of nutrient input and output through a system and indicate relative risk of pollution. Nutrient balance raises farmer awareness about wastage and can be used to derive NUE. NUE in turn enables farm systems to be compared and promoted in terms of their overall efficiency of production.

Whole-farm nutrient budgets have been used very effectively in the USA by Koelsch (2005) to show that voluntary BMP on concentrated animal feeding operations (e.g. feedlots) was more effective (30–60% reduction in P accumulation) than mandatory nutrient management plans and buffer strips (5–7% reduction in P accumulation) in reducing nutrient surpluses (Goulding et al., 2008).

Farms in Denmark and the Netherlands have been able to achieve decreases in N surplus and increases in NUEN by ca. 30% in a 5-y period and 50% over 10 years.

In the Dutch ‘Cows and Opportunities’ project pilot farms, a N surplus reduction of 33 % and a P surplus reduction of 53% was achieved over four years. Purchased N (kg) in fertiliser per Mg milk produced in the pilot farms was 58% of the national dairy farm average whilst N (kg) in feed per Mg milk was the same for both farm regimes (Oenema et al., 2012). The relative mitigation effect of nutrient budgeting on livestock farms is illustrated in Table 8.9 (Newell-Price et al., 2011)

Table 8.9. Relative Mitigation effect of nutrient budgeting on livestock farms

Nitrogen			Phosphorus		Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Nitrate	Nitrite	Ammonium	Part	Sol							
↓	↓	↓	↓	↓	~	~	~	↓	↓	↓	~

Source: Newell-Price et al. (2011)

Appropriate environmental performance indicators

Management indicators

- Calculate whole farm nutrient budget
- Use recognised nutrient accounting tool
- Account for organic nutrient inputs
- Periodically analyse manures for nutrient content

Performance indicators

- Feed conversion efficiency
- Feed crude protein content (kg/kg DM)
- N and P surplus (kg/kg or L product, kg/ha); this indicator is calculated as an average over several years e.g. 3-5 years
- NUE
- Crop NUEN: on a crop level, $NUEN = [N \text{ removal with harvest} / \text{mineral N input} * 100]$ describes the efficiency of N fertilizer utilization in crop production.

On a country/regional level (Bentrup and Palliere, 2010):

- N removal = [yield of arable and permanent crops (FAOStat) x avg. N content]
- Mineral N input = N fertilizer consumption (EFMA/IFA statistics).

Developed in Netherlands is the ANCA (Annual Nutrient Cycle Assessment) which has been adopted by the majority of dairy farmers and which has come up with a suite of 10 indicators measured to assess nutrient use and overall farm efficiency:

- Manure production: nitrogen (N) and phosphate (P₂O₅) excretion of cattle (kg/ha);
- Efficiency of feeding: conversion of N and P₂O₅ from feed into milk and meat (%);
- Ammonia (NH₃) emission, divided over housing, manure storage, grazing, manure spreading and mineral fertiliser application (kg/ha);
- Yield grassland and maize land: dry matter, N, and P₂O₅ (kg/ha) and energy (kVEM/ha),
- Efficiency of fertilisation: conversion of N and P₂O₅ from chemical fertilisers and organic manures into crop yield (%);
- Soil surplus N, P₂O₅ and C (including the longer term development of soil stores; kg/ha);
- Nitrate (NO₃) in groundwater (mg/l);
- Emission of the greenhouse gases methane (CH₄), nitrous oxide (N₂O) and carbon dioxide (CO₂) (kg/ha);
- Farm surplus N, P₂O₅ and C (kg/ha);
- Efficiency of farming: conversion N and P₂O₅ from bought product (mainly feeds and fertilisers) into sold milk and animals (%).

Some attained benchmarks for these indicators are given in Table 8.15.

Nutrient surplus and use efficiency

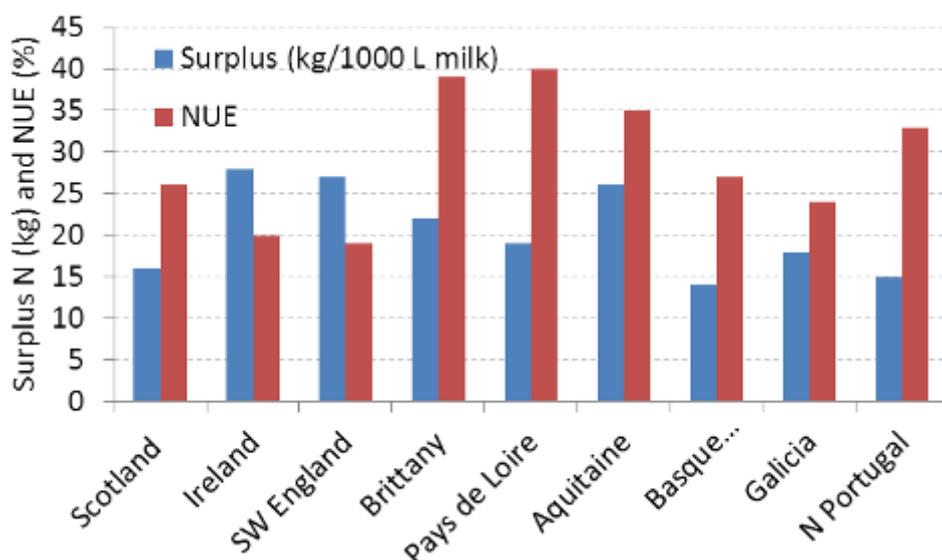
Whilst NUE is most commonly used to denote nitrogen use efficiency, it can also be used to denote nutrient use efficiency e.g. for phosphorus. N input-output balances have been used in research for >100 years and on some farms in some countries for >10 years and as a regulatory tool. Although not widely used by farmers NUE is recognised as an effective way to communicate to farmers their performance compared to other farms and to best practice benchmarks. Best practice is commonly set by experimental farms or the top 5% percentile of commercial farms.

Where data are very sparse, this is because measurement not common. Therefore, best practice can be simply to measure according to a defined best practice procedure (Section 5.1). Table 8.10, Figure 8.11 and Figure 8.12 present some N surplus and NUE_{N,P} values for European farm types. .

Table 8.10. A compilation of N surplus and NUE data from literature on European farms.

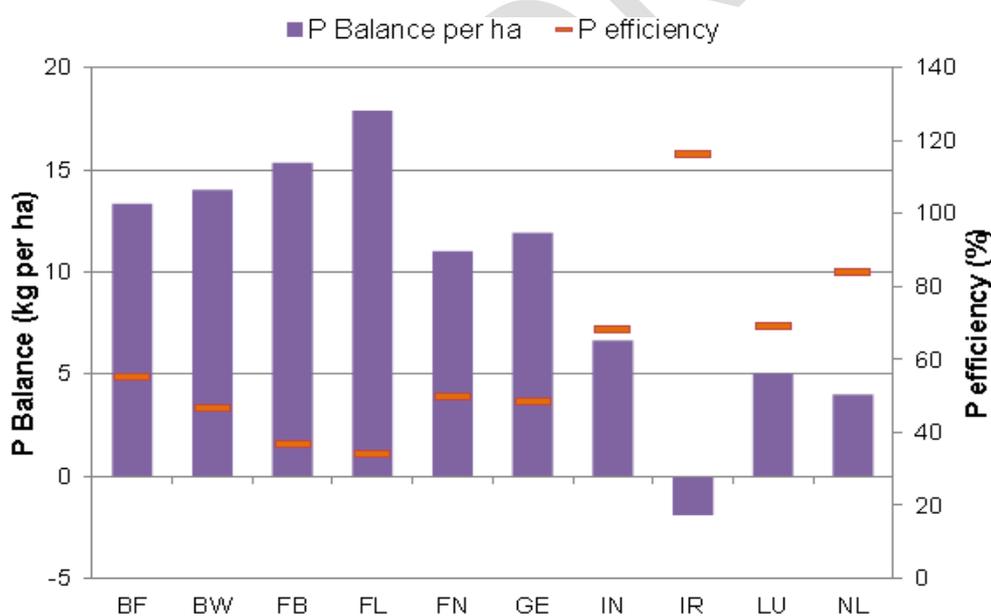
Farm type (country)	N surplus kg/ha	NUE _N %	Source
Dairy commercial UK	255		ADAS (2005)
Dairy commercial NL 2010	195	34 (farm basis)	Oenema et al. (2012)
Dairy 'Pioneers' NL 2010	141		Oenema et al. (2012)
UK upland organic farm	18		Goulding et al. (2008)
UK lowland dairy	120		Goulding et al. (2008)
UK Stockless arable	96		Goulding et al. (2008)
Italy maize (grain)	103-175		Bassanino et al. (2011)
Italy maize (silage)	27-98		Bassanino et al. (2011)
Italy leys/meadows	-40-4		Bassanino et al. (2011)
Italy winter wheat	10-148		Bassanino et al. (2011)
Europe wide dairy farm		25-30	Goulding et al. (2008)

Figure 8.11 and Figure 8.12 display N and P budget indicators, respectively, for dairy farms in European regions participating in the Dairyman project.



Source: Data from Mantovi (2010)

Figure 8.11. Average farm gate N balances for regional dairy farms in the Green Dairy Project



Source: Teagasc (2012)

Figure 8.12. Average farm gate P balances for regional dairy farms in the Green Dairy Project.

Table 8.11. Total N input (sum fertiliser, feed, deposition, fixation) in kg N/ha/1000 kg milk.

	Italy	UK	Denmark	France	Ireland	Flanders	Holland	Germany	De Marke
Total	31	46	33	42	32	31	36	40	16

Note: De Marke is an experimental dairy farm in the Netherlands.

Source: Bos et al. (2005); cited in REDNEX (2012)

Possible benchmark data for N and P balances are referred to for different livestock farm types in Table 8.12, Table 8.13 and Table 8.14, whilst Table 8.15 gives possible benchmarks for N use efficiency and P use efficiency per 1000 L milk on dairy and mixed arable/dairy farms.

Table 8.12. Nitrogen balances (kg/ha) on commercial livestock farms assessed in a UK benchmarking study

	Mixed arable & beef/ sheep	Mixed arable & dairy	Arable & mixed livestock	Mixed arable pigs/ poultry	Dairy only	Mixed livestock	Organic
Number of farms	15	28	6	6	88	11	9
Mean	76	152	136	278	248	186	140
Median	81	148	141	260	244	165	148
Min	34	62	45	102	64	21	53
Max	133	272	215	483	545	392	229
Std. dev.	32	54	59	141	89	117	56
Top ¹ 10%	i.d.	95	i.d.	i.d.	123	i.d.	i.d.
Top ¹ 25%	44	105	i.d.	i.d.	191	63	107
i.d. = insufficient data to compile a robust benchmark							
¹ Top = percentage of farms with a nitrogen balance below the specified kg/ha value.							
Source: DEFRA (2005)							

Table 8.13. Phosphate (P₂O₅) balances (kg/ha) on commercial livestock farms assessed in a UK benchmarking study

	Mixed arable & beef/ sheep	Mixed arable & dairy	Arable & mixed livestock	Mixed arable pigs/ poultry	Dairy only	Mixed livestock	Organic
Number of farms	15	28	6	6	88	11	9
Mean	8	32	16	65	46	36	8
Median	0.4	30	23	57	41	21	6
Min	-31	9	-10	8	-26	9	-13
Max	71	117	37	136	133	128	26
Std dev	29	23	21	50	26	36	14
Top ¹ 10%	i.d.	11	i.d.	i.d.	17	i.d.	i.d.
Top ¹ 25%	-10	17	i.d.	i.d.	33	11	0
i.d. = insufficient data to compile a robust benchmark							
¹ Top = percentage of farms with a nitrogen balance below the specified kg/ha value.							
Source: DEFRA (2005)							

Usually, the top 10% achievers would be taken as best practice but where insufficient data is available to create a robust benchmark, the top 25% is acceptable.

In the Dutch ‘Cows and Opportunities’ project (2013), mean values for efficiencies from 17 farms (16 commercial) are shown in and these could provide suitable benchmarks.

Table 8.14. Nitrogen and phosphorus use efficiency per 1000 litres of milk on dairy and mixed arable/dairy farms

	Nitrogen use efficiency		Phosphorus use efficiency	
	Dairy	Mixed arable & dairy	Dairy	Mixed arable & dairy
Number of farms	88	28	88	28
Mean	26	24	4.6	4.8
Median	25	23	4.4	4.3
Min	9	9	-3.0	1.3
Max	67	47	15.8	17.3
std dev	10	9	2.49	3.1
Top¹ 10%	14	12	2.11	2.35
Standard dairy farm	26		7.5	

¹ Top = percentage of farms with a nitrogen balance below the specified kg/ha value.
Source: DEFRA (2005)

Table 8.15. Efficiencies reported by efficient Dutch dairy farms in Cows & Opportunities project

Reported Efficiency	Mean	Min-Max
Nitrogen efficiency on feed for the whole dairy cattle (%)	26	23-29
Phosphate efficiency on feed for the whole dairy cattle (%)	33	26-37
Feed efficiency (kg milk/kg dm feed intake cattle)	1.05	0.92-1.17
Feed efficiency (kg fat and protein corrected milk/kg dm feed intake cattle)	1.11	0.98-1.29
Nitrogen efficiency soil [from fertiliser (manure and artificial) to crops] %	66	57-81
Phosphate efficiency soil [from fertiliser (manure and artificial) to crops] %	100	81-143

Source: (de Haan, 2013)

Table 8.16. Indicative ranges for target N surplus and N use efficiency as a function of farming system and animal category

Farming system	Category	NUEN %	N surplus Kg/ha/y	Comments
Grassland based ruminant systems	Dairy cattle	30-50	100-150	High milk yield, high NUEN; low stocking density, low N surplus.
	Beef cattle	20-40	50-150	Veal production, high NUEN; 2-y old beef cattle, low NUEN.
	Sheep & goats	20-30	50-150	
Mixed crop-animal systems	Dairy cattle	40-60	50-150	High milk yield, high NUEN; concentrate fed, high NUEN.
	Beef cattle	30-50	50-150	
	Pigs	30-60	50-150	
	poultry	30-60	50-150	
	Other animals	30-60	50-150	

Source: TFRN (2011)

Cross media effects

Overall, increased NUE is associated with improved environmental performance per unit of product exported, in terms of resource efficiency, GHG emissions, acidification and eutrophication burdens per kg produce.

Reduced NH₃ emissions can potentially exacerbate nitrate leaching levels, as in the case of comparing grazing returns with housed animal emissions. Nonetheless, as NH₃ emissions contribute to eutrophication directly and indirectly via re-deposition downwind, and as NH₃ also contributes to acidification, the overall environmental effect of reduced NH₃ emissions is positive.

Operational data

Key aspects to improve nutrient use efficiencies include manure management (Chapter 9), and precision application of fertilisers and manures (Section 5.3).

Review NUE every five years, to allow for inter-annual variations due to adverse weather etc.

According to Tried & Tested (2013), N and P use efficiency can be improved by:

- Buying the correct feeds for the farm system. This means planning to use less and not feeding more N and P than the animals need;
- Having a farm nutrient management plan that targets N and P inputs to each field, according to soil fertility and grass/crop requirements;
- Applying manure and fertilisers at the right time to maximise uptake by the crops and minimise losses to the environment;
- Making sure that K and S inputs are sufficient so that the grass, crop and animal production processes use as much of the N and P supplied as possible;
- Abiding by relevant Action Programme regulations and best practice measures to minimise the risk of losses to air and water;
- Having a soil protection plan in place which is reviewed annually.

Table 8.17 presents a real case study, the PLANET software for farmers, which calculates the manure produced and the land area on which it can be spread (a screen shot from a real example is showed in this table).

Table 8.17. Case Study: PLANET software for farmers calculates manure produced and the land area on which it can be spread; screen shot from a real example

PLANET
NUTRIENT MANAGEMENT
Livestock manure N farm loading for 2013

Farm area and livestock manure total N capacity

	Area (ha)	Livestock manure total N capacity (kg N/yr)
Area of holding in an NVZ	240.79	40,934
Area of holding not in an NVZ	0.00	0
Total	240.79	40,934

Livestock manure total N loading

	Total N loading from grazing livestock (kg N/yr)	Total N loading from pigs and poultry (kg N/yr)
Home-produced livestock manures	37,731	0
Imported livestock manures	0	0
Exported livestock manures	0	0
Net total	37,731	0

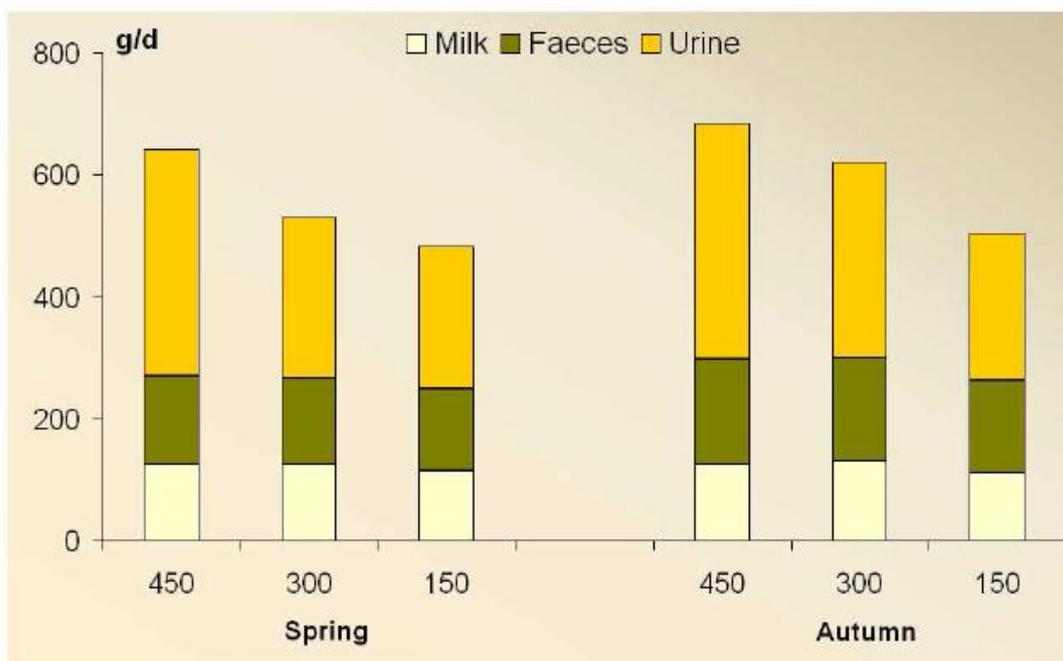
Compliance with NVZ Livestock Manure N Farm Limit

	Livestock manure total N (kg N/yr)
Livestock manure total N loading	37,731
Livestock manure total N capacity	40,934
Difference between the livestock manure total N capacity, and the livestock manure total N Loading (a negative value indicates non compliance)	3,203
Compliance with the NVZ Livestock Manure N Farm Limit	Yes

Average livestock manure total N loading	157 kg/ha
--	-----------

Grazing livestock numbers and manure total N production (home-produced manures)

Livestock type	Number per month												Average number for year	Total N produced kg/yr	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
1 lamb, 9 months and over	9	9	9	9	9	9	9	9	9	9	9	9	9	9	13
1 lamb, 6-9 months	35	35	35	35	35	35	35	35	35	35	35	35	35	35	70
1 sheep (60 kg or over) with lamb(s) up to 6 months	46	46	46	46	46	46	46	46	46	46	46	46	46	46	547
1 calf, up to 3 months	15	15	15	15	15	15	15	15	15	15	15	15	15	15	126
1 dairy heifer replacement, 3-13 months	60	60	60	60	60	60	60	60	60	60	60	60	60	60	2,100
1 dairy heifer replacement, 13 months to first calf	75	75	75	75	75	75	75	75	75	75	75	75	75	75	4,575
1 dairy cow (6000-9000 litres milk yield)	300	300	300	300	300	300	300	300	300	300	300	300	300	300	30,300
Total livestock manure N production (kg N/yr)														37,731	



Source: Valk (2002); cited in REDNEX (2012)

Figure 8.13. Effect of fertiliser N level on N in outputs.

New Zealand has taken the approach of setting targets for adoption of voluntary best practice in the dairy industry relating to water quality via key industry stakeholders including dairy companies, farmer-owned cooperatives, NGOs and fertiliser companies. Data on milk yield and fertiliser purchase will be kept by the dairy and fertiliser companies respectively and where farmers fail to take up Accord initiatives, (the Dairying Clean Streams Accord 2003-2012; Water Accord 2013-2030), these companies have undertaken to provide additional support and if necessary, exert pressure on those who consistently over-fertilise.

Applicability

All livestock farms can implement, and benefit from, farm level nutrient budgeting (Table 8.18).

Table 8.18. Where it is most relevant to undertake nutrient budgeting in livestock farms

Dairy	Grazing LFA	Grazing Low	Mixed	Combinable Crops	Combinable Roots	In Pigs	Out Pigs	Poultry
Yes	No	No	Yes	No	No	Yes	No	No

Source: Newell-Price et al. (2011)

Economics

- Cost of animal feeding strategies to reduce NH₃ emissions via CP adjustment are -2 to +2 euro per kg NH₃-N saved (Table 8.19).
- The cost of undertaking a farm nutrient balance are €200-500 per farm p.a.
- Net cost of improving N management is ca. €-1 to +1 per kg N saved. (all from TFRN, 2012).
- Default fertiliser costs used in MANNER-NPK to calculate fertiliser replacement value of manures are (converted into EUR at 0.85 EUR/GBP):
 - EUR 1.06 per kg N
 - EUR 0.94 per kg P₂O₅
 - EUR 0.71 per kg K₂O

Table 8.19. Annual Costs €/farm¹ for implementing nutrient budgeting on livestock farms, based on the purchase of capital equipment and are amortised

Dairy	Grazing LFA	Grazing Low	Mixed	Combinable Crops	Combinable Roots	In Pigs	Out Pigs	Poultry
2110			410			1470		

¹Converted from Great British Pounds (x / 0.85 ± 10)

Source: Newell-Price et al. (2011)

Driving forces for implementation

- Water Framework Directive
- Ammonia Emissions ceiling

Reference organisations

- Cows and Opportunites project, NL
- Dairyman project, NL
- De Marke experimental farm, NL
- EU Federated Farmers (Mantovi)
- Green Dairy project, pan-European
- Low C farming – Soil Association
- Mengveld-Wijnbergen Farm, NL
- REDNEX project, NL
- Teagasc
- Tried&Tested

Reference literature

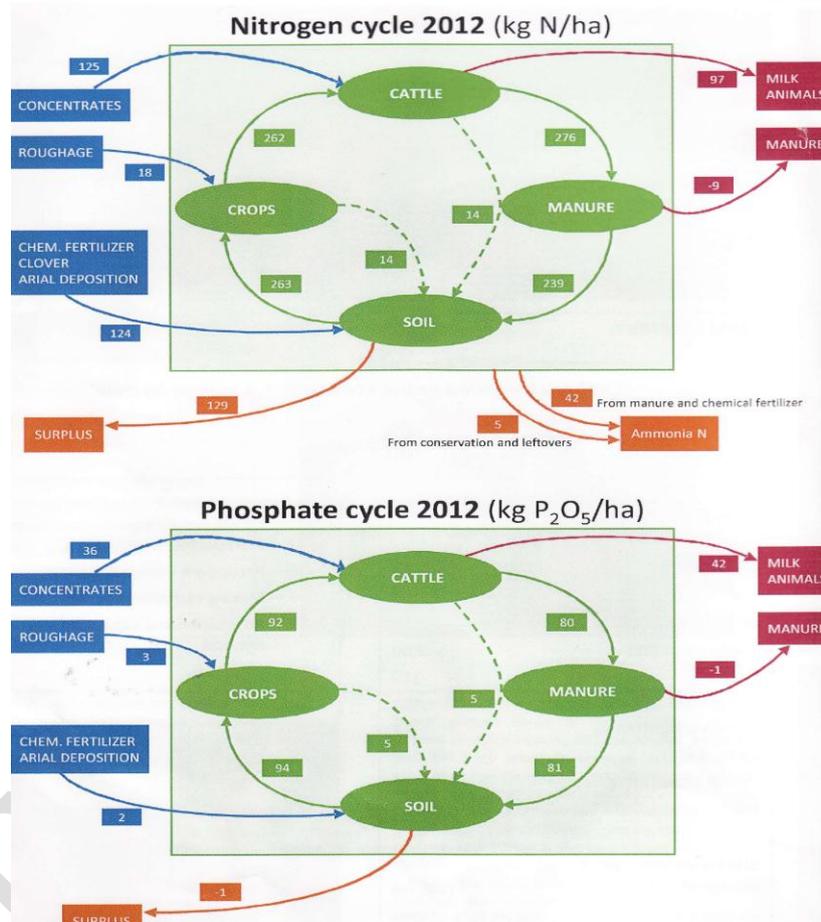
- ADAS, 2013. *Planet nutrient management planning webpage*, accessed August 2013: <http://www.planet4farmers.co.uk/Content.aspx?name=Home>
- Bassanino, M., D. Sacco, L. Zavattaro and C. Grignani 2011. “Nutrient Balance as a Sustainability Indicator of Different Agro-environments in Italy”, *Ecological Indicators*, Vol. 11, No. 2, pp. 715-723.
- Bentrup, F. and Palliere, C., 2010. Nitrogen use efficiency as an agro-environmental indicator. OECD workshop “Agri-environmental indicators: lessons learned and future directions”, 23-26 March 2010, Leysin, Switzerland. Fertilizers Europe (EFMA).
- Cows & Opportunities project 2013. Available online: <http://www.wageningenur.nl/en/project/Cows-and-opportunities.htm>. Accessed January 2014.
- de Haan M., researcher, Wageningen University. Personal communication on October 2013.
- DEFRA 2005. *Farm Nutrient Auditing: Support to PLANET (Benchmarking)*. DEFRA funded project ES0124 prepared by ADAS, IGER, Rothamsted and FWAG. DEFRA, London.
- Frank B, Persson M, Gustafsson G., 2002. Feeding dairy cows for decreased ammonia emission. *Livestock Production Science*, **76**,171-179.
- Goulding, K., Jarvis, S. and Whitmore, A., 2008. Optimizing nutrient management for farm systems. *Phil. Trans. R. Soc. B*. **363**, 667-680.
- IEEP, 2009. IMPEL Project: Comparison Programme on Permitting and Inspection of IPPC Pig Farming Installations in IMPEL Member Countries. Final Report October 2009.

- EC, 2008. Environmental Improvement Potentials of Meat and Dairy Products Eds. P. Eder and L. Delgado, JRC/IPTS. Publ. Luxembourg.
- Koelsch, R., 2005. Evaluating livestock system environmental performance with whole-farm nutrient balance. *J. Environmental Quality*, **34**, 149-155.
- LEAF, 2012, accessed Jan 2014: http://www.leafuk.org/resources/000/678/140/LEAF_Marque_Global_Standard_ver_10.pdf
- Low Carbon Farming, 2013. "Factsheet: Nutrient Budgeting", online document, DEFRA/Ashden Trust; accessed July 2013: <http://fcasoilassociation.org/Documents/Nutrient/NMM%20Factsheet%20-%2020Nutrient%20Budgeting.pdf>
- Mantovi, 2010. Nitrate Directive: how to manage nitrogen in intensive dairy farming. European Dairy Farmers Congress 2010 – Dairy Farming under Mediterranean Conditions Saluzzo (CN), 23 - 25 June 2010.
- Newell-Price, J.P. et al., 2011. *An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture. Mitigation methods: User Manual.*
- Oenema, J, van Ittersum, M., van Keulen, H. 2012. Improving nitrogen management on grassland on commercial pilot dairy farms in the Netherlands. *Agriculture, Ecosystems and Environment* **162**, 116-126.
- Poulsen H D, Lund P, Fernández J A, Holm P B., 2003. Notat vedrørende muligheder for at reducere husdyrgødningens indhold af kvælstof via fodringen. Foulum: Danmarks Jordbrugsforskning. http://www.vmp3.dk/Files/Filer/Rap_fra_t_grupper/18-10-2003-fodring-kvaelstof.pdf
- REDNEX, 2012. "EDF Workshop: Management of N excretion on a dairy farm scale. Presentation slides, accessed Feb 2014: <http://www.rednex-fp7.eu/Docs/EDF%20Workshop/EDF%20Workshop%20Rednex.pdf>
- Sutton M.A., Bleeker A., Howard C.M., Bekunda M., Grizzetti B., de Vries W., van Grinsven H.J.M., Abrol Y.P., Adhya T.K., Billen G., Davidson E.A, Datta A., Diaz R., Erisman J.W., Liu X.J., Oenema O., Palm C., Raghuram N., Reis S., Scholz R.W., Sims T., Westhoek H. & Zhang F.S., with contributions from Ayyappan S., Bouwman A.F., Bustamante M., Fowler D., Galloway J.N., Gavito M.E., Garnier J., Greenwood S., Hellums D.T., Holland M., Hoysall C., Jaramillo V.J., Klimont Z., Ometto J.P., Pathak H., Plocq Fichelet V., Powlson D., Ramakrishna K., Roy A., Sanders K., Sharma C., Singh B., Singh U., Yan X.Y. & Zhang Y., 2013. *Our Nutrient World: The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management.* Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.
- Swensson C., 2003. Relationship between content of crude protein in rations for dairy cows, N in urine and ammonia release. *Livestock Production Science* **84**, 125-133.
- Teagasc, 2012. Agri-Environment Conference 2012 Proceedings. Downloaded April 2013: http://www.teagasc.ie/publications/2012/1637/Agri_Environment_Conference_Proceedings_2012.pdf
- TFRN, 2011. *Draft Guidance Document for preventing and abating ammonia emissions from agricultural sources.* Informal document no. 20. TFRN. Downloaded May 2013: <http://www.clrtap-tfrn.org/documents>
- Tried & Tested, 2013. Feed planning for Cattle and Sheep.

8.2.1 Case Study: Nutrient cycling in BPM ‘pilot’ commercial dairy farms, Netherlands.

Soil phosphate concentrations are historically high in the Netherlands and regulation has focused on reducing this in later years in an effort to improve groundwater quality. For example, it is now mandatory (since January 2014) for poultry and pig farms i.e. landless or farms with small land area (and some dairy farms) to export their manure in order to reduce phosphate inputs (Figure 8.14).

The Dairyman project has 16 commercial farms as pilots for managing nutrients efficiently and reducing surpluses, based on studies at the local de Marke research farm. The N and P cycles of one of the pilot farms is illustrated below where surpluses of 129 kg N/ha and -1 kg P₂O₅/ha were achieved during 2012.



Source: Dairyman project (2012)

Figure 8.14. N and P cycles of a Dutch commercial dairy farm piloting BMP in nutrient management

The two main imports of P are through feed and mineral fertiliser. In 2010, agreement between farmers and the Dutch feed sector was reached to reduce P in feed by 10% which led to a reduction from 179 Mkg P₂O₅ to 161 Mkg P₂O₅ in 2012. This was driven by informed farmers seeing the need to reduce P in feed as the only course of action once they stopped applying P fertiliser. Feed P content in decreasing order of concentration:

- **Wheat by-products > maize by-products > palm oil > soya bean meal.**

Careful rotation of grass ley with maize ensures soil N and P reserves are managed tightly. The same pilot farm offers a ration comprising 70% roughage and 30% concentrates, by phosphate content.

8.3 Dietary reduction of N excretion (ruminants and monogastric)

Description

Within this BEMP, the following measures are discussed:

- N excretion control
- Grass-maize rotations (NL)
- P and N nutrition of animals (NL)

Ruminant diets are high in roughage whereas monogastric diets are high in concentrates.

Dietary N and N excretion control

A close relationship exists between the excretion of N and P by dairy cattle and the amounts consumed with feed. Hence, there are good options to reduce N and P excretion by nutritional measures.

Efficiency of dietary N use by dairy cows is determined in large part by the ratio of energy to protein in the rumen. Intensively managed pasture is high in N and also has high rumen degradability, particularly when liberal amounts of fertiliser N are applied.

There is a linear relationship between the amount of N intake and N excreted in urine (Figure 8.15).

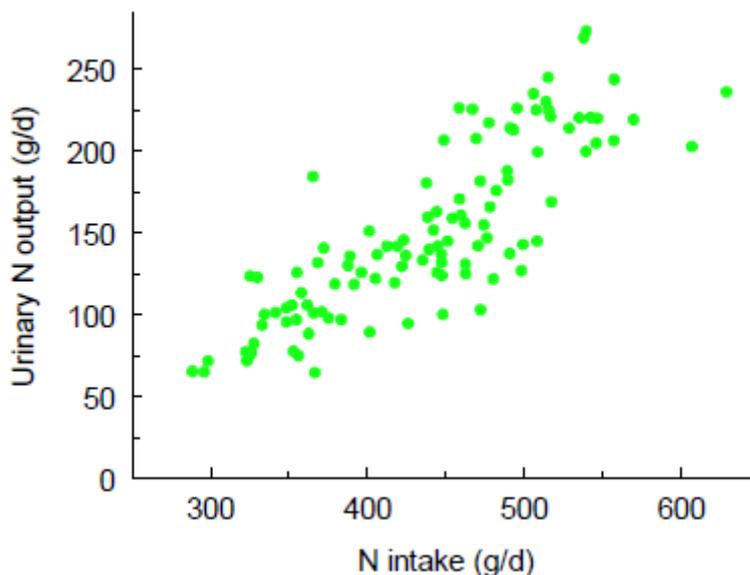


Figure 8.15. Effect of N intake on urinary N output (Kebreab, 2002, cited in REDNEX)

Optimizing rumen synchronisation:

- Balancing Rumen degradable protein with fermentable energy
- Indicator: milk urea level
15 - 20 mg urea / 100 ml = 7 - 9 mg MUN / 100 ml (REDNEX, 2012)

Milk urea nitrogen (MUN) monitoring, available on a weekly basis from most milk companies can provide a useful indication of the efficiency of rumen protein utilisation (DairyCo, Feeding+, 2012a):

- < 0.030ppm Insufficient rumen protein or very efficient use of protein.
- 0.030 – 0.040ppm Sufficient rumen protein in good balance with energy.
- > 0.04ppm Excess rumen protein due to excess supply or poor utilisation.

Milk urea N levels of 4.2 to 5mmol/L are optimal for rumen fermentation and production (Greener Pastures, 2006).

The IMPRO study (EC, 2008) reports that a reduced N content in feed leads to less N in manure and therefore lower ammonia losses from manure handling. The provision of supplementary amino acids maintains a proper balance among the amino acids necessary for optimal protein utilisation and growth in the case of pig production, so that the overall production is not affected.

EC (2008) note that in the western and eastern-southern type of dairy production, cow diets already have moderate N contents so that it is not realistic to reduce the N supply further without impairing the milk yield. For beef systems it is unrealistic to reduce the dietary N given that beef fattening units tend to have optimised N supply, whilst for grazing animals (suckler herds and steers) small amounts of complementary protein rich feed is provided.

Table 8.20. N and P imported into farms in feeds (Tried and Tested, 2013)

Feed	Crude protein (% DM)	N in 100 tonnes fresh weight (t)	P (g/kg DM)	P in 100 tonnes fresh weight (t)
Wheat	10	1.4	3.5	0.3
Barley	12	1.7	4	0.34
Concentrates	12-20	1.6-1.7	3.5-5.5	0.3-0.47
Sugar beet pulp	10	1.4	2	0.18
Maize distillers	31	4.4	1	0.09
Maize gluten	22	3.1	8.6	0.76
Wheat distillers	28	4	2.1	0.19
Rapeseed meal	40	5.8	10.6	0.95
Hipro soya	56	8	7	0.62
Brazilian soya	50	7.1	7	0.62
Trafford Gold	20	1.4	9	0.4
Brewers' grain	25	1.1	5	0.14

High Sugar Grasses

IGER, Aberystwyth University, Wales has pioneered the use of high-sugar ryegrasses for improved production efficiency of ruminant livestock and reduced environmental N-pollution. High sugar grasses (HSG) are high in water soluble carbohydrate that in the rumen increase the C:N ratio of substrate for rumen microflora, leading to improved immobilisation and utilisation of N, thereby increasing enhanced nitrogen use efficiency (NUE), microbial protein synthesis and reducing N-excretion.

HSGs produce measurable performance benefits for dairy, beef and lamb producers, such as:

- Improved milk yield in dairy cows (up to 6% more milk over the grazing season)
- Improved live-weight gains in lambs and beef cattle (up to 20% higher)
- More efficient use of feed nitrogen and a reduction (by up to 24%) in the nitrogen excreted to the environment (IGER, 2005).

Maize silage

In the same way that HSG provides carbohydrate to the rumen that leads to a reduction in N excretion, maize silage (compared to grass silage) plays a similar role. UK work has shown good levels of milk production with low urinary N output by combining legume silages with maize silage (70% less urinary N per kg milk protein; Dewhurst et al., 2005). The ratio of readily fermentable carbohydrates (energy) to rumen degradable protein in N-fertilised pastures can be 10 times lower than what is considered the optimum (Greener Pastures, 2006).

Maize silage is now an integral part of N management on Dutch and UK dairy farms, as it provides a high-energy low-N forage source to complement high-energy, high-N pasture thus balancing the ration and reducing urinary nitrogen losses. It is preferred over starchy concentrates because of its benefits for rumen health. Also, maize silage is often grown on the farm, thus reducing the need for

imported feeds. Typically, Dutch dairy farms land area given to grass is 85% and to maize, 15%. Rotation of grass and maize in itself promotes good nutrient use efficiency as maize is better than grass at utilising soil P and grass is better at utilising N so rotating the two ensures optimum NUE (Aarts, 2000).

P nutrition

The two main imports of P are through feed and mineral fertiliser. Particularly when farmers have stopped applying P fertiliser and still need to reduce P surplus because of high P concentrations in shallow groundwater (e.g. Netherlands), reducing P in feed is a high priority. In 2010, agreement between farmers and the Dutch feed sector was reached to reduce P in feed by 10% which led to a reduction from 179 Mkg P₂O₅ to 161 Mkg P₂O₅ in 2012. This was driven by informed farmers seeing the need to reduce P in feed as the only course of action once they stopped applying P fertiliser (van Stralen, 2013). Feed P content in decreasing order of concentration: wheat by-products > maize by-products > palm oil > soya bean meal.

Mitigation of NH₃ and N₂O via feed strategies includes:

- Phase feeding whereby levels of urea-nitrogen in milk can be used as a diagnostic indicator for protein feeding (Nousiainen et al., 2004). Total ammonia emissions from all farm sources may decrease by 5-15% (average 10%) from a reduction in mean protein content by 10 g per kg in the diet.
- Low-protein feeds is one of the most cost-effective and strategic ways to reduce NH₃ emissions. Low-protein animal feeding also decreases N₂O emissions and increases the efficiency of N use in animal production but is only really applicable to housed animals (Oenema et al., 2012).

Table 8.21. Indicative target protein level (%) of dry feed with a standard dry matter content of 88% for housed animals as a function of animal category and for different ambition levels TFRN (2011)

Animal type	Mean crude protein content of the animal feed, % ¹		
	Low ambition	Medium ambition	High ambition
Dairy cattle, early lactation (>30kg/day)	17-18	16-17	15-16
Dairy cattle, early lactation (<30kg/day)	16-17	15-16	14-15
Dairy cattle, late lactation	15-16	14-15	12-14
Replacement cattle (young cattle)	14-16	13-14	12-13
Veal	20-22	19-20	17-19
Beef <3 months	17-18	16-17	15-16
Beef >6 months	14-15	13-14	12-13
Sows, gestation	15-16	14-15	13-14
Sows, lactation	17-18	16-17	15-16
Weaner, <10 kg	21-22	20-21	19-20
Piglet, 10-25 kg	19-20	18-19	17-18
Fattening pig 25-50 kg	17-18	16-17	15-16
Fattening pig 50-110 kg	15-16	14-15	13-14
Fattening pigs >110	13-14	12-13	11-12
Chicken, broilers, starter	22-23	21-22	20-21
Chicken, broilers, growers	21-22	20-21	19-20
Chicken, broilers, finishers	20-21	19-20	18-19
Chicken, layers, 18-40 weeks	17-18	16-17	15-16
Chicken, layers, >40 weeks	16-17	15-16	14-15
Turkeys, <4 weeks	26-27	25-26	24-25
Turkeys, 5-8 weeks	24-25	23-24	22-23
Turkeys, 9-12 weeks	21-22	20-21	19-20
Turkeys, 13-16 weeks	18-19	17-18	16-17
Turkeys, >16 weeks	16-17	15-16	14-15

¹With adequately balanced and optimal digestible amino acid supply.

A decrease in the protein content in feed of 1% can decrease the total ammonia emissions from all manure types by 10%. The economic costs increase with the level of ambition employed in protein reduction.

Table 8.22. Indicative target levels for crude protein (CP) content as % of dry matter of ration, and resulting efficiency of cattle N utilisation (NUE), in mass fractions (kg/kg) for cattle (adopted from EC, 2003)

Cattle species	CP, %*)	NUE of cattle product kg/kg
Milk + maintenance, early lactation	15-16	0.30
Milk + maintenance, late lactation	12-14	0.25
Non-lactating (dry) dairy cows	13-15	0.10
Veal	17-19	0.45
Cattle <3 months	15-16	0.30
Cattle 3-18 months	13-15	0.15
Cattle >18 months	12	0.05

*) The values presented here can be considered as 'high ambition level'

Table 8.23. Indicative target crude protein levels in feed for pig rations (adopted from EC, 2003)

Species	Phases	Crude protein content, % *)
Weaner	< 10 kg	19-21
Piglet	< 25 kg	17-19
Fattening pig	25-50 kg	15-17
	50-110 kg	14-15
	>110 kg	12-13
Sows	Gestation	13-15
	Lactation	15-17

*) With adequately balanced and optimal amino acid supply. The values presented here can be considered as 'medium to high ambition level' (see Appendix 2 for a further specification of target crude protein levels).

Table 8.24. Indicative target crude protein levels in feed for poultry (adopted from EC, 2003)

Species	Phases	Crude protein content, % *)
Chicken, broilers	Starter	20-22
	Grower	19-21
	Finisher	18-20
Chicken, layers	18-40 weeks	15.5- 16.5
	40+ weeks	14.5- 15.5
Turkeys	< 4 weeks	24-27
	5-8 weeks	22-24
	9-12 weeks	19-21
	13+ weeks	16-19
	16+ weeks	14-17

*) With adequately balanced and optimal amino acid supply. The values presented here can be considered as 'medium to high ambition level' (see Appendix 2 for a further specification of target crude protein levels).

Results on feed efficiency in dairy cows in Netherlands in a project promoting best practice can be used as benchmarks (Table 8.25).

Table 8.25. Mean results of 16 commercial dairy farms in Netherlands piloting best practice

	Benchmark (mean)	Min-max
Nitrogen efficiency on feed for the whole dairy cattle (%)	26	23-29
Phosphate efficiency on feed for the whole dairy cattle (%)	33	26-37
feed efficiency (kg milk / kg dm feed intake cattle)	1.05	0.92-1.17
feed efficiency (kg fat and protein corrected milk/kg dm feed intake cattle)	1.11	0.98-1.29

Source: Cows & Opportunities project, Michel de Haan

Achieved environmental benefits

Feed conversion efficiency = kg feed DM eaten per kg of meat liveweight or litres of milk produced per kg of dry matter intake. Aiming for as high feed conversion efficiency as possible for a given system reduces GHG from feed production and increases NUE.

The EIPRO study (EC, 2008) cites Poulsen et al. (2003) who estimated that for typical Danish (Northern Europe) pig production, the N excretion per pig could be reduced from 5.3 kg N per pig produced to 3.9 kg N, by using two feed mixtures for sows (differing in N content) and reducing the N concentration in slaughter-pig feed by 5 % and instead adding synthetic amino acids. This alone would reduce ammonia emission by 22 %, i.e. from the current 1.26 kg ammonia to 0.98 kg. Frank et al. (2002) and Swensson (2003) observed that a 25 % lowered N supply to dairy cows did not impact milk yield, and reduced ammonia emission in the stable by more than 65%.

Acidification and terrestrial eutrophication from meat and dairy production may be reduced by 8-9 % through optimised protein feeding and by 14-16 % through liquid manure pH reduction. For all pig farming systems, implementation of optimised feeding is expected to reduce the overall N excretion in manure by 32 %. Assuming no change in emission factors from stable and storage, the resulting ammonia emission is reduced by 25 % (a conservative estimate of the reduction potential). In the dairy systems, an optimised feeding (going from 17 % crude protein in dry matter to 14 %) in the relevant systems (central, UK-type, and lowland systems) reduces the overall N excretion from the cattle by approximately 48 kg per cow and year. This is expected to reduce the ammonia emission by 35 % in the systems considered EC (2008).

Table 8.26. Effect of optimising protein feeding and liquid manure pH reduction on input and emissions from pig production (per 10 pigs produced) (EC 2008)

	Average pig farming model EU-27	Improved feeding in all systems	Liquid manure pH reduction in all systems	Combined effect of the two measures
<i>Input:</i>				
Cereals (kg)	2,499	2,845	2,499	2,845
Soy meal (kg)	549	100	549	100
Synthetic amino acids (kg)	17	40	17	40
<i>Output:</i>				
Replacement of artificial fertiliser (Kg N)	22.1	16.3	25.5	18.9
Ammonia (kg)	16.8	12.7	9.5	7.2
Nitrate (kg)	72.9	54.2	85	62.8
N ₂ O (kg)	0.99	0.74	1.03	0.76

Table 8.27. Changes in inputs and emissions in dairy production following improvement options (kg/10 Mg milk in EU-27 average) (EC, 2008)

	Average dairy model EU-27	Optimised feeding in the central, UK-type, and lowland systems (affecting 11.7 million cows in total)	Liquid manure pH reduction in all systems except east-south (affecting 17.3 million cows in total)	Combined effect of the two measures
<i>Input:</i>				
Cereals (kg)	547	1,316	547	1,316

	Average dairy model EU-27	Optimised feeding in the central, UK-type, and lowland systems (affecting 11.7 million cows in total)	Liquid manure pH reduction in all systems except east-south (affecting 17.3 million cows in total)	Combined effect of the two measures
Soy meal (kg)	1,076	430	1,076	430
Fertiliser N	269	281	262	276
<i>Emissions (kg)</i>				
Ammonia (kg)	74	62	60	51
N ₂ O (kg)	23.9	22.7	24.2	22.9
Nitrate (kg)	520	470	540	488

The changes in inputs and outputs of the modelled EU-27 production systems, when implementing optimised protein feeding and liquid manure pH reduction, are reported in Table 8.26 for pigs and in Table 8.27 for dairy cattle and show that optimised protein feeding reduces not only the ammonia emission, but also the leaching potential, due to a lower overall N excretion in manure. The overall impact for EU-27 is reported in table 8.28 for optimised feeding.

Table 8.28. Annual improvement potential by optimising protein feeding in pig and dairy farming. Negative values indicate an improvement. Only midpoint categories contributing > 0.01% change are shown (EC, 2008)

Impact category	Unit	Improvement potential		
		In units of each impact category	In % of total impacts for meat and dairy products	In % of total impacts in EU-27
<i>Midpoint categories</i>				
Acidification	m ³ UES	-7.42E+09	-7.82	-1.95
Ecotoxicity, aquatic	kg-eq. TEG water	3.34E+12	2.34	1.09
Ecotoxicity, terrestrial	kg TEG-eq. soil	6.29E+09	1.04	0.07
Eutrophication, aquatic	kg NO ₃ -eq	-4.07E+08	-4.59	-1.35
Eutrophication, terrestrial	m ² UES	-3.50E+10	-9.01	-3.52
Global warming	kg CO ₂ -eq	7.31E+09	1.09	0.15
Human toxicity, carcinogens	kg C ₂ H ₃ Cl-eq	3.98E+07	2.87	0.23
Mineral extraction	MJ extra	7.67E+07	1.46	0.08
Nature occupation	m ² arable land	-2.01E+10	-2.06	-0.74
Non-renewable energy	MJ primary	1.93E+11	2.20	0.14
Ozone layer depletion	kg CFC-11-eq	4.24E+03	2.22	0.14
Photochemical ozone, vegetation	m ² *ppm*hours	1.02E+11	1.53	0.19
Respiratory inorganics	kg PM2.5-eq	-2.61E+07	-3.07	-0.54
Respiratory organics	person*ppm*h	8.93E+06	1.24	0.16
<i>Endpoint (damage) categories</i>				
Impact on ecosystems	Species-weighted m ² *years	-1.69E+10	-1.29	-0.31
Impacts on human well-being	QALY	-1.80E+04	-2.91	-0.5
Impacts on resource productivity	EUR	-3.91E+08	-2.52	-0.42
All impacts aggregated	EUR	-4.10E+09	-1.67	-0.37

Table 8.29. Relative mitigation effect of the measure of reducing dietary N and P (Newell-Price et al., 2011)

Nitrogen			Phosphorus		Sedi- ment	BOD	FIOs	Ammo- nia	Nitrous Oxide	Me- thane	Carbon Dioxide
Ni- trate	Ni- trite	Ammo- nium	Part	Sol							
↓	↓	↓	↓	↓	~	~	~	↓	↓	↓	~

Appropriate environmental performance indicators

Management Indicators

- Analyse harvested forage nutrient content (ruminants,)
- Produce a feed plan to match crude protein in feed with animal production requirements (ruminants and monogastric)

Performance indicators

- Dairy urea N (Milk urea concentration is a useful indicator for ammonia emissions from a dairy cow barn in a situation with restricted grazing (van Duinkerken et al, 2011). Ammonia emission increases exponentially with increasing milk urea concentration. At levels of 20 and 30 mg of urea per 100 g of milk, ammonia emission increased by about 2.5 and 3.5%, respectively, when milk urea concentration increased by 1 mg/100g).
- Feed conversion efficiency
- N surplus (kg/kg meat or 1000 L milk, kg/ha)
- kg NH₃ per kg meat or per 1000 L milk
- NH₃ losses from housing and slurry storage (kg/y)

Cross-media effects

If a farm system (ruminant) reduces N input too much, this may result in feed passing too quickly through the rumen and failure to digest to NDF (roughage cell walls digestibility is lower when soil N is limiting) and a lower than preferable pH in the rumen, leading to a shortage in ME and CP.

Low N input systems can experience (REDNEX, 2012):

- Reduced energy intake during early lactation
- Reduced general disease resistance
- Metabolic disorders
- Fertility
 - Lower dietary energy and protein might reduce fertility, however
 - Fertility problems are mostly found at high N diets: reduced fertility at Milk Urea N concentrations >18 mg/100 ml
- Close up phase
 - Feeding protein above requirements might be beneficial for animal health
 - Lower fatty liver scores, reduced ketosis incidence, lower prevalence of retained placenta.

There is a trade-off to consider between the advantages in N and P cycling of rotating maize with pasture leys against the increased CO₂ emissions as a result of regular ploughing up of pasture.

Operational data

The critical nutrients for practical rationing on farm are energy (as metabolisable energy, ME) and protein (crude protein, CP), as these are the most costly nutrients to supply. CP is a simple measurement of N content of feed (assumed 16% N for budgeting purposes). Recommended CP and ME requirements for livestock are available in farm reference documents and websites e.g. Tried & Tested (www.nutrientmanagement.org).

Steps to calculating feeding plan: (Source: Tried and Tested, 2013)

1. Work out the ME and CP for all stock for the year;
2. Work out the current feed conversion efficiency i.e. how much feed it takes to produce a unit of meat or milk. Typically, 5.5 – 6.5 kg DM of feed produces 1 kg of meat and 0.8 – 1.8 kg of milk is produced from 1 kg (DM) of feed;
3. Analyse or estimate the ME, CP and digestibility of grass, silage, forages and imported feeds;
4. Monitor stock health and performance;

Calculate nutrient balance by: i) work out the ME and CP requirement for animals for a year taking into account weight, breed, life cycle expectation (calving, lambing singles/twins etc.) and then subtract from - ii) the annual supply of ME and CP from grazing, conserved forages, imported feed. A surplus could suggest that imported feed could be reduced or livestock units increased; a deficit could indicate overstocking, poor animal health (resulting in inefficient feed conversion) or better use of home-grown energy and protein could be made.

Lowering crude protein (CP) of ruminant diets is an effective and a best practice measure for decreasing NH₃ loss (TFRN, 2011):

- The average CP content of diets for dairy cattle should not exceed 15 – 16 % in the dry matter (DM) (Broderick, 2003; Svenson, 2003). For beef cattle older than 6 months this could be further reduced to 12 %.
- Phase feeding can be applied in such a way that the CP content of dairy diets is gradually decreased from 16% of DM just before parturition and in early lactation to below 14% in late lactation and the main part of the dry period.
- Phase feeding can also be applied in beef cattle in such a way that the CP content of the diets is gradually decreased from 16 to 12% over time.

Table 8.30. Typical N excretion rates for different types of livestock (UN ESC, 2001)

Animal type	Production level	N excretion		
		kg N place ⁻¹ year ⁻¹	per unit production	
			kg N per ...	
Dairy cows	less than 5,000 kg milk cow ⁻¹ year ⁻¹	6—110	15-25	1,000 kg milk
	5,000-6,000 kg milk cow ⁻¹ year ⁻¹ , low amount of concentrate	100-140	20-28	1,000 kg milk
	5,000-6,000 kg milk cow ⁻¹ year ⁻¹ , >500 kg concentrate year	80-100	16-20	1,000 kg milk
	9,000-10,000 kg milk cow ⁻¹ year ⁻¹	110-140	11-14	1,000 kg milk
Beef cattle	Extensive: mainly grazing	40-50	10-20	100 kg growth
	Intensive: corn silage, etc.	35-45	7-10	100 kg growth
Breeding sows	including piglets to 25 kg	30-40	1.4-2	per piglet
Fattening pigs	25-100 kg; no phase feeding	15-18	6-8	100 kg growth
	with phase feeding	12-15	5-7	100 kg growth
	phase feeding and pure amino acids	10-14	4-6	100 kg growth
Laying hens	1 bird	0.60-0.80	2.0-3.5	1000 eggs
Broilers	1 bird-place	0.35-0.50	2.0-4.0	100 kg growth

Applicability

Table 8.31 presents the applicability of dietary N and P reduction in dairy sector according to Newell-Price et al., (2011).

Table 8.31 Applicability of dietary N and P reduction (Newell-Price et al., 2011)

Dairy	Grazing LFA	Grazing Low	Mixed	In Pigs	Out Pigs	Poultry
Yes	Yes	Yes	Yes	Yes	Yes	Yes

Economics

Processed barley and rapeseed meal are commonly used as the standard energy and protein ingredients in such comparisons (Table 8.32).

Table 8.32. Relative feed values of different feeds (processed barley at €176/t; rapeseed meal at €171/t using €1 = 0.85p) (DairyCo, 2012)

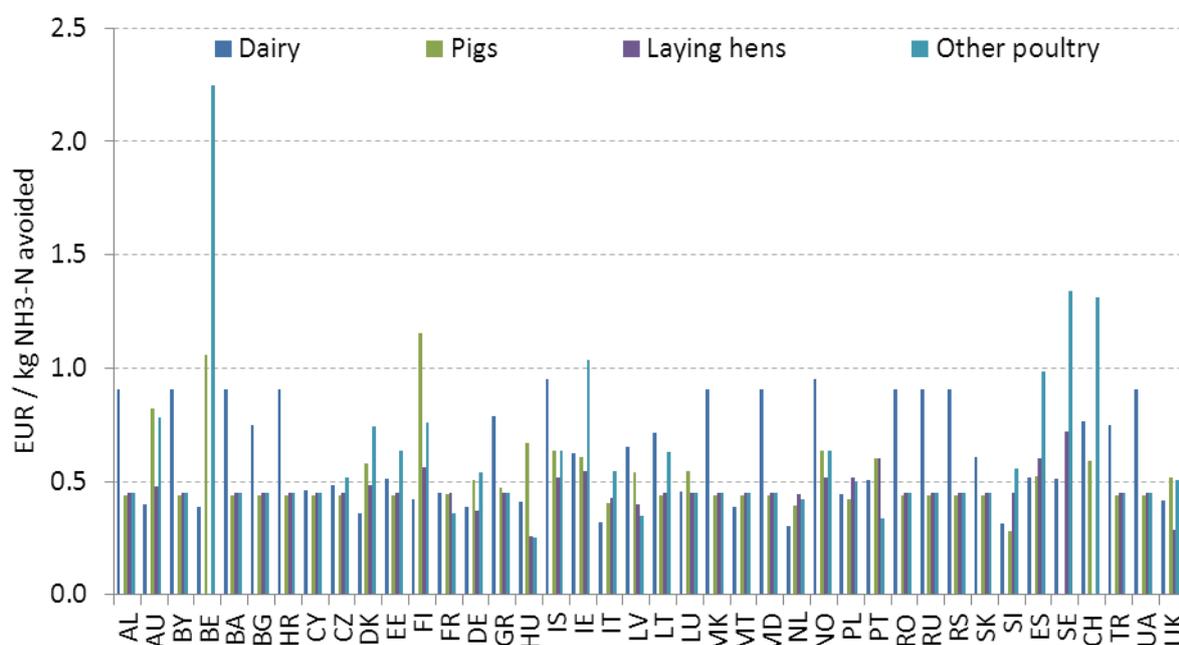
Feed	Dry Matter %	ME MJ/kg DM	Crude Protein g/kg DM	Value €/tonne fresh matter
Wheat	86	13.6	100	181
Maize (grain)	86	14	100	187
Barley	86	13.2	120	176
Crimped wheat	70	13.6	100	148
Crimped maize	70	14	100	152
Biscuit meal	90	15	130	209
Sugar beet pulp	89	12.5	100	173
Citrus pulp	88	12.6	70	172
Cane molasses	75	12.7	40	147
Maize distillers'	89	14	310	195
Maize gluten	88	12.9	220	178
Wheat feed	88	11.3	190	155
Rapeseed meal	90	12	400	171
Hipro soya	89	13.8	560	195
Brazilian soya	89	13.4	500	189
Lupins	87	14	350	192
Beans	85	13.3	290	178
Potatoes	21	13.3	90	44
Carrots	13	12.8	100	26
Fodder beet	18	12	60	33
Trafford gold	44	13.6	200	93
Pressed pulp	25	12	100	47
Brewers' grains	28	11.4	250	51
Vitagold	35	14	360	76
Bread	65	14	140	141
Grass silage	25	11.2	140	44
Fermented wholecrop	40	10.5	100	66
Alkalage	75	10.8	130	126
Maize silage	28	11	90	48

High sugar grass. Economic analysis of the six month lamb production data suggests that the upland high sugar grass AberDart sward provided a financial benefit of approximately £406/hectare (39%) over the return off the Fennema sward.

There had been a highly significant economic advantage in using HSG AberDart, rather than Fennema when re-seeding the upland areas (the Net Value Outputs for the three areas were AberDart, £1149/ha; Fennema, £869/ha; permanent pasture, £1036/ha).

Table 8.33. Annual cost €/farm to implement dietary N and P changes. Costs based on additional feed and management inputs to avoid excess N & P (Newell-Price et al. (2011), using €1 = 0.85p)

Dairy	Grazing LFA	Grazing Low	Mixed	In Pigs	Out Pigs	Poultry
5900	1294	1529	2941	4706	7353	706



NB: Assumes liquid slurry storage systems

Figure 8.16. Marginal abatement costs for low-N diets, across European countries and for different livestock types (Based on data from Winiwarter et al., 2011)

Table 8.34. Median abatement costs for low-N feeding strategies for different livestock types and manure management systems across European member states (Based on data from Winiwarter et al., 2011)

Livestock	Manure storage	Median abatement cost (EUR/kg NH ₃ -N)
Dairy	Liquid	0.56
Other cattle	Solid	0.66
Pigs	Liquid	0.44
	Solid	0.44
Laying hens	All	0.45
Other poultry	All	0.45

Ireland: Reduced fertiliser N usage rates per kg produce use (i.e. improved NUE) has been calculated by Schulte et al., 2012 to give an abatement potential 0.080 Mt CO₂eq for Ireland, with an associated cost saving of M€ 28.9.

Driving forces for implementation

- Water Framework Directive
- Ammonia emissions ceiling
- Avoided expenditure on excess feed protein

Reference literature

- Aarts, H.F.M. 2002. *Resource management in a 'de Marke' dairy farming system*. PhD thesis. Wageningen University, NL. 222pp.
- DairyCo, 2012b. Feeding+. 4. Assessing your feed options. <http://www.dairyco.org.uk/resources-library/technical-information/feeding/feedingplus-section-4-assessing-your-feed-options/#.Uwta1MwDBY>, accessed Oct 2013.
- DairyCo, 2012a. Feeding+ 7. Managing your feeding. <http://www.dairyco.org.uk/resources-library/technical-information/feeding/feedingplus-section-7-managing-your-feeding/#.UwTQb1MwDBY>, accessed Oct 2013
- Dewhurst, R. J., Merry, R. J., Davies, L. J. 2005. Effects of mixtures of red clover and maize silages on milk production and nitrogen utilisation by dairy cows. *Proceedings of the British Society of Animal Science Annual Meeting*: **23**.
- de Haan, Michel, researcher, Wageningen University, Netherlands.
- Greener Pastures, 2006. Profitable and sustainable use of N in dairy pasture systems; accessed Feb 2014:
http://archive.agric.wa.gov.au/objtwr/imported_assets/content/aap/dc/fsmaizesilagerm14aug2006.pdf.
- IGER, 2005. High-sugar ryegrasses for improved production efficiency of ruminant livestock and reduced environmental N-pollution. LINK project LK0638. Aberystwyth University, Wales.
- EC, 2008. *Environmental Improvement Potentials of Meat and Dairy Products*. P. Eder and L. Delgado (Eds.), JRC/IPTS. Publ. Luxembourg.
- EC, 2003. *IPPC Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs* (ILS, BREF) July 2003.
- Newell-Price et al., 2011. *An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture*. Mitigation methods: User Manual.
- Nousiainen J., Shingfield, K.J., Huhtanen, P., 2004. Evaluation of Milk Urea Nitrogen as a Diagnostic of Protein Feeding. *Dairy Science*, **87**, 386–398.
- Oenema, O., Velthof, G., Klimont, Z and Winiwarer, W. Emissions from agriculture and their control potentials. TSAP Report #3 Version 2.1. ENV.C.3/SER/2011/0009. EC DG Environment.
- REDNEX, 2012. “EDF Workshop: Management of N excretion on a dairy farm scale. Presentation slides, accessed Feb 2014: <http://www.rednex-fp7.eu/Docs/EDF%20Workshop/EDF%20Workshop%20Rednex.pdf>
- Schulte et al., 2012. *Marginal Abatement Cost Curve for Irish Agriculture, Appendix B: Detailed methodologies for the computation of the marginal abatement cost-abatement potential of individual measures*. Teagasc. Ireland.
- TFRN, 2011. *Draft Guidance Document for preventing and abating ammonia emissions from agricultural sources*. Informal document no. 20. TFRN. Downloaded May 2013: <http://www.clrtap-tfrn.org/documents>
- Tried and Tested, (no date). Feed planning for beef and sheep. <http://www.nutrientmanagement.org/assets/12028> accessed Nov 2013.
- UN ESC, 2001. UNECE Framework code for good agricultural practice for reducing ammonia. EB.AIR/WG.5/2001/7. Economic Commission Europe.
- van Duinkerken G, Smits MC, André G, Sebek LB, Dijkstra J. 2011. Milk urea concentration as an indicator of ammonia emission from dairy cow barn under restricted grazing. *J Dairy Sci*. **94**(1):321-35.

- Van Stralen, W. (policy adviser, LTO, Netherlands), *pers. comm.*, October 2013.
- Winiwarter, W., Hettelingh, J.P., Bouwman, L. Future scenarios of nitrogen in Europe. In: *The European Nitrogen Assessment*, ed. M.A. Sutton, C.M. Howard, J.W. Erisman et al., Cambridge University Press.

FINAL DRAFT

8.4 Dietary reduction of enteric fermentation methane (ruminants)

Description

Within this BEMP, the following measures are discussed:

- Grazing vs. silage grass
- High quality grass – timing for silage cut
- Concentrates
- Trade-offs with upstream feed impacts (cross-refer to section 8.5)

This BEMP is only relevant to sheep and cattle. Enteric fermentation is a major source of GHG emissions for ruminant livestock farms, accounting for almost half the CF of milk production. The digestive process of enteric fermentation, in which microorganisms break down carbohydrates, releases CH₄ as a by-product. Both dairy and non-dairy emissions are shown below in Figure 8.17 and Figure 8.18 respectively (FAOSTat, 2013).

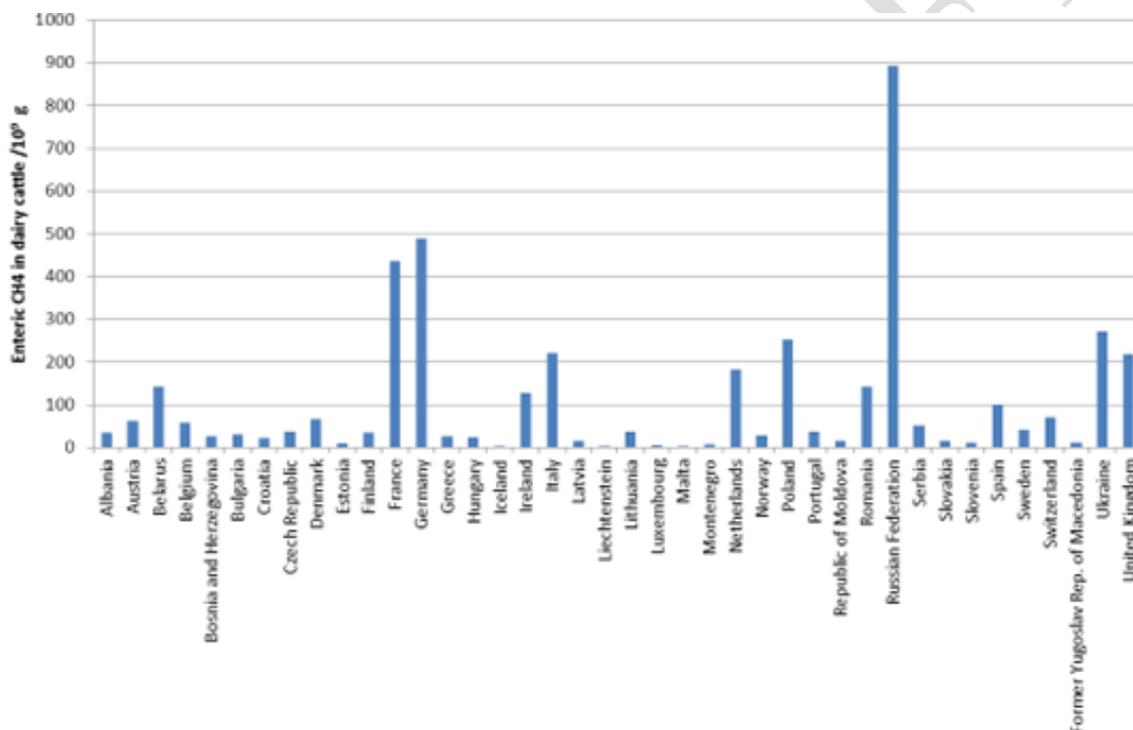


Figure 8.17. Enteric CH₄ (Gg) emissions in dairy cattle (FAOSTat, 2013)

High fibre diets give rise to greater methane per unit of energy intake than high concentrate diets and present a challenge to systems with high levels of forage (including silage). High fibre, high rumen pH and a slow rate for rumen passage all favour methanogenesis (bacterial production of methane). Methane production tends to be less with legume silage than grass because the former is lower fibre, stimulates higher DM intake and increased rate of rumen passage (Dewhurst, 2013).

Good quality clover silage according to Nordic standards (Stein-Bachinger et al., 2013):

- 30-50% clover
- 11 MJ/kg DM
- 15-20% CP

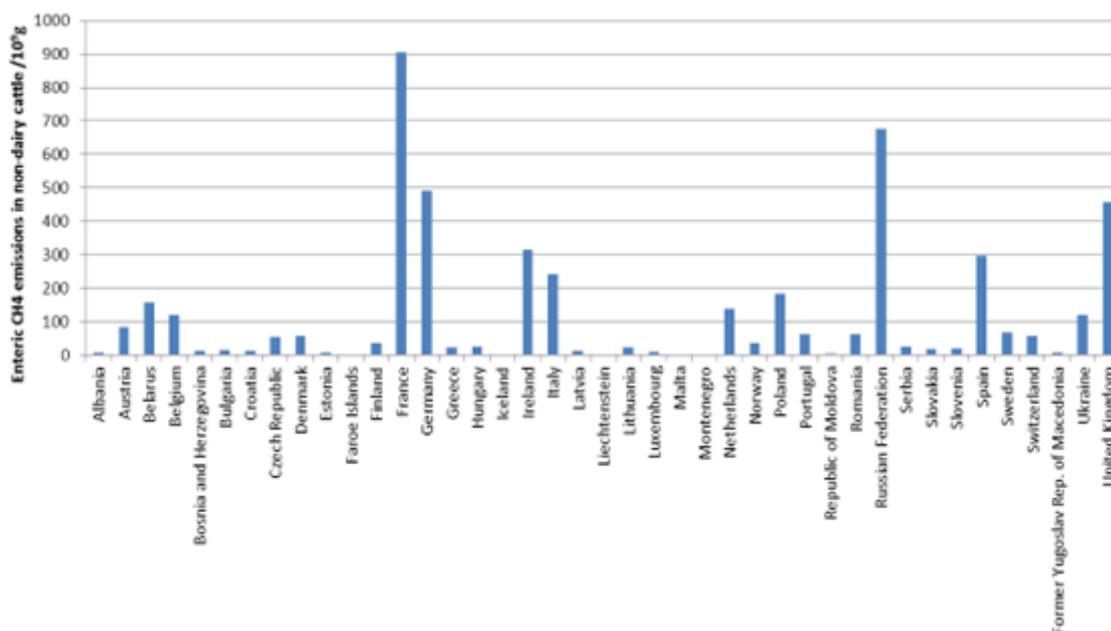


Figure 8.18. Enteric CH₄ (Gg) emissions in non-dairy cattle (FAOSTat, 2013)

Effective Methane mitigation practices (Hristov et al., 2013):

- Increasing forage digestibility and digestible forage intake
- Feeding legume silages compared to grass silage, (due to their lower fibre concentration)
- Dietary lipids can be effective
- C4 grasses produce greater amount of CH₄ than C3 grasses
- Introduction of legumes in warm climates may be effective (although low persistence and a need for long establishment periods are important agronomic constraints).

It is well established that increasing the level of concentrate in the diet leads to a reduction in CH₄ emissions as a proportion of energy intake or expressed by unit of animal product (milk and meat). Replacing structural carbohydrates from forages (cellulose, hemicellulose) in the diet with non-structural carbohydrates (starch and sugars) contained in most energy-rich concentrates is associated with increases in feed intake, higher rates of rumen fermentation and accelerated feed turnover, which results in large modifications of rumen physico-chemical conditions and microbial populations (Martin et al., 2010). However, research⁴⁰ has so far shown that high sugar grasses (refer to Section 8.3), whilst providing higher than usual water soluble C, do not reduce methane emissions in *in vitro* studies (IGER, 2005).

Supplements

- Garlic is known to kill the methane-producing stomach bacteria and is therefore a potential means of reducing methane in cattle. It also prevents intestinal parasites.
- Ivy contains saponins that kill ciliate protozoa which live in the rumen. Elimination of these protozoa increases microbial protein supply and can reduce methane production by 25%. Thus elimination of ciliate protozoa from the rumen will lead to an increased production efficiency and sustainability of meat and milk for food, whilst reducing greenhouse gas emissions from the supply chain (Aberystwyth University, 2014).
- A recent review by Grainger and Beauchemin (2011) concluded that addition of fat to the diet can result in a persistent decrease in CH₄ emissions, and not lower animal production. The challenge is to identify fat sources that can be feasibly added to the diet in a cost effective manner that also result in a net reduction in GHG emissions (as kg/d and kg/kg of product).

⁴⁰ Wageningen University (2014) has a research programme investigating the management and feeding options to reduce methane emission in the gastrointestinal tract of dairy cattle and results are expected in 2015.

Increasing the concentration of dietary fat from 3 % to 5 % in the dairy cow diets will reduce the methane emission by 17 %. It is well known that the use of unsaturated fatty acids can reduce the methane emission even further (EC, 2008).

Achieved environmental benefits

Methane emissions from Dutch dairy farms piloting best practice measures could provide potential benchmarks.

Table 8.35. Mean results of 16 commercial dairy farms in Netherlands piloting best practice (de Haan, 2014)

Report	Mean (Benchmark)	Min-Max
Enteric methane fermentation (kg CO ₂ per kg fat, protein corrected milk)	0.34	0.31-0.37
Methane emission for the whole farm (kg CO ₂ per kg milk in 2012)	0.61	0.51-0.67

Table 8.36. Differences in enteric methane emissions per kg lamb produced achieved by increasing flock output (Hyby Cig Cymru, 2011)

Increasing lambs reared by 20%		
	Scenario 1	Scenario 2
Rearing percentage	120%	140%
Reduction in enteric methane emissions per kg of lamb produced		-9% ¹
Increasing growth rate of single lambs by 10%		
	Scenario 1	Scenario 2
Average growth rate to sale (g/day)	225	248
Reduction in enteric methane emissions per kg of lamb produced		-1.50% ¹

¹The results are based on modelling changes within a single year and exclude longer term implications on female replacement rates, ewe live-weight and cull ewe and ram carcass output. Methane values for maintenance, growth, lactation, pregnancy and activity were estimated using IPCC Tier 2 equations. These results are produced from a project to develop a unique tool to model the impact that genetic improvement can play in reducing methane emissions during Welsh lamb production. The project, funded by the Rural Development Plan for Wales, has been carried out on behalf of HCC by Aberystwyth University (IBERS) with support from KN Consulting and Innovis.

The EC (2008) assumes a 17% reduction potential through increased fat intake. They state that CH₄ from enteric fermentation in cattle is sensitive to manipulation through dietary means and can be reduced through a concentrate rich diet at the expense of roughage, and especially through a higher concentration of fat in the diet. They cite Kirchgessner et al. (1995) who estimated that increasing the concentration of dietary fat from 3 % to 5 % for dairy cows can reduce the methane emission by 17 %. Corresponding to this reduction, the overall impact of this is shown in table 8.37.

Table 8.37. Annual improvement potential by methane reducing diets for dairy cows and gasification of pig and dairy cow liquid manure in EU-27. Only midpoint categories contributing more than 0.01% change are shown. Negative values signify an improvement (reduced impact) (EC, 2008)

Impact category	Unit	Improvement potential					
		In units of each impact category		In % of total impacts for meat and dairy products		In % of total impacts in EU-27	
		Diet change	Biogas	Diet change	Biogas	Diet change	Biogas
<i>Midpoint categories</i>							
Acidification	m ³ UES		-1.01E+09		-1.06		-0.27
Ecotoxicity, terrestrial	kg TEG-eq s		-8.94E+09		-1.48		-0.10
Eutrophication, aquatic	kg NO ₃ -eq		-6.97E+06		-0.08		-0.02
Eutrophication, terrestrial	m ² UES		-9.51E+08		-0.24		-0.10
Global warming	kg CO ₂ -eq	-1.70E+10	-2.93E+10	-2.54	-4.37	-0.36	-0.62
Human toxicity, carcinogens	kg C ₂ H ₃ Cl-eq		-2.97E+06		-0.21		-0.02
Human toxicity, non-carc.	kg C ₂ H ₃ Cl-eq		-4.44E+06		-0.39		-0.03
Mineral extraction	MJ extra		-6.80E+06		-0.13		-0.01
Non-renewable energy	MJ primary		-3.21E+11		-3.66		-0.23
Ozone layer depletion	kg CFC-11-eq		-4.93E+02		-0.26		-0.02
Photochemical ozone, veg.	m ² *ppm*hours	-2.29E+11	-2.04E+11	-3.44	-3.06	-0.43	-0.38
Respiratory inorganics	kg PM2.5-eq		-6.59E+06		-0.77		-0.14
Respiratory organics	Pers. *ppm*h	-2.81E+07	-2.25E+07	-3.89	-3.12	-0.50	-0.40
<i>Endpoint (damage) categories</i>							
Impact on ecosystems	species-weighted m ² *years	-1.01E+12	-1.74E+10	-0.77	-1.33	-0.19	-0.32
Impacts on human well-being	QALY	-4.33E+02	-5.31E+03	-0.07	-0.86	-0.01	-0.15
Impacts on resource productivity	EUR	-5.97E+07	-1.54E+08	-0.38	-0.99	-0.06	-0.16
All impacts aggregated	EUR	-1.51E+09	-3.01E+09	-0.62	-1.22	-0.14	-0.27

Table 8.38. Relative mitigation effect of reducing enteric fermentation (Newell-Price et al., 2011)

Nitrogen			Phosphorus		Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Nitrate	Nitrite	Ammonium	Part	Sol							
~	~	~	~	~	~	~	~	~	~	↓	~

Appropriate environmental performance indicators

Management indicators

- Match dietary energy intake to animal production and maintenance requirements
- Maximise digestibility of diet within feed strategy constraints

From the Swedish climate label for food criteria (Klimatmärkning för mat, 2010):

- The nutrient content in harvested forage must be analysed and feeding must be reviewed annually; wasted feed and overfeeding must be dealt with. In the review, the feed consumption rate must be compared in relation to the planned consumption in the diet.

Environmental indicators

- kg CH₄ per kg meat/milk
- D value feed
- Feed conversion efficiency
- Methane conversion factor of feed
- Calving rate (%)

Cross-media effects

Diets dominated by concentrate feeds lead to lower methane generation, but often a higher upstream CF of feed production (section 8.5).

Higher starch content and lower fibre in maize silage can reduce methane compared to grass silage. However, Vellinga and Hoving (2011) highlighted that a reduction in methane from feeding maize silage may be offset by loss of soil C associated with ploughing permanent pasture to grow maize.

Whilst enteric CH₄ formation decreases with feeding more concentrate, higher starch in the diet may potentially have a destabilizing effect on rumen fermentation, pH, overall rumen health and nutrient digestibility. If total tract OM digestibility is impaired, due to excessive inclusion of starch in the diet, animal production will decrease and GHG emission per unit product will increase. In addition, manure CH₄ emissions may also increase, due to increase concentration of available substrate, and this will counteract the enteric CH₄ mitigation effect on a whole-farm scale (FAO Stat, 2013).

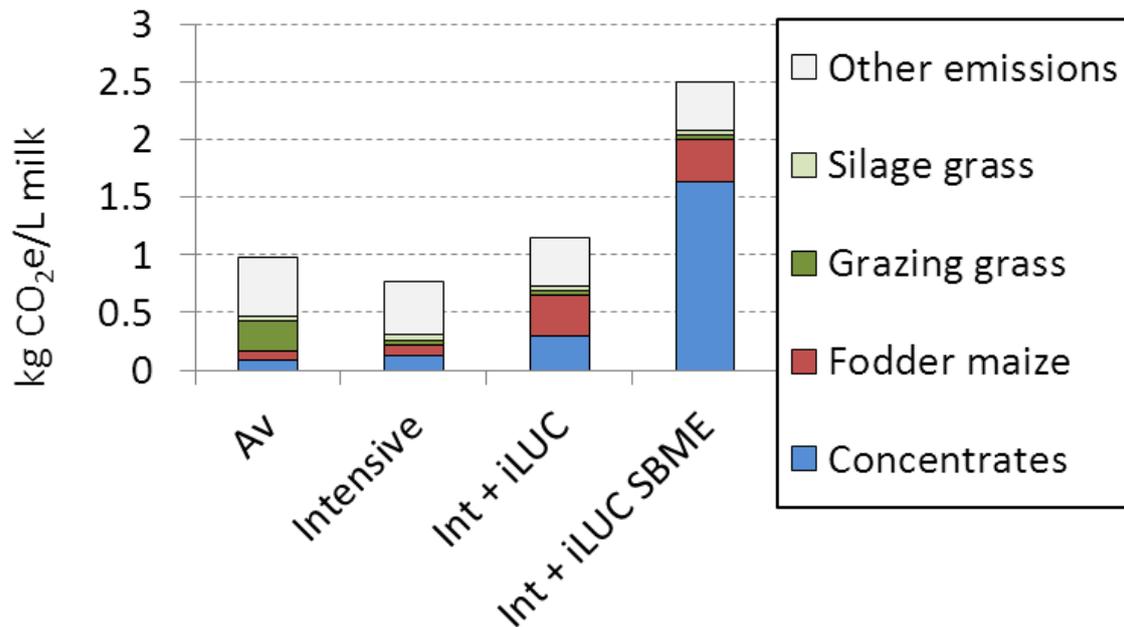


Figure 8.19. The GHG emissions per L milk for average and intensive (int) dairy systems (left two bars), taking account of land use change (LUC) for on-farm cereal crop (third bar from left) and LUC if Brazilian soya bean meal is used (right-hand bar) (ATP, Bangor, 2013).

Figure 8.19 illustrates average (largely grass based, bar 1) and intensive (mostly indoors, bar 2) dairy farm carbon footprints for milk production (kg CO₂e/L milk), then the possible effects of land use change to provide more maize and concentrate feed for the intensive farm (bar 3); if the farm changes from grass to concentrate feed, land use change (LUC) could be incurred. The import of SBME from countries where deforestation has occurred to grow soya leads to very high LUC. This illustrates the potential trade-offs between digestability/feed use efficiency and upstream iLUC effects.

van Middelaar et al. (2013) showed from LCA that intensive farms in the Netherlands that can reduce their area of grassland, annual emissions reduced by 17.8 kg CO₂e per ton fat protein corrected milk (FPCM) at farm level, and 20.9 kg CO₂e per ton FPCM at chain level. Ploughing grassland into maize land, however, resulted in non-recurrent emissions of 913 kg CO₂e per ton FPCM. At farm and chain levels, therefore, the strategy does not immediately reduce GHG emissions as opposed to what results at animal level may suggest and at chain level, it takes 44 years before annual emission reduction has paid off emissions from land use change.

In Table 8.39, the consequences of increasing milk yield from the EU current 5,900 kg/cow to Swedish and Danish achieved 8,500 kg/cow are estimated, assuming the same on-farm land use, an increased import of feed to the farm, and a marginal biological efficiency of transforming feed into milk of 60%. Per cow, more cereals and concentrates are needed to support the larger milk yield (0.64 kg per kg extra milk produced) and so farms become net importers of cereals. The need for fertiliser N decreases due to the larger N import in feed, while this also leads to slightly larger N emissions per cow unit (EC, 2008).

However, per kg milk, methane emission from the dairy farms is reduced by 24%, land use at the farm is reduced by 29% and emissions of ammonia, N₂O and nitrate per kg milk are reduced. But this improvement at the intensive dairy farm is offset by the concomitant increase in feed requirement and reduction in beef output (30% less beef produced, due to a smaller number of calves born and a smaller number of cows slaughtered), leading to increased emissions from feed production and from the induced additional beef production from suckler cows necessary to keep meat output unaltered. The net effect for methane emissions is only 4% of the emissions from the dairy farms, and this is

further counteracted by a net increase in CO₂ emissions, so that the net effect on global warming is negligible. Also, the reduction in emissions is accompanied by a significant increase in area and energy requirement for feed production (EC, 2008).

Operational data

Table 8.39 lists a scenario of intensification and higher feed input on dairy farms (EC, 2008). In particular, two options are presented; a. the so called present with 26 million dairy cows and b. the option with larger milk yield with 18 million dairy cows. The feed input on dairy farms and the related emissions are showed per cow unit and per 10 Mg milk (EC, 2008).

Table 8.39. Scenario of intensification and higher concentrate feed input on dairy farms (EC, 2008)

	Present (26 million dairy cows)		With larger milk yield (18 million dairy cows)	
	Per cow unit	Per 10 Mg milk	Per cow unit	Per 10 Mg milk
<i>Land use at dairy farm (ha)</i>	1.25	2.1	1.25	1.5
<i>Inputs (kg)</i>				
Cereal	–	–	963	1,133
Soy meal	634	1076	1,055	1,241
Fertiliser N	159	269	150	176
Fertiliser P	5	9	5	6
Mineral P	4	6	3	4
<i>Products (kg)</i>				
Cereals	280	474	–	–
Beef (live weight)	338	573	338	397
<i>Emissions (kg)</i>				
Methane	168	284	182	215
Ammonia	44	74	48	56
N ₂ O	14.1	23.9	14.4	16.9
Nitrate	306	520	330	388
Phosphate	0.83	1.4	0.89	1.05

Applicability

The applicability of reduction of enteric fermentation is relevant to ruminants only (Table 8.40).

Table 8.40. Applicability of reducing enteric fermentation (Newell-Price et al., 2011)

Dairy	Grazing LFA	Grazing Low	Mixed	In Pigs	Out Pigs	Poultry
Yes	Yes	Yes	Yes	No	No	No

Economics

In overall terms (utilised yield, food value and production cost) grazed grass is best. Silage has the advantage it can be conserved when stock cannot graze over winter. Maize silage has notably high utilised DM and low CP (which is useful in managing dietary N (refer to Section 8.3).

Table 8.41. Overview of forage quality and costs of production (EBLEX, 2010)

Crop	Utilised DM yield t/ha	Energy MJ/kg DM	Crude Protein % in DM	Cost per tonne of utilised DM (€/t DM)
Grazed grass	8.8	11.5	17	88
Grazed grass, old	6.0	10.5	15	96
Grass silage 1 st cut, or round bale	5.0	11.2	15	124
1 st cut round bale	5.0	11.2	15	131
Grass silage 3 rd cut	1.9	10.8	14	151
3 rd cut, round bale	1.9	10.8	14	167
Maize silage	11.7	11.2	9.0	118

Driving forces for implementation

- Low carbon farming certification
- Reduced cost per unit production with improved feed conversion ratio

Reference organisations

- Cows and Opportunities project farms, NL.

Reference literature

- Aberystwyth University, Wales. http://users.aber.ac.uk/cjn/index.htm_files/IVY%20for%20ruminants.pdf, accessed Feb 2014.
- Bangor University, Wales. 2013. ATP lecture series.
- de Haan, Michel, researcher Wageningen University, NL . pers. comm. Oct 2013.
- Dewhurst, R.J., 2013. Milk production from silage: comparison of grass, legume and maize silages and their mixtures. *Agriculture and Food Science* 22, 57-69.
- EBLEX, 2010. Forage choices, costs and rotations report. Kingshay report.
- FAO, 2013. Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO2 emissions. Editors: Gerber, P.J., Henderson, B. and Makkar, H.P.S. Paper 177. FAO, Rome, 2013.
- FAO Stat, 2013 <http://faostat3.fao.org/faostat-gateway/go/to/download/G1/GU/E>
- Grainger, C, Beauchemin, K.A., 2011. Can enteric methane emissions from ruminants be lowered without lowering their production? *Animal Feed Science and Technology*, 166– 167, 308– 320.
- HCC (Hyby Cig Cymru), 2011. http://hccmpw.org.uk/publications/farming_industry_development/environmental_roadmap/
- Hristov et al., 2013. Special topics: Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. *J Animal Sci*, 91, 5045-5069.
- IGER, 2005. High-sugar ryegrasses for improved production efficiency of ruminant livestock and reduced environmental N-pollution. LINK project LK0638. Aberystwyth University, Wales.
- JRC, 2008. Environmental Improvement Potentials of Meat and Dairy Products. P. Eder and L. Delgado (Eds.), JRC/IPTS. Publ. Luxembourg.
- Klimatmärkning för mät (2010). Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010. Sweden: Klimatmärkning för mät.
- Kirchgessner M, Windisch W, Muller H L.,1995. Nutritional factors for the quantification of methane production. Pp. 333-258 in Engelhards, Leonhard-Marek, Breves, Giesecke (Eds.):

‘Ruminant Physiology: Digestion, Metabolism, Growth and Reproduction.’ Proceedings VIII International Symposium on Ruminant Physiology. Martin, C. Morgavi, D.P. and Doreau, M., 2010. Methane mitigation in ruminants: from microbe to the farm scale. *Animal*, 4, 351-365.

- Newell-Price et al., 2011. An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture. Mitigation methods: User Manual.
- Stein-Bachinger, K., Reckling, M. & Granstedt, A. 2013. Ecological Recycling Agriculture-Farming Guidelines, Vol. 1. Järna, Sweden. ISBN 978-3-00-042440-3, 136.
- van Middelaar, C.E. et al., 2013 Evaluation of a feeding strategy to reduce greenhouse gas emissions from dairy farming: The level of analysis matters. *Agricultural Systems*, 121, 9–22.
- Vellinga, T.V. and Hoving, I.E., 2011. Maize silage for dairy cows: mitigation of methane emissions can be offset by land use change. *Nutrient Cycling in Agroecosystems* 89, 413-426.
- Wageningen University, Netherlands. 2014. “Low emissions animal feed”, [accessed Jan2014: http://www.wageningenur.nl/en/show/Lowemission-animal-feed.htm](http://www.wageningenur.nl/en/show/Lowemission-animal-feed.htm)

FINAL DRAFT

8.5 Green procurement of feed (ruminants and monogastric)

Description

Within this BEMP, the following measures are discussed:

- Select feeds with low upstream impacts, including indirect land use change
- Certified soya, maize and palm oil, etc.

Feed production is very important for total emissions of greenhouse gases in the life cycle of animal feed. For eggs, chicken and pork, it usually constitutes 60-80% of emissions up to the farm gate, for milk and beef 35-45%. It makes up a relatively smaller proportion for ruminants because methane from feed digestion comprises the dominant fraction of total emissions for milk and beef (refer to Section 8.3) (Sonesson et al., 2009).

Concentrates are used in a ration to boost milk production. However, as production increases, so do GHG emissions (Figure 8.20) due largely to embedded CO₂e associated with fertiliser application and transport of the concentrates.

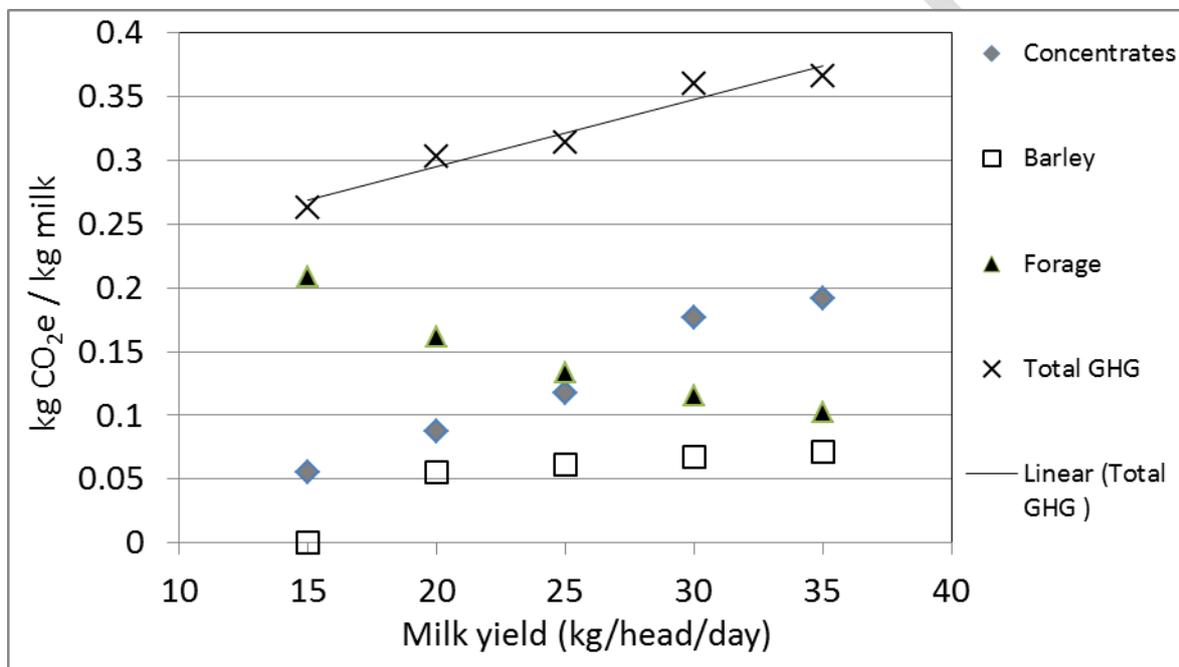


Figure 8.20. The relation between high milk yield concentrates in ration and GHG emissions per litre of milk (Data from Hortenhuber et al., 2013).

Feeding soy can reduce methane emissions but where soy is grown on land previously supporting rainforest (worst case scenario, e.g. Brazil), the GHG emissions factor per litre of milk is hugely increased from 0.7 to 3.4 kg CO₂e /L milk (Figure 8.21). Thus, there is a need to use sustainably produced soy.

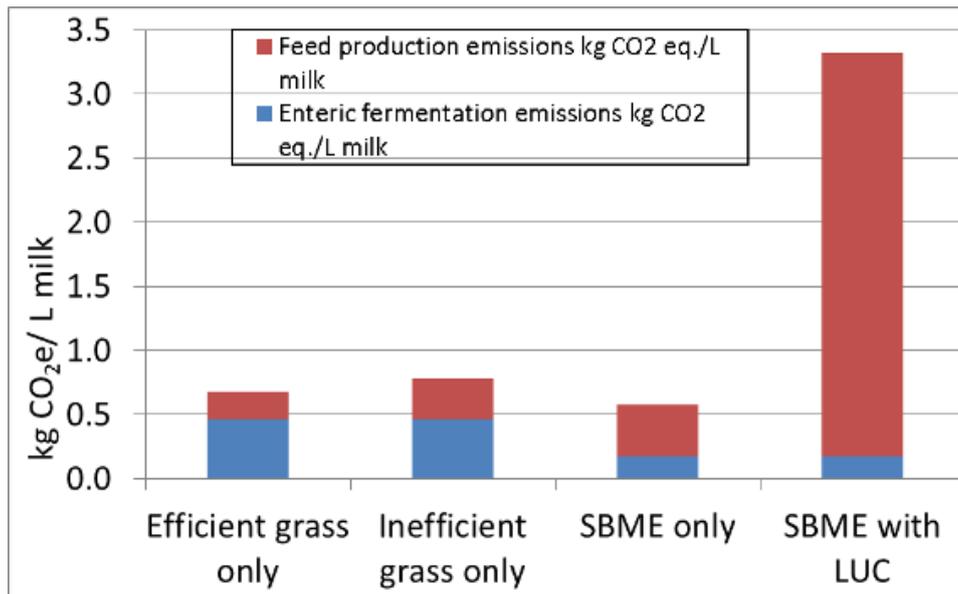


Figure 8.21. The impact of where SBME is grown on feed-related-GHG emissions per L milk (ATP, Bangor 2013).

Figure 8.22 depicts the breakdown of stages in the production of soy and attributed GHG emissions. These values do not include land use change from deforestation, which would add another estimated 600 g CO₂e/kg SBM (Sonesson et al, 2009).

There is sustainability-certified soya bean meal available on the market, e.g. regulated by Campina in the Netherlands and companies in Switzerland. The WWF and COOP in Switzerland have developed the so-called ‘Basel criteria’ for sustainable soya bean production. These regulations have not allowed conversion of natural vegetation to land for soya bean growing since 2004 and also demand that compensation be made for soya bean grown on land deforested in the period 1995-2004 (Sonesson et al., 2009; Klimatmärkning för mät, 2010).

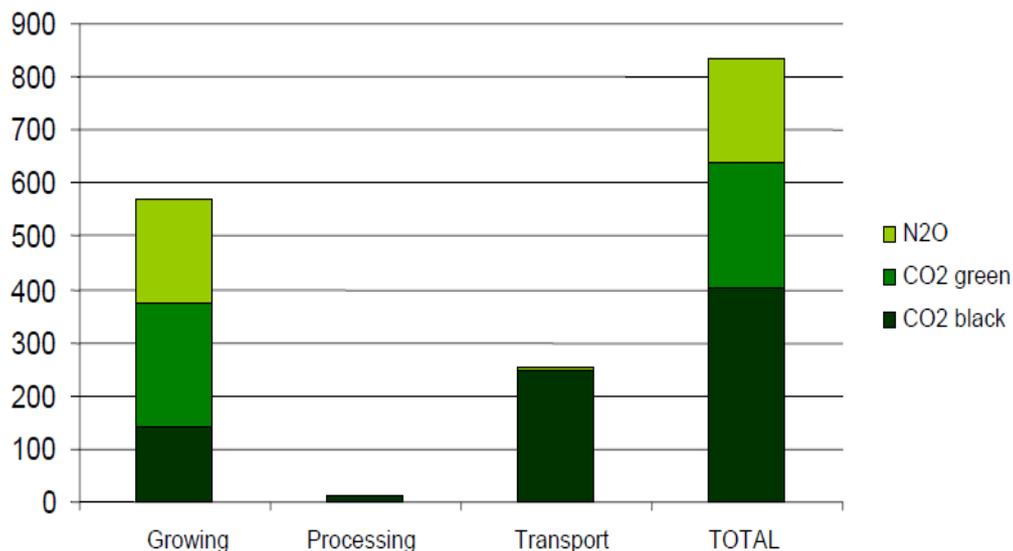


Figure 8.22. Emissions of GHG in g CO₂e/kg SBM produced. ‘CO₂ green’ is from soil after the change in land use; ‘CO₂ black’ is from fossil fuels (Sonesson et al., 2009).

Certified production of farm produce enables an enterprise to assure its customers of the sustainability of the entire supply chain. It is a growing field and is gaining credibility, as very large and powerful enterprises are subscribing to it, and investing in ensuring sustainable production across the supply

chain. Increasingly, consumers are demanding certification, to the extent that certified agriculture products are increasing their market share at significant rates (FAO, 2013).

Achieved environmental benefits

Given the worst case scenario of SBME coming from deforested areas, with a carbon footprint of approximately 9 kg CO₂e per kg SBME (Hortenhuber et al., 2011), avoided GHG emissions from green procurement of feed could amount to 8.5 kg CO₂e per kg feed, or 2.8 kg CO₂e per kg milk on a dairy farm.

In addition, avoiding land use change from animal feed production can lead to large avoided impacts on biodiversity, soil degradation, water stress, etc.

Appropriate environmental performance indicators

Management indicator

- Select feeds with low upstream (cultivation and transport) impacts.
- Avoid soya based feeds
- Select feeds certified to be from areas not recently converted from natural habitats (e.g. RTRS)

FAO (2013) lists:

- The enterprise keeps a procurement record which identifies the certification status for all procurement, distribution and production;
- The enterprise is able to provide evidence of assessments for any non-certifiable procurement, distribution or production, and this assessment details the problem, reason for the decision, plan to remedy and date for review;
- The enterprise has evidence that it transparently reports its progress towards certified procurement, distribution and production to its stakeholders.

Performance indicators

- Feed related kg CO₂e per kg feed or per kg meat or milk output

Dutch dairy organisation (NZO) sustainability targets:

- 100% use of RTRS (Round Table on Responsible Soy) certified sustainable soya and sustainable palm kernel expeller by 2015 <http://www.duurzamezuivelketen.nl/eng/content/objectives>
- Green procurement, Basel Criteria and RTRS for soy from non-deforested areas.
- Focus on maximising grass as forage (optimum soil nutrients, SOM, avoid compaction, cross-ref to Chapter 7) rather than feeding concentrate wherever possible.
- Since 1 January 2013, the soya used must be sustainability certified according to an internationally accepted system, e.g. RTRS, IFOAM or ProTerra (Klimatmärkning för mät, 2010).
- % of certified sustainable product generated, distributed and procured will be the primary measure (FAO, 2013).

Cross-media effects

Avoiding soy based feeds could lead to lower feed conversion efficiencies, depending on the alternatives found. However, Hortenhuber et al. (2011) demonstrated how regional (Austrian) feedstocks could be used to substitute SBME in high-yielding dairy cows.

Operational data

Detailed requirements relating to animal feed are contained in the Swedish climate label for food (Klimatmärkning för mät, 2010). Some pertinent requirements are replicated below, under general and animal-type-specific headings.

General feed criteria for the Swedish climate label for food

It must be shown that account has been taken of the climate impact in the choice of purchased feed. When feed mixes are bought in, the feeds selected must be climate-calculated and have verified low emissions of climate gases. The calculation method must be reported openly.

This does not apply to purchase of feeds from neighbouring farms (see Definitions section for an explanation of neighbouring farms).

Recommendation: If grain fertilised with mineral fertiliser is purchased, it should be fertilised with N mineral fertiliser produced with low emissions of climate gases, at most 4 kg CO₂e per kg N, according to an openly reported calculation provided by the manufacturer. From 1 January 2012, purchased mineral-fertilised grain should be fertilised with mineral fertiliser where the production emissions are at most 3 kg CO₂e per kg N.

If the proportion of feed produced on the farm is less than half the total feed requirement, the following requirement must be fulfilled: From 1 January 2013, at least 50% of purchased grain must be cultivated using mineral fertiliser with production emissions that have not exceeded 3 kg CO₂-e per kg N, which must be demonstrated in an openly reported calculation provided by the supplier.

Swedish climate label for food criteria for dairy feed

Any feed used that contains soya or palm kernel products must be able to fulfil one of the following three requirements: (i) the milk producer must be able to present a guarantee from the manufacturer that the crops have been produced on land where primary ecosystems or High Conservation Value Areas have not been destroyed to create open arable land since 1990; (ii) IFOAM-certified soya or palm kernel products must be used; (iii) a maximum of 100 kg soya or palm kernel expeller may be used per cow and year, and from 1 January 2013 any soya and palm kernel products used must be sustainability-certified according to an internationally accepted system, e.g. RTRS, RSPO or ProTerra.

Swedish climate label for food criteria for beef feed

Soya and/or palm kernel products are not permitted in the diet.

Forage fraction: At least 70% of the diet during the housed period must consist of roughage and at least 50% must consist of grass forage.

Locally produced feed: The proportion of feed used in beef production that is produced on-farm or in partnership with neighbouring arable farms must be at least 70%.

Swedish climate label for food criteria for lamb feed

Purchased soya. Soya is not permitted in the diet from 1 January 2012. Verification requirements: Declarations of contents and delivery notes for purchased feed must be available. For purchases from neighbours, the amount, type, delivery date and seller of the feed must be reported.

Forage fraction. At least 70% of the diet for ewes and rams during the housed period and at least 50% of the diet for lambs after weaning must consist of good quality forage. During the grazing period, at least 90% of the diet for all animal categories must consist of forage, as a herd average.

The proportion of forage for ewes near lambing or suckling must be at least 60%. During a 3-month period early in the lactation, the forage fraction may be decreased to 50%. This period can start earlier if growth of the foetus is preventing forage consumption in ewes near lambing.

Verification requirements: Documentation to confirm this must be available on request. By forage is meant grazing, silage, hay, straw, green forage, beet pulp and root vegetables.

The proportion of feed used in the housed period in lamb production that is produced on-farm or in partnership with neighbouring arable farms must be at least 70%. Verification requirements: Documentation on the proportion of feed produced on the farm compared with purchased feed, confirmed through invoices or equivalent, showing that at least 70% is home-produced.

Applicability

Green procurement of feed is applicable to all livestock farms. However, it should be mentioned that the availability of certified soy is sometimes limited (for instance in the UK there was no availability on mid June 2014).

Economics

There may be a small price premium associated with certified feeds.

Driving forces for implementation

- Low-C farming certification
- Increasing public awareness

Reference literature

- Bangor University Wales. 2013. ATP lecture series.
- DEFRA, 2012 Green Food Project Dairy Subgroup Report. Defra, London. Available to download at <http://www.defra.gov.uk/food-farm/food/environment/>.
- FAO, 2013. Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO₂ emissions. Editors: Gerber, P.J., Henderson, B. and Makkar, H.P.S. Paper 177. FAO, Rome.
- Hortenhuber, S.J., Lindenthal, T., Werner, Z. 2011. Reduction of greenhouse gas emissions from feed supply chains by utilizing regionally produced protein sources: the case of Austrian dairy production. *J. Sci. Food Agric.*, **91**, 1118–1127.
- Klimatmärkning för mät. 2010. *Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010.* Sweden: Klimatmärkning för mät.
- Sonessen U., Cederberg, C., Berglund, M. 2009. Greenhouse gas emissions in animal feed production. Decision support for climate certification. Klimatmärkning för mät.
- van Middelaar, C.E. et al., 2013 Evaluation of a feeding strategy to reduce greenhouse gas emissions from dairy farming: The level of analysis matters. *Agricultural Systems*, 121, 9–22.

8.6 Maintain animal health

Description

Within this BEMP, the following measures are discussed:

- Produce a health programme for the whole farm to include: routine preventative inspections, plan shared treatments with neighbouring farms wherever possible to reduce cost and to improve animal health over a larger area
- Responsible use of medicines e.g. rotate vet products to avoid resistance
- Quarantine periods for animals brought on to farm
- Exclude stock from wet areas to break liver fluke breeding cycle;
- Water provision to animals
- Maintain in general the animal welfare based on the 'five freedoms'

Animal health is a state of physical, sentience and group well-being. For the sake of simplicity, it can also be understood as the absence of illness and injury. This BEMP covers practices and activities implemented that support animal health and that reduce the need for veterinary treatments, as well as unwanted animal losses (FAO, 2013).

Production is strongly related to animal health. The reason is that healthy and contented animals produce more milk and meat, so the climate impact caused by each animal can be divided across more products (Klimatmärkning för mät, 2010).

Improved animal health and reduced mortality and morbidity are expected to result in increased herd productivity, diluting non-CO₂ GHG emissions per unit product (FAO, 2013).

The Netherlands has a scoring board for sustainable animal husbandry (Smit, 2013). The animal well-being issues which are taken into account in this scoring board are:

- Ammonia emissions: Stables must have an ammonia reducing system that reduces ammonia emissions more than legally required.
- Animal welfare in stables: measures should be taken to improve the well-being of the animals since the measures are based on the value of the animal.
- Animal health: measures are based on three principles - prevention of diseases entering the farm, preventing a disease spreading within the herd and improving disease resistance of the animal in the stable.
- Particulate matter: measures are aimed at reducing emissions of particulate matter to the environment and the reduction of particulate matter in the animal quarters within the stable.

Best practice in information delivery

The South West Healthy Livestock Initiative (SWHLI) was an RDPE project funded over three years in SW England. Work was delivered through an academic institute, reaching a wide distributed set of beneficiaries. The delivery model of advice plus incentives (free diagnostic blood tests) proved effective e.g. Johne's disease advice strand. The delivery model of training for specialists (e.g. vets) delivered by regionally based co-ordinators also worked well enabling vets to then better deliver advice/ events to farmers.

Ectoparasites: Sheep ectoparasites are treated by organophosphates (OP) and synthetic pyrethroids (SP). There is a need to reduce the use of SPs which have very significant environmental impacts, but at the same time improve the control of ectoparasites in the UK sheep flock. This could be done through a combination of management practices which reduce the need for chemical controls and controlled use of OPs. The majority of sheep scab is found in upland and hill flocks and as reservoir, pose a threat to lowland flocks (EA, 2001).

Herd/flock management to avoid/reduce use of chemicals: Do not mix young and older animals on the same pasture as young animals are very susceptible to internal parasites and should be put out onto clean pasture. ‘Clean’ refers to previously no grazing by same species for a year or, the field has been cultivated since grazing adults.

Mix or rotate grazing with other species e.g. cattle and lamb. This not only controls internal parasite burden but also more efficiently uses available grass. Following sheep with cattle or horses is considered best (Stein-Bachinger et al., 2013).

Pasture contamination and infectivity levels can be reduced by grazing sheep and cattle together. This effectively reduces the stocking density of the host species but can make pasture utilisation more difficult. In single-suckled beef production systems, the grazing of immune cows with their calves acts in a similar way by reducing pasture infectivity levels for the susceptible calves (Taylor, 2011).

Environmental effect of OP and SP: OP use is still permitted. SPs are less effective and accumulate in clay sediment from rivers. In uplands where there may be less clay, SPs reside in water and affect living organisms before becoming bound to clay in lowland waters, but effects on stream biology are still noticed here. The key is to balance toxicity with animal health. The Veterinary Medicines Directory lists approved substances and holding times (M. Price, 2014).

Best practice in sheep dipping is for farmers to dip cooperatively so that less active material is used and therefore discarded per animal unit (M. Price, 2014).

Condition scoring of cattle is an easy technique and can be applied even to groups of animals in the field, although individual handling is necessary in most situations. It allows essential management decisions to be made and enables high standards of husbandry to be achieved – and ensures costly welfare problems are avoided (Table 8.42 and Table 8.43).

Table 8.42. Target condition scores for beef cattle (DEFRA, 2001a)

Suckler cows and heifers	Autumn calving	Spring calving	Summer calving
At calving	3	2-2.5	2-2.5
At service	2.5-3	2.5	2.5-3
At turnout	2	2	2
At housing	2.5-3	3	2.5

Table 8.43. Target condition scores for dairy cattle (DEFRA, 2001b)

Dairy cows	Cows	Heifers
Pre-calving	2.5-3	2.5-3
Pre-service	2-3	2-2.5
Drying off	2.5-3	

Liver fluke can have a major effect on the performance of cattle and sheep. Current estimates suggest that fluke can reduce the market value per finished animal by 10 to 15%. Apart from liver condemnation, liver fluke has important effects on the following health indicators:

- Reduced live weight gain
- Lower feed conversion efficiency
- Reduced fertility
- Lower milking ability
- Occasional deaths due to acute or untreated chronic infections (HCC, 2009).

Good conditions: In the Pontbren project in Wales (refer to Section 3.3.1), a farmer-led initiative (outside of any agri-environment scheme) undertook tree-planting and other initiatives to reduce

environmental pollution (run-off of nutrients and pesticides) and improve eco-efficiency, enabled fewer sheep per ha to achieve same yield output in an upland context, with outdoor lambing reducing labour requirements. The trees provided riparian strips and shelter, improving animal health and productivity.

Access to water: Access to water is essential for animal welfare, both in the field and when housed. In buildings water troughs should always be sited to maximise accessibility to all animals. At pasture cows should not have to walk more than 250 m to a drinking trough. 70cm of water trough space needs to be allowed per cow – a 100-cow herd requiring 7m of total trough space. The trough space should be sufficient for 10% of the herd to drink at once. Cows require at least 60 litres of water/head/day and may need 100 litres or more depending upon yield. All non-mains water should be tested annually for pH, total dissolved solids, total coliform bacteria, faecal coliform bacteria, total plate count and key minerals (DairyCo, 2012).

Best practice for scab treatment: Once an outbreak of scab is found in a flock, it is advised that the treatment of the whole flock should be undertaken as soon as practicable. Once treated, sheep should not be returned to the original pasture for at least 16 days to prevent re-infestation by the scab mites - a very basic rule but one that is often forgotten in practice (Price, 2014).

Best practice for use of dips: Timing is key factor, the use of dips 4-6 weeks post-shearing ensures both maximum efficacy and lowest risks from wool scouring. Also, application of pour-on products to short fleece lengths ensures better control of lice (Environment Agency, 2001).

Additionally, the animal welfare, which includes mental and physical aspects, is defined as the so called five freedoms (Bousfield and Brown, 2010; Hansson and Lagerkvist, 2015):

1. Freedom from Hunger and Thirst: by providing ready access to fresh water and a diet to maintain full health and vigor.
2. Freedom from Discomfort: by providing the appropriate conditions/environment i.e. including shelter and a comfortable resting area.
3. Freedom from Pain, Injury or Disease: by prevention or rapid diagnosis and appropriate medical treatment (if required)
4. Freedom to Express Normal Behavior: by providing sufficient space, proper facilities and company of the animal's own kind.
5. Freedom from Fear and Distress: by ensuring conditions and treatment which avoid mental suffering.

In a more detailed context, the animal welfare e.g. in dairy production systems is assessed and monitored using a combination of measures that indicate the level of delivery within the five aforementioned action areas. In particular, the observation of the animal behaviour that indicates stress or distress is one important indicator of the animal welfare. Additionally, other factors such as: i. the assessment of environmental stressors e.g. local weather conditions, like excessive heat or cold, housing density etc., ii. assessment of the body condition, iii. relevant physiological indicators/signs, iv. amount of water and feed consumed and v. records of animal treatments can be either qualitative or quantitative indicators that could be used for the measurement of the animal welfare (International Dairy Federation, 2008).

Regarding feed conversion efficiency there is strong evidence that over the last 20 years have resulted in substantial reductions in resource use and in GHG per unit product for many different species. In particular, the amount of feed is required to produce a certain amount of meat or animal product is reduced. According to Houses of Parliament (2011) the FCE ratio value for broilers was 2.3 in 1973 whereas in 2001 was slightly less than 1.8. Nevertheless, due to various economic constraints farmers are in favour of applying diets with lower environmental burden but on the other hand when they do so they lose some of the FCE value (e.g. rapeseed, human food refuse).

Achieved environmental benefits

There is no direct metric of animal health in a comprehensive sense and partly for this reason, it thus can be difficult to determine the effects of health-promoting measures with certainty. For some measures, including some vaccinations, there is disagreement as to whether they are necessary (FAO, 2013).

However, in general, improved animal health leads to improved resource efficiency through high feed conversion ratios and improved nutrient use efficiency (i.e. a higher share of inputs end up in final products).

It has been reported in the literature that farms where preventive herd health plans are in place a reduction of approximately (on average) 30% in antibiotic use is achieved.

Appropriate environmental performance indicators

Management indicators

- Produce a health plan that includes routine health monitoring (vet inspections and animal health indicators)
- Vet, medicine and labour costs associated with welfare
- Use of antibiotics/medicines; frequency (no./year)

FAO (2013) lists:

- Preventive measures are preferred and no synthetic growth promoters (including hormones) are used
- Injury and disease rate at a minimum - lower than benchmark values if available, or lower than during last assessment
- Regular check-up, if feasible, by professional animal healthcare.

Performance indicators

- Feed conversion efficiency (FCE); it should be mentioned that this indicator should be only used to monitor health of herd and not be used to increase FCE at all costs.
- kg meat (milk) / head/ life time
- % animals with health issues requiring drugs
- Animal longevity
- Occurrences of treatment per head over year

Veterinary inspections at the farm can be seen in different ways: preventive visits or last resort visits; the number of veterinary inspections is thus not a good indicator.

Irrespective of the option chosen, consideration must be given to the following health parameters and in the event of deviations a remedial plan must be drawn up in consultation with a veterinary surgeon or advisory officer:

The Klimatmärkning för mät, (2010) proposes the following indicators:

Sheep farms

- Drop-out rate of ewes
- Mortality in different animal groups (guideline max. 10% before weaning for lambs)
- Total number of veterinary treatments
- Hoof health
- Use of antibiotics or other pharmaceuticals
- Number of disease recordings at slaughter compared with the national average.

- Verification requirements
- It must be possible to calculate lamb mortality and ewe drop-out rate from the herd book or other records.
- The results of assessments at slaughter must be saved for three years.
- A medication and procedure journal must be kept.
- Any remedial plan required must be in place.

Chicken farms

- Mortality
- Claw health
- Incidence of coccidiosis
- Use of antibiotics or other pharmaceuticals
- Number of chickens per square meter.

Laying bird farms

- Mortality (guideline value max. 5% in cage systems, max. 8% in systems with free range hens regardless of whether they are allowed outdoors - these values are per batch).
- Laying percentage (guideline value given in the hybrid manual)
- Pecking injuries
- Feather loss
- Presence of mites
- Presence of ascaris worms

Pig farms

- Mortality in different animal groups (the guideline value for number of piglets produced per sow and year is 22 and that for mortality in the fattening pig phase is 3%).
- Total number of veterinary treatments
- Use of antibiotics or other medicines
- Number of disease recordings at slaughter compared with the national average

Different associations and organisations proposed benchmarks for this topic. In particular, FAO (2013) proposed that:

- 100% of animals in the company's sphere of influence benefit from integrated health-promoting measures
- 100% of animals in the enterprise' sphere of influence have the possibility to behave according to their specific needs

Likewise, the Klimatmärkning för mät, (2010) requires for dairy farms:

- The dairy farm must be a member of an established health auditing system with health parameters for animal welfare. These parameters must be monitored in a systematic way and deviations documented. An analysis must be made of the reasons for deviations and the measures that must be implemented.

For sheep, pig, chicken and laying bird farms, the Klimatmärkning för mät, (2010) stipulates that the above can be met through either:

- Joining an established health auditing system for sheep and lambs with at least one annual visit by a veterinary surgeon, or
- The producer drawing up and implementing an on-farm programme for preventive healthcare. This programme must include at least one annual visit to the herd by a veterinary surgeon.

Cross-media effects

A major issue with the latest advice on ectoparasites is the increases in the meat withdrawal periods e.g. a 70 day withdrawal period for meat is stated when using treatments containing the active ingredient Dimpylate (VMD, 2012), which deterred many farmers from dipping / showering, resulting in an increase in the use of injectible products. The most effective treatment for scab in a flock is plunge dipping and there appears to be fewer contractors offering this service, with showers seeming to take over. OP dips such as Diazinon were never approved for use in showers, only plunge dips. This grey area continues to persist and could be a major problem in the making with dips being less frequently offered (Martin Price, 2013).

Operational data

The Dutch scoring board system

The system works with a scoring board. All measures that could be taken by farmers are rated with sustainability points. There are basic standards for each of the sustainability issues. On top of that, farmers have to earn additional points for specific issues to get a final minimum score. The farmer is allowed to choose on which specific issue or issues these additional points are earned (Smit, 2013).

For farms with large and very large numbers of animals, a higher level of ambition on the issues of animal welfare and health is expected: the minimum number of points required for these issues depends on the number animals on the farm. As an entrepreneur certifies the stable, the determination of farm size (number of animal places) throughout the whole farm is determined and not only the size of the reported stable. The minimum number of points on the metrics mentioned is related to farm size counted in nge (Dutch size unit) and defined at three levels:

- Company size ≤ 350 nge
- Company size > 350 nge and ≤ 700 nge
- Company size > 700 nge

The scoring board for sustainable animal husbandry is developed for the animal categories ducks, turkeys, rabbits, hens, goats, dairy cattle, pigs, calves, chickens (meat and eggs) and beef cattle.

Liver fluke

Develop an effective quarantine strategy for any new stock. Treat bought-in livestock with a flukicide that kills immature fluke and, if possible keep treated imported animals on drier pastures or housed for 3-4 weeks. Try not to graze sheep and cattle close to muddy ponds or ditches or on heavy, low-lying pastures. If possible, fence off boggy areas and try to improve drainage. The risk of severe outbreaks of liver fluke increases following wet springs and summers. Forecasting systems help to predict the likely incidence and severity of liver fluke based on data from the preceding months (HCC, 2009).

Applicability

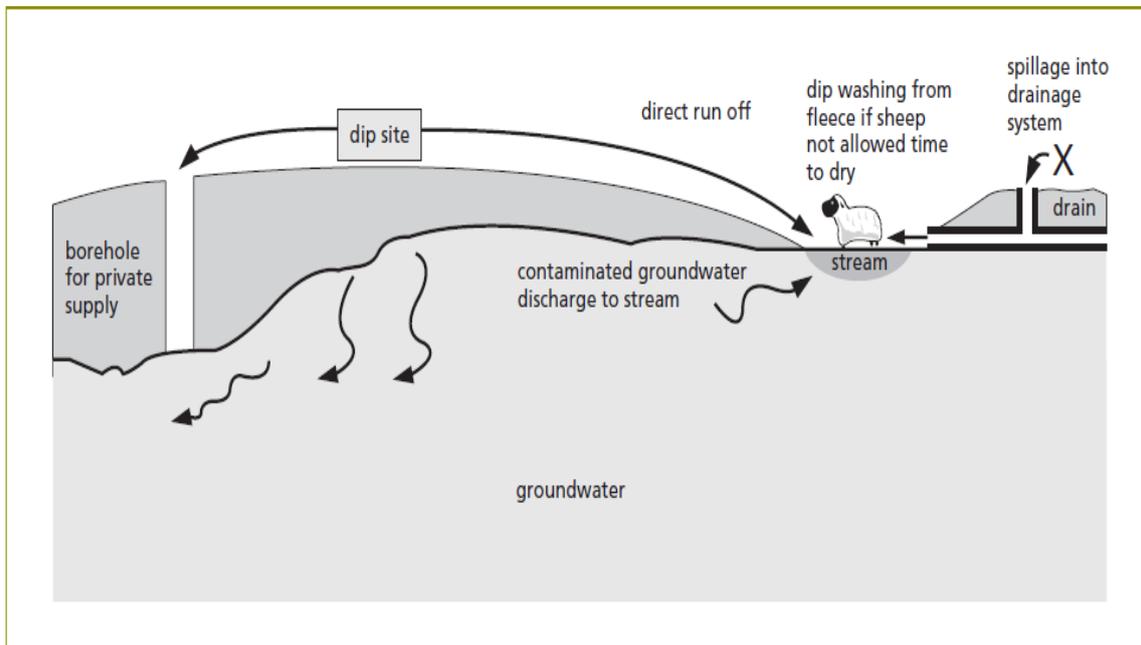
Maintaining animal health is applicable to all farm types for both environmental and economic reasons as healthy animals are more productive.

Flock and herd management to reduce infestation best practice is applicable to all livestock-containing farms. Scab treatment is applicable to all farms with sheep.

Economics

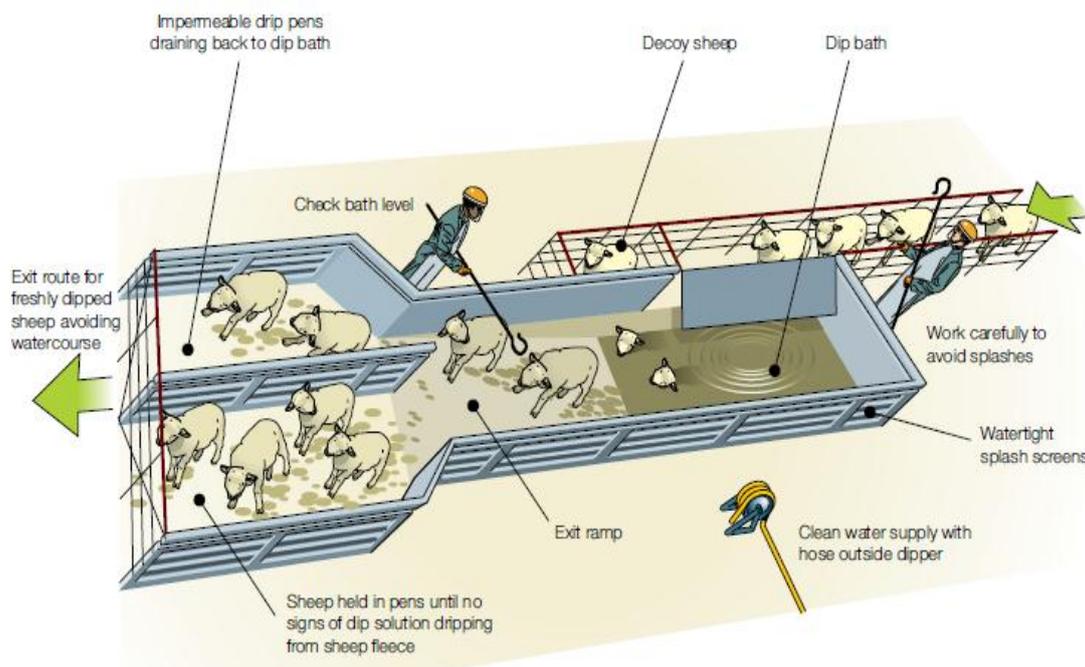
Cost in the UK of applying for an Environmental Permit for disposal of spent sheep dip under the terms of the Environmental Permitting Regulations 2012 is currently £390 (EUR 460) with an annual subsistence fee of £153.90 (EUR 181.00) therefore this can add considerably to farm costs.

Fluke infection is estimated to cost the UK agriculture industry about £300 (EUR 353) million a year. Liver condemnations alone cost £3.2 (EUR 3.76) million in 2010 (Taylor, 2011).



Source: DEFRA (2006)

Figure 8.23. Pathways of loss of sheep dip leading to pollution



Source: HSE (2013)

Figure 8.24. A well-designed sheep dip bath engineered to reduce loss of dip to environment and operator (note PPI apparel).

Driving forces for implementation

- Customer confidence in a high quality food source and eradication of sheep scab in the U.K. by good husbandry.

- Resource efficiency (reduced costs per unit output)
- Environmental Permitting Regulations 2012
- Water Framework Directive
- Animal Welfare Act 2006 UK
- Welfare of Farmed Animals (England) Regulations 2007
- Council Directive 91/629/EEC
- Council Directive 97/2/EC
- Commission Decision 97/182/EC

Reference literature

- ADAS, 2000. Guidance on Construction, Repair and Maintenance: Sheep dip handling facilities and drainage yards. (CGN) 006. <http://archive.defra.gov.uk/foodfarm/landmanage/water/csf/documents/cgn006Xp.pdf>
- Bousfield B., Brown R. (2010), Animal welfare, Veterinary Bulletin-Agriculture, Fisheries and Conservation Department Newsletter, 1(4).
- DairyCo, 2012. Feeding+. 7. Managing your feeding. <http://www.dairyco.org.uk/resources-library/technical-information/environment>.
- DEFRA, 2001a. Action on animal health and welfare. Condition scoring of beef suckler cows and heifers. <http://archive.defra.gov.uk/foodfarm/farmanimal/welfare/onfarm/cattle.htm>
- DEFRA, 2001b. Action on animal health and welfare. Condition scoring of dairy cows. <http://archive.defra.gov.uk/foodfarm/farmanimal/welfare/onfarm/documents/pb6492.pdf>
- Defra, 2006. Groundwater Protection Code. Use and disposal of sheep dip compounds August 2001 (reprinted June 2006). Defra, London. 28pp.
- Environment Agency (EA), 2001. Sheep Flock Management R&D Technical report P396. Publ. Environment Agency, Bristol. UK.
- FAO, 2013. SAFA Indicators. FAO, Rome.
- Hansson H., Lagerkvist C.J. (2015), Identifying use and non-use values of animal welfare: Evidence from Swedish dairy agriculture, Food Policy, 15, 35-42.
- HCC, (2009), “Liver fluke”, accessed July 2013: http://hccmpw.org.uk/publications/farming_industry_development/animal_health_and_welfare/
- House of Parliament (2011), improving livestock, Houses of Parliament, Parliamentary office of science and technology, Postnote, number 393, October, available online at: http://www.parliament.uk/pagefiles/504/postpn393_improving-livestock.pdf, last accessed February 2015.
- HSE, 2013. Sheep dipping: Advice for farmers and others involved in dipping sheep. Booklet AIS41. <http://www.hse.gov.uk/pubns/ais41.htm> accessed Mar 2014.
- International Dairy Federation, (2008), Guide to good animal welfare in dairy production, ISBN: 978-9-290980-41-4.
- Klimatmärkning för mät (2010). Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010. Sweden: Klimatmärkning för mät.
- Price, M., *pers comm*. Mar 2014
- NFU, no date. Stop Every Drop. <http://www.vmd.defra.gov.uk/pdf/stopeverydrop.pdf>
- Smit, J.H. Policy worker, fertiliser and environment. Ministry of Economic Affairs, The Hague, Netherlands. *pers comm*, Oct 2013.
- Stein-Bachinger, K., Reckling, M. & Granstedt, A. (2013): Ecological Recycling Agriculture - Farming Guidelines, Vol. 1. Järna, Sweden. ISBN 978-3-00-042440-3, www.beras.eu, 136 pp.
- Taylor, M.A. 2011. Sustainable worm control strategies for cattle. Publ. AHDB, Warwick, England.
- VMD, 2012. Veterinary Medicinal Products (dips, injectables, pour-ons, sprays and drenches)

8.6.1 Case Study: Sheep Dipping and Treatments for Scab in UK flocks

Description

The two most pathogenic ectoparasite diseases of sheep in the U.K. are myiasis and soroptic mange commonly described as blowfly strike and sheep scab respectively. For many years both have been well known as major problems in sheep husbandry.

Sheep scab is caused by the presence of the stigmatid mite *Psoroptes ovis* and causes skin inflammation, surface exudation and severe irritation leading to restlessness, biting and scratching of infested areas and wool loss. If left untreated then the infestation may cover as much as 75% of the hosts' body after 40-50 days.

The primary agent of Blowfly strike is the 'greenbottle fly', the adult flies laying their eggs in the sheep wool and the subsequent feeding activity of the larvae at the skin surface rapidly results in tissue damage, resulting in the development of inflamed, abraded or undermined areas of skin.

Since 1995 there has been an increased awareness of the environmental problems associated with the use of sheep dips and as a result, a scheme for Permitting sheep dip disposal sites was introduced under the Groundwater Regulations in 1998. These Authorisations determined the dip disposal areas and limited the volume and frequency that dip could be disposed of to once per site per annum to assist soil biota recovery.

Treatment

There are several ways of providing treatment/protection of the flock which include plunge dipping, showering, injectible and pour-on products. Concerns due to the number of pollution incidents due to the disposal of spent sheep dip in recent years have led to the withdrawal of Synthetic Pyrethroid (SP) dip products with the result that at present only Organophosphate (OP) products are approved for use in plunge dips.

An increasing number of contractors are using OP compounds in sheep showering activities; however, whilst not an "approved" method it is currently accepted until various studies by DEFRA and the Environment Agency are completed.

Once an outbreak of scab is found in the flock, it is advised that treatment of the whole flock as soon as practicable is advised. Once treated, sheep should not be returned to the original pasture for at least 16 days to prevent re-infestation by the scab mites a very basic rule but one that is often forgotten.

Achieved Welfare/Environmental benefits

By introducing a flock management regime to minimise sheep scab being introduced to the whole flock this can be a major help to animal husbandry, help reduce costs and be a major step in eradicating the problem. To this end, the Environment Agency commissioned the production of just such a strategy document in 2002, updated in 2004 entitled "Flock Management and Ectoparasite Control in Sheep" – and this has been taken on board by the industry with the full support of the National Sheep Association with some success.

Appropriate environmental performance indicators

Failure to control the spread of sheep scab particularly can have a major financial impact on the farm business and therefore sustainability. By adopting a preventative strategy, this results in reduced animal welfare issues and improves farm sustainability through reduced costs (veterinary, medicine and labour costs).

Cross-media effects

Failure to control scab infestation can have a negative effect on public perception of the industry particularly where animals affected by the problem are visible to the public. Due to the rising cost of approved products, there were reported incidents where farmers had been using Cypermethrin (SP) products approved for use on vegetables which were a fraction of the sheep- treatment approved products. This resulted in serious water pollution incidents, loss of confidence in the meat products and less than effective treatment of the sheep as well as prosecution of the offenders.

Operational data

Whilst plunge dipping has been the preferred method of control in the past, operator health concerns have been a factor in farmers moving away from this method to the use of SP-based pour-on or injectible products.

Applicability

Whilst sheep scab problems appear to be of lesser importance/frequency in mainland Europe, the adoption of a sheep flock management regime should be adopted by all sheep farmers to minimise impact on flocks

Economics

Minimising the risk of infection of the flock offers significant economic benefit whilst also offering high standards of animal welfare, improved end product and good marketing potential. Cost of applying for an Environmental Permit for disposal of spent sheep dip under the terms of the Environmental Permitting Regulations 2012 is currently £390 (EUR 460) with an annual subsistence fee of £153.90 (EUR 181.00) therefore this can add considerably to farm costs.

Problems can arise where there is a need for a disposal permit after an outbreak has been identified and a need for treatment confirmed as the Environment Agency have up to 4 months to determine the application which is not conducive to dealing with the dip disposal issue in a speedy manner unless the contractor can supply this service.

Driving forces for implementation

- Groundwater Regulations 1998
- Environmental Permitting Regulations 2012
- Customer confidence in a high quality food source and eradication of sheep scab in the U.K. by good husbandry.

Reference organisations

- Environment Agency
- Scottish Environment Protection Agency
- National Sheep Association (NSA)

Reference literature

- Environment Agency Flock Management and Ectoparasite Control in Sheep
- HSE Leaflet AS29 Sheep dipping
- ADAS Construction Guidance Note (CGN) 006
- NSA/EA “Stop every drop” guidance

8.7 Herd/flock profile management

Description

The scope of this BEMP is the reduction of methane emissions from enteric fermentation as well as the maximisation of resource efficiency and maximisation of the final production.

Global analyses have clearly shown that non-CO₂ GHG emissions (CH₄ and N₂O) are inversely related to animal productivity. Higher producing animals consume more feed, produce more manure and emit greater absolute amounts of GHG from enteric fermentation, manure storage, manure application and returns than low-producing animals. Converted per unit of animal product, however, higher-producing animals usually have lower GHG emissions than low-producing animals. Therefore, enhancing animal productivity is usually a successful strategy for mitigating GHG emissions from livestock production systems (Hristov et al., 2013). Refer to Section 8.1.2 for UK 2020 emissions targets by livestock type.

The largest GHG emissions in a beef production system (about 80 percent of the total) occur in the cow-calf phase, when cows and their calves are consuming predominantly forage-based diets (Beauchemin et al., 2011, cited in FAO, 2013).

Poor fertility increases GHG emissions from animal production systems; this is primarily because poor fertility causes livestock producers to maintain more animals per unit of production and keep more replacement animals to maintain herd/flock size (FAO, 2013).

Increased longevity of cow is direct measure of efficiency.

Higher calving rates reduce carbon footprint by increasing output per cow unit, thus "diluting" the GHG footprint over a greater quantity of meat or milk.

Reducing age at first calving is associated with lower feed, enteric fermentation and manure management emissions for first calving heifers.

The impact of improved average lifetime daily gain for beef production systems is to "dilute" the GHG emission association with production. No changes in feed efficiency are assumed in this measure (Crosson, 2012).

Optimised cull age: this can be calculated from growth curves based on daily weight gain vs enteric fermentation to minimise CH₄ for each breed.

Achieved environmental benefits

There are three main efficiency improvement opportunities available for the beef and sheep industries (EBLEX, 2009):

- Increasing the longevity of breeding stock, so the costs of their non-productive rearing phase are spread over a greater weight of meat produced;
- Increasing the fertility efficiency of breeding stock, so they produce more slaughter stock and a greater weight of meat in their productive lives;
- Increasing the feed efficiency of slaughter stock, so they produce more meat per unit of input.

Whilst they all offer worthwhile GHG emission reduction benefits, the extent of their relative value varies widely, with beef modelling showing that industry-wide increases in feeding efficiency through either genetic or nutritional improvement and fertility offer markedly greater benefits than improvements in longevity (Table 8.44).

Table 8.44. GHG emissions savings from UK beef production efficiency improvements (EBLEX 2009)

Area	Change in physical performance	GWP100 Saving (kg CO ₂ eq/kg meat)
Fertility efficiency	+ 0.02 calves/cow/year	0.26
Longevity	+ 1 year productive life	0.07
Feeding efficiency - genetic improvement	+ 5% lifetime growth rate	0.30
Feeding efficiency - feed quality improvement	+ 5% forage energy density (ME)	0.31

Appropriate environmental indicators

Management indicators

- Produce herd/flock profile plan
- Keep flock/herd management records
- Optimise cull age to minimise methane emissions

Performance indicators

- kg CH₄ per kg meat/milk
- daily CH₄ emission (g CH₄/d/animal)
- g CH₄/kg meat/ 1000 L milk
- daily weight gain (kg/d/animal)
- age at first calving
- calving rate

Benchmarks of excellence

In Ireland, for beef cattle, Crosson (2012) suggests:

- Target date of first calving is 24 months;
- Target slaughter of heifers is 20 months;
- Target slaughter of steers is 24 months.

Klimatmärkning för mät, (2010) for beef cattle:

- The highest permissible slaughter age for bulls is 19 months.
- The highest permissible slaughter age for steers and heifers is 25 months.
- For suckler herds, the guideline value for age at first calving is at most 26 months as a herd average. A remedial plan to rectify any deviations from this must be drawn up in consultation with a veterinary surgeon or advisory officer.
- For suckler herds, the guideline value for calving interval is at most 13 months as a herd average. A remedial plan to rectify any deviations from this must be drawn up in consultation with a veterinary surgeon or advisory officer.

Klimatmärkning för mät, (2010) for lamb:

- The highest permissible slaughter age for lambs that are kept for at least 75% of the time on grazing is 190 days. 5% of these lambs may be exempted from the 190 day limit but must be slaughtered at max. 280 days of age.
- The highest permissible slaughter age for lambs that are kept for less than 75% of the time on grazing is 140 days as a herd average.

For verification of the above, the Klimatmärkning för mät, (2010) requires that a herd book approved by a national body must be used on the farm. It must be saved for 3 years.

Cross-media effects

- By increasing productivity and reducing cull ages, there may be less diversity in farming landscape;
- Increased productivity may reduce the possibility for animals to behave according to their specific needs.

Applicability

Herd profile management is applicable to all livestock farming systems.

Economics

Precise management of herd profiles is concordant with production optimisation and profit maximisation. However, there could be some trade-off between optimisation of cull age for GHG mitigation and profit maximisation.

Driving forces for implementation

- Low C farm certification
- Resource efficiency
- Profit maximisation

Reference literature

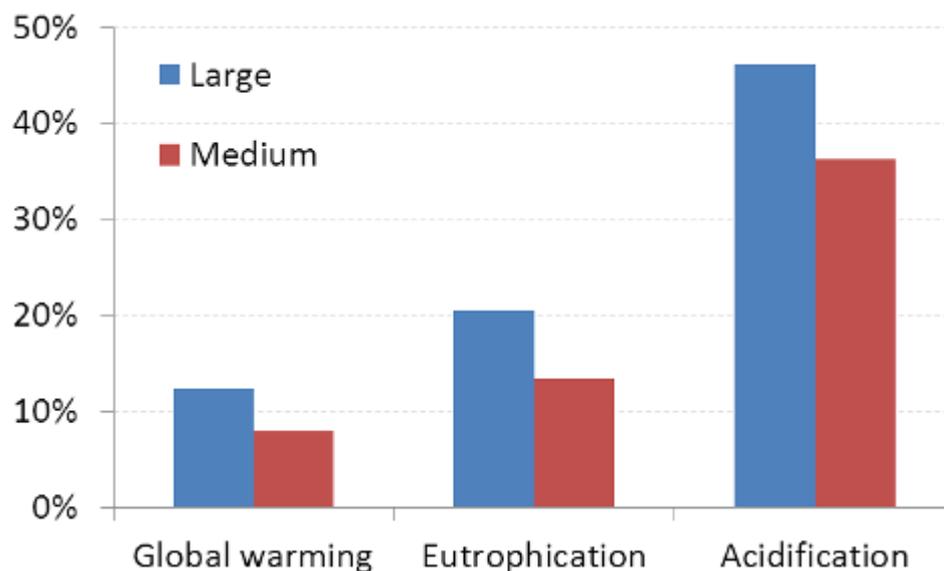
- Beauchemin K.A., Janzen H.H., Little S.M., McAllister T.A., McGinn S.M., 2011. Mitigation of greenhouse gas emissions from beef production in western Canada – Evaluation using farm-based life cycle assessment. *Anim. Feed Sci. Technol.* 166–167, 663–677.
- Crosson P., 2012. Mitigating greenhouse gas emissions from Irish beef cattle systems – the Carbon Navigator. In: Agri Environment Conference 2012 ‘Sustainable Pathways to Food Harvest 2020’ Farmleigh, Dublin. 5 December 2012.
- EBLEX, 2009. *Change in the wind. The English Beef and Sheep Production Roadmap – Phase 1.* AHDB, Warwick, U.K.
- FAO, 2013. Mitigation of greenhouse gas emissions in livestock production: A review of technical options for non-CO₂ emissions. Editors: Gerber, P.J., Henderson, B. and Makkar, H.P.S. Paper 177. FAO, Rome.
- Hristov, A.N. Ott T., Tricarico J., Rotz A., Waghorn G., Adesogan A., Dijkstra J., Montes F., Oh J., Kebreab E., Oosting S.J., Gerber P.J., Henderson B., Makkar H.P., Firkins J.L., 2013. Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. *J. Anim. Sci.* 91, 5095–5113.
- Klimatmärkning för mät (2010). *Criteria for Mitigation of Climate Impact from Food Production and Distribution. Version 2010:3, accepted by the project steering group on October 5th, 2010.* Sweden: Klimatmärkning för mät

9 MANURE MANAGEMENT

Introduction

Manure management in this instance refers to the management of liquid and solid animal excreta in animal housing and storage, which give rise to significant emissions of NH_3 (contributing to acidification and eutrophication, and indirectly to climate change) and CH_4 (contributing to climate change and also ozone formation). The way that manures are managed has implications for other practices like manure spreading, especially in terms of N partitioning across solid and liquid fractions and N fractionation (availability). Animal excreta during grazing is accounted for in Chapter 7. Housing and storage emissions arise during animal housing period, which may be all year around for some systems (pig and poultry systems, confinement dairy systems) or not at all for others (extensive grazing in southern Europe). Manure management is thus especially important for intensive animal production systems where animals are housed for most or all of the year. Best practice guidance for industrial pig and poultry production is provided in the relevant BREF (EC, 2003), a new version of which is currently in preparation (EC, 2013).

Nonetheless, manure management is also important for more extensive dairy and beef production systems in a whole-farm approach. Figure 9.1 shows the contribution of manure management to three major environmental burdens arising from milk production, for a large (10-month per year animal housing) and medium (6-month per year animal housing) size dairy farm assuming storage in a slurry tank with crust. Manure management accounts for 8-12% of dairy farm GHG emissions, 13-20% of eutrophying emissions and 36-46% of acidifying emissions (Figure 9.1).



Source: Bangor University Farm LCA tool (2013).

Figure 9.1. Relative contribution of manure management (housing plus storage) to global warming, eutrophication and acidification burdens on large and average size dairy farms

Ammonia is concentrated in urine and volatilises quickly following excretion. Therefore, NH_3 emissions from housing, before excreta reaches storage areas, can represent a large share of manure management NH_3 emissions. Ammonia volatilisation is usually calculated as fraction of total ammonical N (TAN) in excreta, which typically represents 60% of cattle and sheep excreted N (N_{ex}) and 70% of pig and poultry N_{ex} (Webb and Misselbrook, 2004). Ammonia emission factors for TAN excreted in animal housing can exceed 30%, and are considerably higher than those for TAN excreted by grazing animals (typically 6%) owing to impermeable surface areas indoors leading to prolonged exposure of large urine and dung surface areas to the atmosphere. Depending on the climate and

season, temperatures may also be higher in animal housing than outdoors. Consequently, Webb and Misselbrook (2004) estimate average TAN emission factors of 30% across livestock housing, compared with 20% during storage and 40% following spreading (Table 9.1).

Table 9.1. Ammonia-N emission factor from housing across animal types and manure handling systems calculated for the UK in the NARSES model

Animal type	Manure type	NH ₃ -N emission factor (% TAN)
Cattle general	Slurry	31.0
Cattle excl. calves	Farmyard manure	21.0
Calves	Farmyard manure	6.0
Sheep	Farmyard manure	22.5
Pigs excl. weaners	Slurry	22.5
Weaners	Slurry	15.0
Sows and boars	Farmyard manure	23.5
Fatteners and weaners	Farmyard manure	34.0
Laying hens	Manure	37.0
Pullets	Manure	37.0
	Litter	24.5
Breeders	Manure	24.5
	Litter	26.5
Broilers and turkeys	Litter	26.5

Source: Webb and Misselbrook (2004).

The EIPRO study (EC, 2008) reported that the rate of ammonia emission from manure facilities increases with NH₄ concentration, temperature, pH and evaporation surface area. For EU27 pig farming systems, NH₃ emissions varied from 1.26 kg per pig produced in northern Europe to 1.75 and 2.62 kg NH₃ per pig produced in the eastern and southern systems, respectively, reflecting differences in the N content of feed, manure handling facilities and temperature variations. EC (2008) report the following proven interventions to reduce ammonia losses from animal husbandry:

- Optimised protein feeding by reducing protein (N) supply in feed (Section 8.3)
- Reducing the pH of the liquid manure, which can reduce NH₃ emission from housing and storage by 60-70 % (translating into a 40 % reduction across the manure handling chain, including field application).
- Reduced surface area for liquid manure through improved construction of manure channels
- Cooling of the storage facilities of liquid manure.

In addition, the pig and poultry BREF currently in development (EC, 2013) proposes techniques such as nitrification-denitrification of manures to convert NH₄ into N₂ in areas of high N surplus.

Meanwhile, GWP burdens arising from CH₄ emissions are more strongly dependent on the storage of manure management, on factors including redox conditions, temperature, surface area, storage duration, and the presence of natural (crust) or artificial storage covers.

This chapter selectively focusses on high priority BEMP measures that are widely applicable and particularly well suited to cattle systems. Readers are directed towards the draft BREF for intensive pig and poultry production (EC, 2013) currently under development for detailed BAT on manure management for pig and poultry systems.

Reference literature

- Bangor University, 2013. Farm LCA tool (Styles, D., Gibbons, J., 2013).
- EC, 2003. Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (July 2003). IPTS, Seville.

- EC, 2008. Environmental Improvement Potentials of Meat and Dairy Products. IPTS, Seville.
- EC, 2013. Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry and Pigs. Draft 2 (August, 2013). IPTS, Seville.
- Misselbrook, T.H., Gilhespy, S.L., Cardenas, L.M. (Eds.), 2012. Inventory of Ammonia Emissions from UK Agriculture 2011. DEFRA, London.
- Webb, J., Misselbrook, T.H., 2004. A mass-flow model of ammonia emissions from UK livestock production. Atmospheric Environment 38, 2163–2176.

FINAL DRAFT

9.1 Efficient housing

Description

This BEMP focusses on the reduction of NH₃ emissions from cattle housing in the context of overall manure handling. Implementation of this BEMP should also reduce CH₄ emissions from housing. Detailed guidance on best practice for pig and poultry housing is contained in the draft BREF for those sectors (EC, 2013). This section therefore focusses on cattle systems.

Cattle are typically housed over winter months (November to March in northern Europe) but may be housed all year round in intensive confinement dairy systems. In some regions cattle are housed for part of the day during summer (TFRN, 2011). In some cases, best practice is firstly to minimise the amount of time animals spend indoors, where this is practicable and compatible with good environmental management of grazing (see Section 7.1).

An efficient housing system should balance carefully the trade-offs between the animal welfare and the environmental impacts, when they exist. In other words, in modern efficient housing systems it is a great challenge to balance the reduction or elimination of the polluting effects on the environment with the animal welfare demands (e.g. type of floor, indoor temperature, space per animal). In particular, careful housing design and proper management of the housing system can minimise ammonia emissions (EC, 2013). According to TFRN (2014), abating ammonia emissions from animal housing is based on one or more of the following principles:

- Decreasing the surface area fouled by manure;
- Rapid removal of urine; rapid separation of faeces and urine;
- Decreasing of the air velocity and temperature above the manure;
- Reducing the pH and temperature of the manure;
- Drying manure;
- Removing (scrubbing) ammonia from exhaust air;
- Increased grazing time;

Table 9.2. Measures to reduce NH₃ emissions in cattle housing listed in TFRN (2011)

Category 1 (best practice)	Category 2	Category 3
<ul style="list-style-type: none"> • Grooved floor • Optimal barn climatisation • Grazing 18-22 hours/day 	<ul style="list-style-type: none"> • Chemical scrubbers for ventilation exhaust • Alternative bedding materials • Grazing 12 hours/day 	<ul style="list-style-type: none"> • Scraping and flushing systems

TFRN (2011) stated that straw-based systems producing solid manure for cattle are not likely to emit less NH₃ in the animal houses than slurry-based systems, and usually lead to higher N₂O and N₂ losses via (de)nitrification. Although solid manure management can lead to lower NH₃ emissions after low-efficiency field application, there are fewer efficient spreading options for solid manure than for slurry. TFRN (2011) emphasised that measures to reduce NH₃ emissions during housing should consider implications for emissions across all stages of manure management (Table 9.2).

Solid flat concrete floors are favoured as they can easily be swept clean to minimise volatilisation. Separation of urine and faeces in the animal housing can reduce housing emissions of NH₃ (see Section 9.3). On the other hand, slatted floors reduce the amount of urine, which is exposed to atmosphere.

Moreover, it should be assured that a perfect balance between animal welfare, environmental impacts and economics is maintained.

Newell-Price et al. (2011) evaluated a number of best practice measures in the ADAS best practice manual (Table 9.3).

Table 9.3. Measures described in ADAS best practice manual related to animal housing

Measure	Description
Increase scraping frequency in dairy cow cubicle housing	Increase the number of times that cubicle passages are scraped from twice to three (or more) times per day.
Additional targeted straw-bedding for cattle housing	Add 25% extra straw bedding to the cattle house and target the additional straw to 'wetter/dirtier' areas of the house.
Washing down dairy cow collecting yards	Dairy cows are 'collected' on concrete yard areas prior to milking. These areas are usually scraped at least once per day to remove excreta. This method involves pressure washing (or hosing and brushing) of the yards immediately following dairy cow use to more effectively remove the excreta.
Out-wintering of cattle on woodchip stand-off pads	For cattle, as an alternative to winter housing in a building, construct purpose-built woodchip pads (including an impermeable liner and drainage collection system), with a feeding area.
Part-slatted floor design for cattle housing	Replace fully-slatted floors, with a part-slatted floor, including domed solid floor area and beneath-slat slurry storage with sloping sides.
Install air-scrubbers or biotrickling filters to mechanically ventilated cattle housing	Treat exhaust air from mechanically-ventilated pig/cattle housing, using acid scrubbers or biotrickling filters, to remove NH ₃ .
Convert caged laying hen housing from deep-pit storage to belt manure removal	In a deep-pit storage system, manure from laying hens drops in to a pit below the tiered cages where it is stored for a period (of months) prior to removal. This is replaced by a series of belts below each tier of cages, which remove manure from the house (usually on a weekly basis).
More frequent manure removal from laying hen housing with belt clean systems	Laying hen houses with manure belts typically operate weekly manure removal. This method increases the frequency of manure removal to twice weekly.
<i>Source: Newell-Price et al. (2011)</i>	

Achieved environmental benefits

Ammonia emissions

Table 9.4 summarises NH₃ emissions and abatement potential for measures outlined in TFRN (2011). Alongside various housing design measures, two contrasting strategies can lead to large NH₃ reductions:

- high tech housing with ventilation control and chemical scrubbers (possibly applicable to a small number of very intensive confinement dairy systems)
- extended grazing (more widely applicable, where weather, soil conditions and grass quality allow)

Table 9.4. Ammonia emissions and abatement potential for different housing systems/strategies

Housing type	NH ₃ emissions (kg per cow per year)	Abatement (relative to cubicle house)
Grooved floor*	9	25–46%
Optimal barn climatisation*	9.6	20%
Chemical scrubbers for ventilation exhaust	1.2	70–95%
Grazing 12 hours per day	10.8	10%
Grazing 18 hours per day*	8.4	30%
Grazing 22 hours per day*	6.0	50%

Housing type	NH ₃ emissions (kg per cow per year)	Abatement (relative to cubicle house)
New or largely rebuilt cattle housing**		1-20%
New and largely rebuilt broiler housing**		1-15%
Existing poultry housing on farms with > 40,000 poultry**		0-3%
*TFRN (2011) "category 1" best practice techniques, Based on floor area of 4–4.5 m ² per animal and grazing season of c.200 days ** Bittman et al., (2014) <i>Source:</i> TFRN (2011); Bittman et al., (2014)		

Total annual emissions from dairy systems may be reduced by up to 50% with nearly all-day grazing, compared with animals that are fully confined. However, the amount of emission reduction depends on the daily grazing time and the cleanliness of the housing (Table 9.4) (TFRN, 2011).

Overview

The ADAS best practice user manual provides an overview of emissions changes for different management measures relevant to this BEMP (Table 9. 5).

Table 9. 5. Changes in emissions to air and water for measures recommended in Newell-Price et al. (2011)

	Nitrate	Nitrite	Ammonium	Particulates	Solubles	Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Increase scraping frequency in dairy cow cubicle housing	↑	↑	↑	~	~	~	~	~	↓	↑	~	↑
Additional targeted straw-bedding for cattle housing	↓	↓	↓	~	~	~						
Washing down dairy cow collecting yards	↑	↑	↑	~	~	~	~	~	↓↓	↑	~	↑
Out-wintering of cattle on woodchip stand-off pads	↓	↓	↓	↓	↓	~	↓	↓	(↓↓)	(↓)	(↓)	~
Convert caged laying hen housing from deep-pit storage to belt manure removal	↑	↑	↑	~	~	~	~	~	↓↓	↑	↓	~
More frequent manure removal from laying hen housing with belt clean systems	↑	↑	↑	~	~	~	~	~	↓↓	↑	~	↑
<i>Source: Newell-Price et al. (2011)</i>												

Appropriate environmental performance indicators

Environmental performance indicators

The two main environmental performance indicators for this technique are:

- % TAN excreted by animals emitted as NH₃ from housing
- kg NH₃ emitted per cow place or per livestock unit per year

These indicators feed into farm level NUE and N surplus indicators (Section 8.2).

Management indicators

The following management indicators summarise best practice:

- Minimise time indoors (BEMP 7.1)
- Install grooved floors and automated floor scrapers
- Install barn ventilation (and ammonia scrubbers in exhaust system for intensive pig/poultry systems)
- Minimise time between excretion and removal to storage areas
- The number of days per year of grazing (Section 7.1) is also a relevant indicator with respect to minimising indoor excreta.

Cross media effects

Where NH₃ emissions are reduced from housing, it is important minimize downstream losses of the conserved NH₃ during storage and spreading (TFRN, 2011), through best practice in storage (section 9.2 and 9.3) and application (section 9.6 and 9.7).

Although outdoor grazing can reduce housing and storage emissions, and overall emissions for typical dairy and beef farms, it rules out a number of high-tech opportunities for efficient nutrient cycling in intensive systems. TFRN (2011) note that in some cases grazing can contribute to increased pathogen and/or nutrient loading to surface waters.

There is a conflict between minimising the soiled floor area and therefore NH₃ emissions by restricting animal movement (“tied” systems), and maintaining high standards of animal welfare (TFRN, 2011).

Operational data

The following information is extracted and summarised from TFRN (2011) in relation to implementation of best practice measures.

Grooved floors with “toothed” scrapers running over them should be equipped with perforations to allow drainage of urine. This results in a clean, low-emission floor surface with good traction for cattle to prevent slipping.

In houses with traditional slats, optimal barn climatisation with roof insulation and/or automatically controlled natural ventilation (e.g. opening louvres) reduces NH₃ emissions by reducing maximum summer temperatures whilst avoiding high air velocities.

Though emissions from grazing will increase the emissions from animal housing systems decrease much more, provided surfaces in the house are clean while the animals are grazing outside.

Applicability

High capital cost measures such as chemical scrubbing may be applicable in large confinement dairy systems, but not in typical dairy and beef systems.

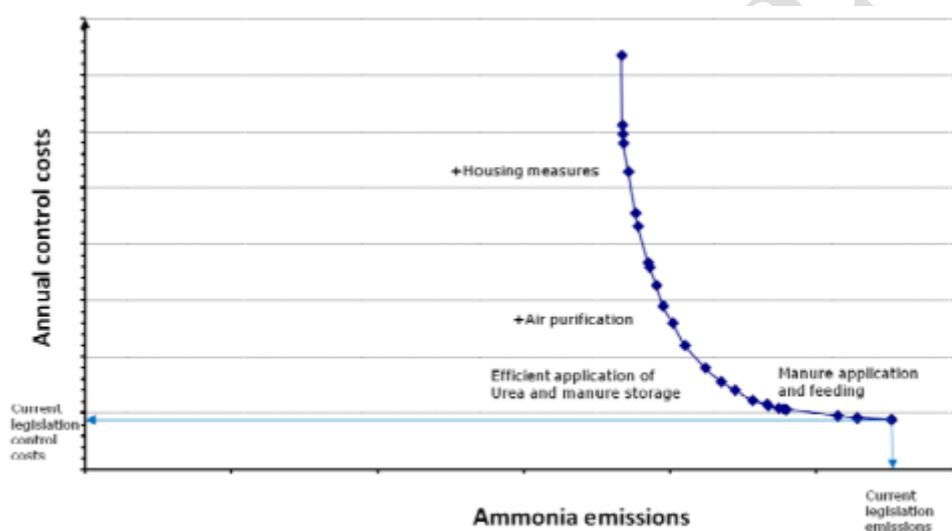
Extended grazing is more widely applicable to dairy and beef systems where weather and soil conditions and grass quality allow (see section 7.1).

These measures can be cost-effectively implemented when building new housing, or heavily renovating existing housing.

Economics

Ammonia abatement costs

Winiwarter et al. (2011) present median, minimum and maximum NH₃-N abatement costs for housing options for dairy cattle of 30.29, 10.58 and 58.42 €, respectively. These values are high compared with a maximum potential benefit to the farmer of 1.06 €/kg conserved N (avoided fertiliser cost), and compared with other NH₃ abatement measures (Figure 9.2). Thus, housing measures are driven by regulation and environmental responsibility rather than economics.



Source: Klimont and Winiwarter (2011).

Figure 9.2. Indicative ammonia abatement cost curve

Farm level costs

Table 9.6 summarises estimated costs for implementation of relevant best practices measures across typical UK farm types, from the ADAS best practice manual (Newell-Price et al., 2011).

Table 9.6. Estimated net cost for different farm types to implement best practice measures

	Dairy	Grazing LFA	Grazing Low	Mixed	In Pigs	Out Pigs	Poultry
	€ per farm per year						
Increase scraping frequency in dairy cow cubicle housing	6,500			2,700			
Additional targeted straw-bedding for cattle housing	800	1,400	1,700	1,000			
Washing down dairy cow collecting yards	8,800			1,700			
Out-wintering of cattle on woodchip stand-off pads	8,800	3,000	3,500	3,300			
Convert caged laying hen housing							17,700

	Dairy	Grazing LFA	Grazing Low	Mixed	In Pigs	Out Pigs	Poultry
from deep-pit storage to belt manure removal							
More frequent manure removal from laying hen housing with belt clean systems							300
<i>Source:</i> Newell-Price et al. (2011)							

Additionally, it should be also mentioned that the animal welfare plays a key role in the economics of the farmer. Therefore, in order for the farmers to achieve an efficient animal housing, they should properly balance the profits with the animal welfare (Figure 9.3). Initially, the farmer should identify the 'hidden' costs and benefits of different farm-level decisions and secondly to understand the 'animals' perspective and simultaneously to integrate this understanding in the business plan of the farm that eventually will be integrated to the farmer decisions (Lawrence and Stott 2009). In particular, for most relevant practical information, farmers should look at BEMP 8.6 (Maintain animal health) where the practical measures for maintaining the animal welfare are summarised.

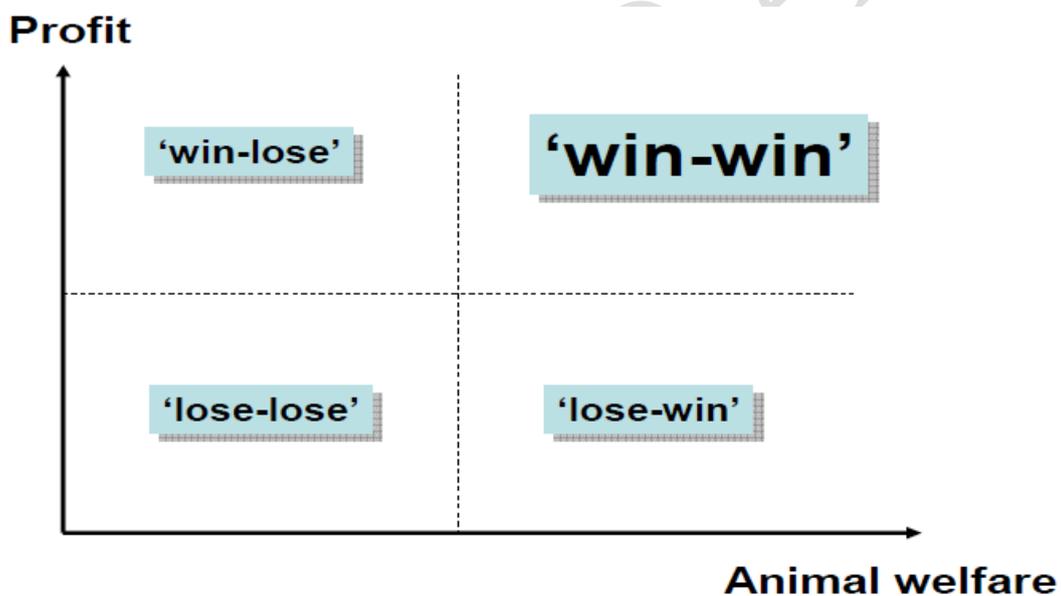


Figure 9.3: The potential trade-offs between animal welfare and profit; 4 groups/areas are illustrated as a combination of win and lose; the 'win-win' group/area is the most efficient and attractive to farmers (Lawrence and Stott 2009)

Table 9.7 presents an overview of the extra cost for the major animal categories for implementing techniques for animal housing expressed as €/kg_{NH₃-N reduced} (Bittman et al., 2014).

Table 9.7. Extra cost for implementing ammonia reduction techniques for animal housing (Bittman et al., 2014)

Category	Extra cost (€/kg NH ₃ -N reduced)
Existing poultry housing farms with > 40,000 poultry	0-3
New or largely rebuilt cattle housing	1-20
New and largely rebuilt layer housing	1-9
New and largely rebuilt broiler housing	1-15

Category	Extra cost (€/kg NH ₃ -N reduced)
New and largely rebuilt animal housing on farms for animals, which are not listed in this table	1-20

Driving forces for implementation

The main driving forces for implementation are the implementation of efficient animal housing systems which balance the animals profit and the animal welfare achieving a sufficient environmental performance.

Reference literature

- Bittman, S., Dedina, M., Howard C.M., Oenema, O., Sutton, M.A., (eds), 2014, Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen, Centre for Ecology and Hydrology, Edinburgh, UK.
- EC, 2003. *Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (July 2003)*. IPTS, Seville.
- EC, (European Commission). 2008, *Environmental Improvement Potentials of Meat and Dairy Products*. IPTS, Seville. Technical Report EUR 23491 EN.
- EC, 2013. *Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry and Pigs*. Draft 2 (August, 2013). IPTS, Seville.
- FNR, 2009. *Biogas-Messprogramm II*. (2nd Edition), Gülzow, Available from: <http://mediathek.fnr.de/broschuren/bioenergie/biogas/biogas-messprogramm-ii-61-biogasanlagen-im-vergleich.html>
- HCC, 2013. *Alternative bedding for livestock publications page*. HCC Wales. Webpage last accessed December 2013: http://hccmpw.org.uk/publications/farming_industry_development/alternative_bedding_for_livestock/
- Klimont, Z., Winiwarter, W., 2011. *Integrated ammonia abatement – Modelling of emission control potentials and costs in GAINS*. IIASA, Laxenburg.
- Lawrence A.B., Stott A. (2009), Profiting from animal welfare: an animal-based perspective, The Oxford Farming Conference, available online at: http://www.fao.org/fileadmin/user_upload/animalwelfare/lawrence%2009.pdf, last accessed 15th of January 2015.
- Newell-Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R., Misselbrook, T.H., 2011. *An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture*. ‘ADAS’ and ‘Rothamsted Research, North Wyke’; Defra Project WQ0106 (Dec. 2011).
- TFRN, 2011. *Draft Guidance document for preventing and abating ammonia emissions from agricultural sources*. WGSR Informal document no. 21.
- TFRN, 2014. Options for ammonia mitigation, Guidance from the UNECE task Force on Reactive Nitrogen, ISBN: 978-1-906698-46-1.
- Winiwarter, W., Klimont, Z., Sutton, M., 2011. *Summary of ammonia abatement costings in GAINS*. Spreadsheet 2b. TFRN.

9.2 Anaerobic digestion of organic waste

Description

Anaerobic digestion is the controlled decomposition of organic materials in a low oxygen environment. Anaerobic digestion (AD) of farm organic “wastes” such as slurries and manures produces biogas that can be captured and used to generate heat and electricity, displacing fossil energy carriers, and converts organic N into TAN that is more readily available for plant uptake, thus potentially enhancing the fertiliser replacement value of organic wastes. Controlled production and capture of methane (CH₄) in biogas through AD can lead to significant reductions in CH₄ emission to the atmosphere from manure storage. Best practice is to store digestate in gas-tight stores, to minimise fugitive emissions of CH₄ and NH₃. Denmark’s Green Growth strategy sets a target for 50 % of livestock manure in Denmark to be used for green energy by 2020.

This BEMP refers to the implementation of on-farm AD to treat slurries, manures and other organic wastes, or the sending of slurries and manures to nearby AD units for digestion. The latter is likely to be a more cost-effective option owing to high capital investment costs, and grid connection costs, etc. Farm cooperation to establish shared AD units may be required.

Anaerobic digestion offers an opportunity to convert agricultural wastes, commercial organic wastes and separated municipal organic wastes into digestate fertiliser that can substitute mineral fertilisers and increase soil organic carbon (Chapter 4). Thus, whilst AD can treat slurries and manures generated on livestock farms, it is applicable to arable and horticulture farms that have large areas of often carbon-depleted soils that would benefit from digestate application. Supplementing slurries and manures with other organic wastes can compensate for reduced feedstock availability during the grazing season. Silage grass and maize may also be co-digested with manure for this purpose, but cultivation of crops for AD is associated with poor life cycle environmental balance and is not best practice (DEFRA, 2013). Best practice includes:

- On-farm AD of slurries and manures generated within livestock farms
- On-farm AD of slurries and manures imported from multiple livestock farms
- On-farm AD of farm, industrial, or municipal organic wastes
- Sending farm organic wastes for treatment in centralised AD plants (provided that digestate is subsequently utilised efficiently as a fertiliser on agricultural land); organic waste that can be used in the feedstock mixture are food waste, other vegetative waste materials, maize, whole-crop wheat or grass silage (or energy crops in general) etc.

However, it should be mentioned that treating within an AD plant only manures and slurries technical problems may arise. In particular, the anaerobic reactor may not work properly affecting the amount and the quality of the biogas produced and also the digestate may not meet the required digestate parameters. Therefore it is necessary to use supplementary vegetative materials/crops (like those where mentioned above) in order to maximise the operational stability of the AD plant, maximise its energy efficiency and eventually ensure the digestate parameters e.g. the C:N ratio.

Achieved environmental benefits

The introduction to AD to a farm system leads to extensive resource flow and emission effects, including fertiliser additional fertiliser replacement, fossil energy carrier replacement and potentially waste management replacement if food waste or slurry from other farms is imported. Thus, expanded boundary farm scale assessment is required to fully capture net environmental changes. The results of a recent DEFRA study are presented below for dairy farms, and a large arable farm receiving slurry from an indoor pig farm.

Dairy farm effects

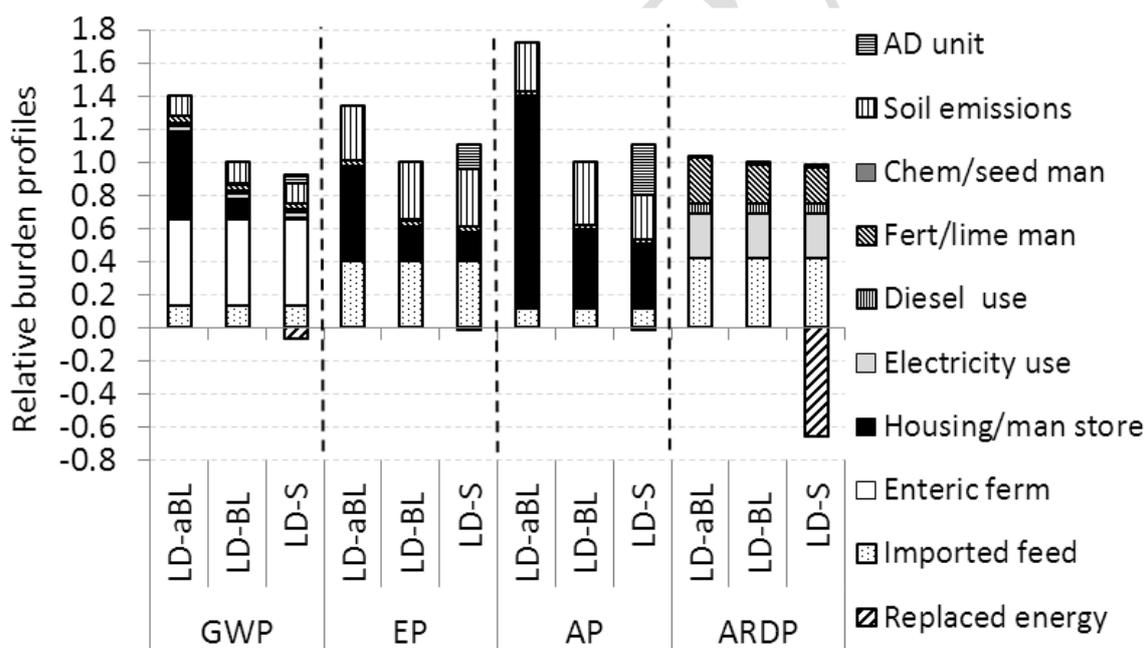
Global warming and resource depletion burdens can be significantly reduced via the introduction of AD to dairy farm systems, especially large dairy farms where CHP units can be installed and electricity exported to the grid to displace fossil-based electricity (Table 9.8).

Table 9.8. Life cycle environmental burden changes arising on a large- and medium- dairy farm following the introduction of AD to treat all slurry and manure (DEFRA, 2013)

	Global warming CO ₂ e	Eutrophication PO ₄ e	Acidification SO ₂ e	Resource depletion MJe
Large dairy (AD + CHP)	-14%	+9%	+10%	-67%
Medium dairy (AD heat only)	-5%	+13%	+9%	-8%

NB: Effect on whole-farm lifecycle burdens following introduction of AD to treat all slurry and manure from a large, 481 milking cow, and medium, 142 milking cow, dairy. Assumes electricity is exported to displace marginal grid electricity generated by natural gas combined cycle turbines for the large dairy farm, and heat is used for dairy farm and farmhouse heating.

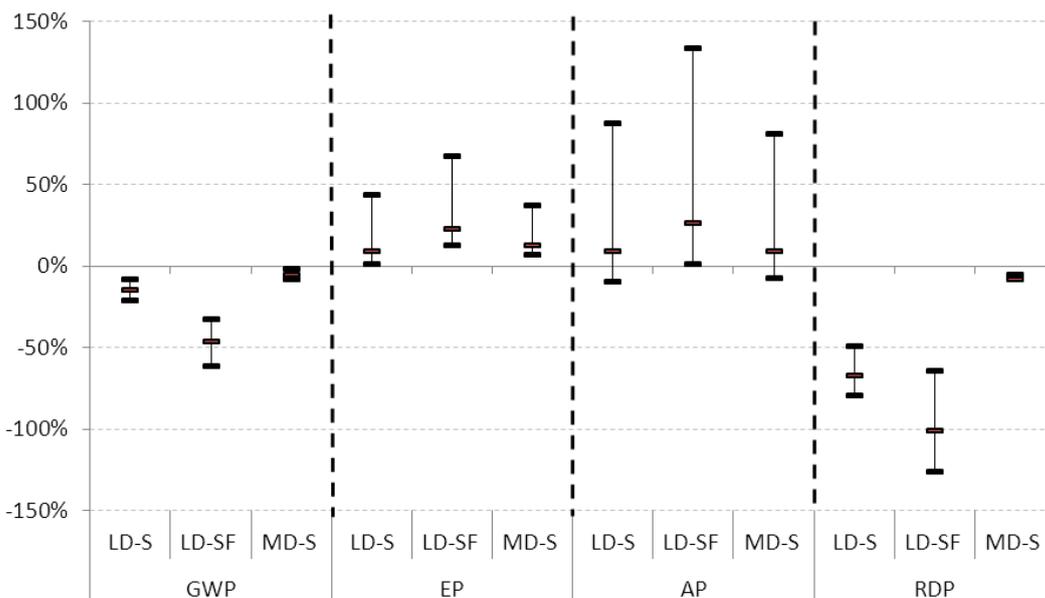
However, eutrophication and acidification burdens may be increased owing to NH₃ emissions from TAN-rich digestate, during storage and application, depending on the counterfactual (pre-existing) slurry storage type (Figure 9.4).



LD-BL = large dairy baseline, with tank storage of slurry.
 LD-aBL = large dairy alternative baseline, with lagoon storage of slurry.
 LD-S = large dairy with a slurry-only AD unit generating heat and electricity.

Figure 9.4. Changes in environmental burdens on a large dairy farm following the introduction of slurry-only AD (open tank digestate storage), against a tank slurry storage (LD-BL) and lagoon slurry storage (LD-aBL) baseline (DEFRA, 2013)

Gas-tight storage of digestate and trailing shoe or injection application of digestate can minimise NH₃ emissions so that eutrophication and acidification burdens can be curtailed, or even reduced, following the introduction of AD to dairy farm systems (Figure 9.5). These results emphasise the need for careful design and management of AD units. Economies of scale mean that good design and management (especially gas-tight digestate storage tanks) is more likely for larger AD units that may require feedstock from multiple farms.



LD-S = large dairy, slurry AD; LD-SF = large dairy, slurry and food waste AD; MD-S = medium dairy, slurry AD for bio-heat only.

Figure 9.5. Range of life cycle environmental burden changes at the farm level for dairy farm AD scenarios, depending on AD design and management factors such as biogas yields and digestate storage (from open lagoon to gas-tight tanks) (DEFRA, 2013)

Arable farm effects

The introduction of AD to treat pig slurry imported to arable farms, and supplementation with food waste as an AD feedstock, can lead to large reductions in global warming and resource depletion burdens (Table 9.9) – through avoided slurry storage emissions, avoided landfill or composting of food waste, avoided fertiliser manufacture, and avoided marginal electricity generation (via combined cycle natural gas turbines). If digestate is separated and the liquid fraction injected into soils, NH₃ emissions are minimised and acidification burdens can also be reduced relative to counterfactual pig slurry management. However, the application of greater quantities of total nutrients (because availability of organic fractions is lower than nutrient availability in replaced mineral fertiliser) results in higher leaching losses and thus in a small increase in the farm eutrophication burden.

Table 9.9. Life cycle environmental burden changes arising on a large arable farm spreading pig slurry following the introduction of AD to treat that pig slurry plus imported food waste (DEFRA, 2013)

	Global warming CO ₂ e	Eutrophication PO ₄ e	Acidification SO ₂ e	Resource depletion MJe
Net change	-329%	+7%	-85%	-135%
Effect on the lifecycle burdens for a 400 ha arable farm following introduction of AD to treat 5,098 m ³ of imported pig slurry plus 6 000 m ³ of imported food waste				

European level environmental benefits

EC (2008) extrapolated the following environmental burden reductions at the EU-27 scale for the introduction of economically-viable AD to treat livestock slurries and manures:

Burden	Change in loading EU-27	Change as % overall meat and dairy burden
GWP	-2.93 x 10 ¹⁰ kg yr ⁻¹	-2.54%
RDP	-3.21 x 10 ¹¹ MJ yr ⁻¹	-3.66%

The above figures were calculated on the basis that AD treatment of each tonne of manure leads to:

- a 1.1 kg reduction in CH₄ emission
- a 0.014 kg reduction in N₂O

It is estimated that dairy and pig farming in the EU-27 comprises 55 million livestock units, producing 830 Tg manure annually, and that 50% of this may be available for biogas production (i.e. excluding solid manure and farms that too small or distant from other larger farms). Assuming 22 m³ biogas generated per Mg manure, an energy content of 23 MJ/m³ biogas and a 37 % efficiency of electricity generation, EC (2008) estimate an electricity production potential of 52 kWh per Mg manure, or 21.6 TWh/year across the EU-27.

Appropriate environmental performance indicators

The most rigorous indicators of environmental performance following the introduction of AD are environmental burden indicators based on LCA of entire farm systems (above), to reflect the multitude of system effects.

Emission factors

Environmental burden changes attributable to the implementation of on-farm AD are largely determined by the following emission factors related to specific management systems (Table 9.10).

Table 9.10. Key emission factors to calculate the environmental performance of AD systems, and environmental benefit relative to pre-existing or alternative manure management

Burden	Aspect	Emission factor
Global warming	Avoided manure storage CH ₄ emissions	Methane conversion factors, per manure storage type and climate (Table 10.17 in IPCC, 2006) (Section 9.4)
	Fugitive CH ₄ emissions from AD unit	% CH ₄ generated, per digestate storage type (operational data, below)
	Avoided manure storage N ₂ O emissions	kg N ₂ O-N per kg N stored, per manure management system (Table 10.21 in IPCC, 2006) (see Section 9.4)
	Avoided manure and fertiliser N ₂ O emissions	kg N ₂ O-N per kg N applied (Table 11.1 in IPCC, 2006)
	Digestate application N ₂ O emissions	kg N ₂ O-N per kg N applied (Table 11.1 in IPCC, 2006)
	Avoided N-fertiliser manufacture GHG emissions	kg CO ₂ e per kg N (see section 5.4)
	Avoided electricity GHG emissions	kg CO ₂ e per kWh electricity displaced (relevant national data: circa 0.5 kg CO ₂ e kWh ⁻¹)
	Avoided heat GHG emissions	kg CO ₂ e per kWh heat displaced (heating fuel specific data: circa 0.3 kg CO ₂ e kWh ⁻¹)
Eutrophication and acidification	(Avoided) manure storage NH ₃ emissions	% TAN, per manure storage type (e.g. Webb and Misselbrook, 2004) (see Section 9.4)
	Fugitive NH ₃ emissions from AD unit	% TAN, per digestate storage type (operational data, below)
	(Avoided) manure spreading NH ₃ emissions	% TAN, per spreading type and timing (e.g. MANNER-NPK or alternative NMP tools) (Section 9.5 and 9.6)
	Digestate spreading NH ₃ emissions	% TAN, per spreading type and timing (e.g. MANNER-NPK or alternative NMP tools)

Nitrate leaching is not likely to be strongly affected following the digestion of manures, and soil N₂O emissions only to the extent that less total N will be applied based on higher N availability in digestate

(assuming accurate nutrient budgeting: Section 5.1). Specific emission factor values for different manure management systems are provided in the sections referred to in Table 9.10. Indicative fugitive emission factors and operational indicators are provided under ‘operational data’, below.

Management indicators

The most relevant management indicators for this technique are listed below:

- Percentage of (%) slurry and manure generated on farm treated in an anaerobic digestion system from which digestate is returned to agricultural land
- Minimisation of fugitive emissions via gas-tight digestate storage and trailing shoe or injection application of digestate to soils
- Certification of digestate according to relevant standards for use as a fertiliser (e.g. PAS 110 or the Biofertiliser Certification Scheme in the UK)
- Percentage of (%) of the co-digestion material (e.g. crops, food, feed) that eventually derives digestate

Cross-media effects

Owing to the elevated TAN content and pH of digestates, emissions of NH₃ can be increased at the farm level through storage and spreading losses (Boulamanti et al., 2013), unless digestates are stored in gas tight tanks (Section 9.4) and spread using efficient methods (Sections 9.6 and 9.7). Good design and management of AD units is essential. Periodic leak tests should be performed on the fermenter and gas-tight digestate storage tanks.

Operational data

Operational data are also presented in the case study immediately after this section (Section 9.2.1).

Feedstock and digestate characteristics

Some key characteristics of AD feedstocks are presented in Table 9.11, assuming manures are sent directly for AD following excretion and not diluted by farmyard runoff or rain into storage tanks.

Table 9.11. Key characteristics of various AD feedstocks and post-AD digestate (BFE, 2011; DEFRA, 2010; DEFRA, 2013; FNR, 2009; FNR, 2010; Liebetrau et al., 2012; WRAP, 2010)

Feedstock	Dry matter	Total N	NH ₄ -N	NH ₄ -N increase	P ₂ O ₅	K ₂ O	Biogas yield		Biogas CH ₄
							Median	Range	
	%	kg/m ³ fm	kg/m ³ fm	% TN	kg/m ³ fm	kg/m ³ fm	m ³ /t fm		%
Dairy slurry	10	4.21	2.31	20	1.8	4	24	20–28	55
Food waste	26	7.1	0.04	80	1.3	3.3	160	140–180	60

Feedstock characteristics will vary depending on factors such as animal diet, housing and bedding systems, intermediate storage duration and type, and local food waste composition. It is important to undertake periodic analyses of feedstock and digestate in order to manage the AD unit correctly and accurately budget nutrients on farm (Sections 5.1 and 8.2). There may be various waste handling regulatory and licensing requirements to comply with if organic wastes are being imported. This can be a significant deterrent to farmers considering the installation of AD. The feedstock mixture depends on the capacity of the AD plant and/or the population of the cows in the farm. Therefore for medium scale plants e.g. 250 dairy cows, the optimum ratio (slurry):(crop waste) is approximately 70:30, for large scale plants (e.g. 500 dairy cows) the related feedstock ratio is estimated 60:40 (NNFCC, 2011).

Energy crops can also be used in order to ensure the operational stability of the AD plant. Several crops can be used from adjacent fields (see also BEMP 5.2 regarding crop rotations schemes for energy crops). Farmers can select various energy crops; for instance the methane yield for wheat (capo variety) ranges from 229 to 245 m³/ha and for rye from 140 to 275 m³/ha (Amon et al., 2007).

AD unit operational performance

Larger AD units are typically designed and managed more efficiently owing to economies of scale in capital investment, so that closed storage tanks are likely for larger units but not small farm units (unless national regulations require this). The electricity conversion efficiency of CHP plants is also likely to be slightly greater for larger units. Some typical performance parameters are displayed in Table 9.12 and Table 9.13, expressed for different levels of design and management.

Table 9.12. Operational performance parameters for small (<250 kWe) farm AD units at different levels of design and management quality

Variable parameter	Best case	Good default	Default	Poor default	Worst case
Storage type	Gas-tight	Closed	Open tank	Large open tank	Lagoon
Storage loss CH ₄ [%]	0	2.5	5	7.5	10
CH ₄ loss in CHP [%]	0.1	0.5	0.5	0.5	1
Storage loss NH ₃ [% NH ₄ in digestate]	0.0	2.0	10.0	16.0	52.0
Fermenter electricity demand*	0.78 MJ per produced Nm ³ biogas				
Fermenter heat demand*	1.64 MJ per produced Nm ³ biogas				
Heat efficiency CHP [%]	43	43	43	43	43
Electricity efficiency CHP [%]	37.5	37.5	37.5	37.5	37.5
*Represents 10% electricity output and 20% heat output in default scenario					
<i>Source:</i> DEFRA (2013), derived from Jungbluth et al. (2007); Voigt (2008), and Misselbrook et al. (2012).					

Table 9.13. Operational performance parameters for large (>250 kWe) farm AD units at different levels of design and management quality

Variable parameter	Best case	Good default	Default	Poor default	Worst case
Storage type	Gas-tight	Well sealed	Closed	Poorly sealed	Open tank
Storage loss CH ₄ [%]	0	1.25	2.5	3.75	5
CH ₄ loss in CHP [%]	0	0.1	0.1	0.1	0.5
Storage loss NH ₃ [% NH ₄ in digestate]	0	1.25	2.5	5	10
Fermenter electricity demand*	0.78 MJ per produced Nm ³ biogas				
Fermenter heat demand*	1.64 MJ per produced Nm ³ biogas				
Heat efficiency CHP [%]	43	43	43	43	43
Electricity efficiency CHP [%]	41	41	41	41	41
*Represents 10% electricity output and 20% heat output in default scenario					
<i>Source:</i> DEFRA (2013), derived from Jungbluth et al. (2007); Voigt (2008), and Misselbrook et al. (2012)					

Factors such as the continuous monitoring and control of the fermentation process and periodic leak inspections of the fermenter and digestate storage tanks can have significant consequences for AD unit environmental performance.

Digestate management

Best practice is to separate digestate into N- and K-rich liquid and P-rich solid fractions (section 9.3) to facilitate optimal NMP. Solid fractions can be applied to increase soil organic matter content (Section 4.2). The liquid fraction should be spread using an efficient technique such as trailing shoe (Section 9.7) or injection (Section 9.6).

It is critical that feedstock and digestate nutrient characteristics are used to inform farm- and field-scale NMP. In particular, sufficient land bank should be available to spread digestate, on the AD farm or neighbouring farms willing to accept digestate. As a rule of thumb, 1 kWe capacity requires 1.2 ha for digestate spreading (Fre-Energy, 2013).

Optimised integration of AD operations into farm systems can lead to significant fertiliser replacement benefits⁴¹.

Applicability

Slurries are better suited to AD than solid manures, which may be composted, although it is possible to feed manures into AD units as a minority feedstock.

The farm types suitable for different AD arrangements are shown in Table 9.14.

Table 9.14. Applicability of different AD options for farm and other organic wastes

AD type	Applicability
On-farm AD of slurries and manures generated on-farm	Large, intensive pig, poultry and dairy farms
On-farm AD of slurries and manures imported from multiple farms	All farms, especially small and medium sized pig, poultry and dairy farms, and arable and horticultural farms (land bank for digestate spreading)
On-farm AD of farm, industrial, or municipal organic wastes	All farms, especially arable and horticultural farms (land bank for digestate spreading)
Centralised AD of organic wastes*	All farms
*Best practice only if digestate is utilised efficiently as a fertiliser on agricultural land	

A key consideration for the economic viability of on-farm AD is scale, related to feedstock availability. Fre-Energy (2013) estimated that a minimum economically-viable AD-CHP plant size of 80 kWe, on farms of at least 100 ha.

The Hub and Pod concept of food waste distribution for AD in smaller farm units, so that digestate can be spread efficiently. Gate fees are likely to be necessary for food waste to be economically viable. They note that heat-only AD units could be viable below 50 kW owing to the low parasitic electrical demand and the synchronicity of heat generation from winter-manure storage with demand.

Economics

Capital investment

Marginal capital investment costs decrease as scale increases. Fre-Energy (2013) provided the following approximate estimates of capital investment costs for different-sized on-farm AD units (

Table 9.15):

⁴¹ Further useful information sources include:

- Anaerobic digestion portal, UK: <http://www.biogas-info.co.uk/index.php/agri>
- FNR, Germany: <http://mediathek.fnr.de/grafiken/daten-und-fakten/bioenergie/biogas.html>
- ValBiom, Belgium: <http://www.valbiom.be/index.php?url=fr/outils/outils-biomethanisation/>

Table 9.15. Capital investment costs for different sized on-farm AD units

Size (kWe CHP output)	Capital investment costs (€)
500	2,120,000
250	1,200,000
160	880,000
80	650,000
<i>Source: Fre-Energy, (2013)</i>	

Fre-Energy estimate that capital investment costs could be reduced by up to 40% if units were mass produced, and suggest that government backed loans would be a cost-effective mechanism to encourage AD. Heat-only use is a lower capital investment option for small farms.

Renewable heat and electricity incentives

Subsidy schemes for renewable electricity and heat operate in many EU member states, often in the form of feed-in-tariffs (FITs). In the UK, FITs range from 0.18 €/kWh for small AD CHP < 250 kWe to 0.11 €/kWh for larger AD CHP units > 500 kWe, and renewable heat incentive (RHI) credits worth up to 0.09 €/kWh can also be claimed for heat used for commercial purposes (excluding domestic farmhouse heating, etc.) and from CHP units below 500 kW thermal capacity.

Food waste

Food waste may be eligible for a gate fee in the region of 10 €/t, though this varies considerably across member states. Consequently, if waste management licensing and logistical issues surrounding pasteurisation can be overcome, then use of food waste can represent an economically attractive option (more likely for large scale, arable farm AD units).

Overview

EC (2008) calculate a net cost for AD, before subsidies, of 3.4 €/t manure, based on generation of 52 kWh electricity at a price of 0.054 €/kWh (2.8 €/t manure income), set against capital costs of 1.8 €/t manure and operating costs of 4.4 €/t manure.

DEFRA (2013) calculated that implementation of AD on a large dairy farm would lead to a reduction of 33,000 € in annual net margin, before subsidies, but an increase of 69,000 € in annual net margin after FIT and RHI subsidies.

Driving forces for implementation

The main driving forces for AD implementation include:

- Economic incentives for renewable heat and electricity generation
- Enhanced N availability from organic N, especially important in NVZs where total N applications are limited
- Fertiliser replacement value of imported feedstocks
- Gate fees for food wastes
- Proper and rational management of manure and other organic waste streams

Reference organisations

A few reference organisations are listed below:

- Anaerobic Digestion and Biogas Association, UK
- deMarke Farm, Netherlands
- Fachagentur Nachwachsende Rohstoffe e.V (FNR), Germany

- Lodge Farm and Fre-Energy (see following case study)
- ValBiom, Belgium

Reference literature

- ADAS, 2013. PLANET page for MANNER NPK. Accessed July 2013: <http://www.planet4farmers.co.uk/Manner>
- Amon T., Amon B., Kryvoruchko V., Machmuler A., Hopfner-Sixt K., Bodiroza V., Hrbek R., Friedel J., Potsch J., Wagenstrisl H., Schreiner M., Zollitsch W. 2007. Methane production through anaerobic digestion of various energy crops grown in sustainable crop rotations. *Bioresource Technology* 98, 3204-3212.
- BFE (Bundesamt für Energie), 2011. *Life Cycle Assessment of Biogas Production from Different Substrates*. BFE, Schlussbericht Switzerland.
- Boulamanti, A.K., Maglio, S.D., Giuntoli, J., Agostini, A., 2013. Influence of different practices on biogas sustainability. *Biomass and Bioenergy* 53, 149-161.
- DEFRA, 2010. *Fertiliser Manual RB209*. UK: TSO. Retrievable at <http://www.defra.gov.uk/publications/2011/03/25/fertiliser-manual-rb209/>
- DEFRA, 2013. *Comparative Life Cycle Assessment of Anaerobic Digestion and other bioenergy options*. Report for project AC0410. Prepared by Bangor University and the Thünen Institute.
- FNR, 2010. *Leitfaden Biogas: Von der Gewinnung zur Nutzung (5th Edition)*. Gülzow, 2010. Available to download from: <http://mediathek.fnr.de/leitfaden-biogas.html>
- FNR, 2013. Biogas data webpage. Last accessed October 2013: <http://mediathek.fnr.de/grafiken/daten-und-fakten/bioenergie/biogas.html>
- Fre-Energy, 2013. Personal communication during farm visit, April 2013.
- IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>
- EC, 2008. *Environmental Improvement Potentials of Meat and Dairy Products*. IPTS, Seville.
- Jungbluth N., Chudacoff M., Dauriat A., Dinkel F., Doka G., Faist Emmenegger M., Gnansounou E., Kljun N., Schleiss K., Spielmann M., Stettler C. and Sutter J., 2007. *Life Cycle Inventories of Bioenergy*. Ecoinvent report No. 17. ESU-services, Uster, CH, retrieved from: www.ecoinvent.org.
- Liebetrau J. et al., 2012. *Emissionsanalyse und Quantifizierung von Stoffflüssen durch Biogasanlagen im Hinblick auf die ökologische Bewertung der landwirtschaftlichen Biogasgewinnung und Inventarisierung der deutschen Landwirtschaft*. Project Report: FKZ: 22023606.
- Misselbrook, T.H., Gilhespy, S.L., Cardenas, L.M. (Eds.), 2012. *Inventory of Ammonia Emissions from UK Agriculture 2011*. DEFRA, London.
- NNFCC, 2011. Farm-scale Anaerobic Digestion Plant Efficiency, available online at: http://www.swarmhub.co.uk/downloads/pdf/farm_scale_ad.pdf, Accessed January 2015.
- Voigt, R., 2008. *Basisdaten zu THG-Bilanzen für Biogas-Prozessketten und Erstellung neuer THG-Bilanzen*. pp.48. [Ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH, Heidelberg](http://www.ifeu.de).
- Webb, J., Misselbrook, T.H., 2004. A mass-flow model of ammonia emissions from UK livestock production. *Atmospheric Environment* 38, 2163–2176.
- WRAP, 2010. *Food Waste Chemical Analysis. Chemical characterisation of food wastes collected from Welsh Local Authorities for supporting decisions related to anaerobic digestion process design and operation*. WRAP, UK.

9.2.1 Dairy farm AD case study: Lodge Farm

Overview

Lodge Farm is an organic dairy farm with 650 dairy cows, each producing approximately 6,000 L milk per year, fed with grass, imported wheat, peas and soya. The farm area comprises 445 ha, mainly grassland with red and white clover used to fix nitrogen. Organic rules require > 60% dry matter feed to be from forage, and the farm complies with an N spreading limit of 170 kg N ha⁻¹ yr⁻¹ (same as NVZ limit). However, the stocking rate (3.6 cows per ha) and milk productivity has been maintained since the transition to organic farming 13 years previously, in part through the use of digested manure with a high TAN.

Cows graze from April to November, with a morning top-up ration of concentrate feed during the grazing season. Indoors, cows are bedded on lime ash and woodchip (sand is the ideal bedding material as it is clean and maintains animal health).

This case study is based on a site visit and personal communication with the farm managers in April 2013. It provides useful technical and practical information on implementation of on-farm AD. However, it does not represent best practice in all aspects.

Best practice	Not best practice
<ul style="list-style-type: none"> • Treatment of all slurry and manure in on-farm AD unit • Import of manure from neighbouring farms for AD • Digestate separation • Application of digestate, and use of clover, to replace mineral N application • Export of electricity generated to grid • Use of heat output for farm operations and farmhouse 	<ul style="list-style-type: none"> • Open lagoon storage of liquid digestate • Open tank storage of slurry pre-digestion

Feedstock management

Lodge Farm's standard agricultural AD licence includes permission to feed milk-based waste and vegetable peelings that originate directly from the field, in addition to animal manures. Currently for Lodge Farm, accepting food waste would require £ 15,000 plus annual costs, plus a lot of administration. An experimental licence allowed 50 t/day food waste to be digested on a research and development basis (no problems were observed with this).

Feedstock comprises:

- 30 t/day cattle slurry
- 4 t/day broiler muck bought in @ £ 10/t (includes wood chip bedding material)

NB: broiler muck c.60% DM compared with c.20% DM in laying-hen muck.

Of the approximately 13 000 tonnes year inputs, approximately 5 % is converted to biogas. Slurry previously went directly to an anaerobic lagoon (below).



Now, it is stored for 2-3 weeks directly adjacent to the cow shed, then pumped 1 km in batches (to maximise efficiency) to the large storage tank (below) next to the digester and stored for a further 2-3 weeks.



It is then mixed with imported broiler manure (from neighbouring farm) in a mixing pit (below) prior to being fed in to the digester.



Previously a long-fibre chopper was used (foreground, picture below), but this is unnecessary and was expensive to buy and operate (50 kW for 2 hours per day, plus pumps requiring 22 kW and 7.5 kW = additional 159 kWh/day). Farm yard manure is not fed into the digester, but is composted for one year prior to spreading.

Fermenter management

There is a 30 day retention time in the fermenter (below). The mixing is achieved via sequential unconfined gas mixing. Compressed gas taken from the top of the tank is blown through individual pipes mounted on a de-gritting arm rotating slowly around the base of the digester. Large gas bubbles rise up through the digester, expanding as they rise. This is the most energy efficient mixing system available and is widely used in the wastewater treatment industry in the UK. Using the rotating de-gritting arm for the compressed gas enable the whole area of the tank to be covered by the mixing, and avoids 72 separate fixed supply pipes. The gas pumps draw 3 kW for 80 seconds out of every 8 – 12 minutes under normal operations.



The de-gritting arm is hydraulically operated and is fitted with “sweeps” that can be activated on the bottom arm. The hydraulic operation is highly efficient, drawing 1 kW compared with a 15-20 kW draw for a conventional motor. Inverted motors are used throughout the system to optimise efficiency and to enable monitoring of system performance via current monitors – an increase in the draw of a motor can be an early indication of vibration and wear, etc. temperature data is also monitored. Consequently, parasitic load is just 7 kW (4% peak output). Critical components are installed in replicate; redundancy minimises downtime and requires a relatively small additional capital investment.

The digester has a single-skin fibreglass roof with an estimated 30 year lifespan. A leak test was procured from a German company to check for leaks in the fibreglass panel seals, and those found were sealed using silicone injected below the leak. A few subsequent leaks developed around the pipe-work and the rotating joint at the top of the digester. Such leaks can be detected through periodic inspections using washing-up liquid.

Digestate becomes stratified within the fermenter, facilitating separation and syphoning-off of mature digestate (often the mid-layer is the most digested). Feedstock can be fed in and digestate removed from different levels, enabling optimisation.

Heat and electricity generation

Vent gas is routed through a conventional boiler to be combusted off. Hydrogen sulphide gas scrubbing is achieved using ferric chloride and injection of air into head-space. 65 ppm H₂S achievable with air-only. CHP generators run OK with 120 ppm, and up to 250 ppm with more frequent oil changes and maintenance.

Two generators are based on six cylinder Perkins diesel engines with spark ignition for the gas (right). Maximum output from the two engines is 160 kWe with 35% electrical efficiency and 40-45% thermal output for a combined efficiency of c. 80%. The goal is for the generators to run for 8000 per year at 85% of their capacity, generating 1,088,000 kWh per year though output has so far been below this level.

The fermenter uses 60 kW of heat, with a further 65 kW used in buildings in winter, reduced to 25 kW in summer with the remainder dumped to an outdoor swimming pool, a further 60 kW heat is dumped throughout the year. Because of the excess heat produced relative to on-site demand, only 75 % of the heat recoverable from the CHP is actually recovered. Further exhaust heat recovery would be possible from the second generator. Enough heat is available for a chicken house.

During the visit, the CHP generators were running on biogas with 62% methane and at 98% capacity. The older engine had 22,000 hours operational time and the newer engine 6,200 hours operational time and 361,000 kWh (average 58 kWe).

Large fans and gaps in the walls allow a through-flow of air to minimise the main safety risk of H₂S fumes. The main danger point for explosions is the air cooler (heat-exchanger) for the incoming gas, where the gas could become present in explosive concentrations through any leaks. In case the CHP generators are down and biogas is produced, it must be routed via a boiler to combust off the methane (below).





Fre-Energy offer service contracts on the units they install for £ 6,000/y, with a minimum load factor of 75%. Telemetry is used to relay information on system performance to Fre-Energy's offices, where performance is checked daily. Two thirds of maintenance costs are for the engines.

Digestate use

Approximately 12,350 tonne digestate is produced annually, with approximately 2,500 tonnes as solids (c.25 %-27% dry matter) (pictured below). The solid fraction varies depending on feedstock. For slurry entering the digester with 8 % dry matter content, approximately half the dry matter remains in digestate. It should be noted that for chicken manure entering the digester with 60 % dry matter content, approximately 40% of the dry matter remains in digestate.



The digestate is separated using the de-gritting mechanism in the digester (solid fraction removed from the bottom). It would be possible to wash the grit, sterilise with waste heat and re-use for animal bedding.

The liquid digestate fraction is pumped into the storage lagoon, where Fre-Energy estimated a methane loss of 5-10%. A further disadvantage of the uncapped lagoon storage is that 2.5 cm of rain translates into £1000 additional spreading cost. Covered storage would require a further £ 120,000 for a 20 m diameter tank with capacity for 2,500 m³ digestate plus 750 m³ head space, although this could be reduced: most methane is likely to be emitted during first few days after leaving the digester, as the temperature cools, so temporary storage could effectively capture more methane and reduce fugitive emissions. This issue is less important for manure where emissions would occur during uncovered storage anyway, but Fre-Energy suggest loss rates of 15-20% for uncovered digestate from crop-only digesters.

Digestate spreading rates limited by the organic cap of 170 kg N ha⁻¹/yr.⁻¹ maximum, and digestate now exported from the farm. Liquid digestate is pumped between the main storage lagoon and a storage tank adjacent to the cow shed 1 km depending on where it is to be spread. The solid digestate fraction is spread on fields reached by road that have lower historical loading with slurry.

Digestate is spread to maximise spreading efficiency – i.e. three spreads at full equipment capacity:

- Mid April
- Mid June
- Mid August to September

Digestate has not yet been analysed since the inclusion of broiler muck in the feedstock. Soils are about to be analysed for nutrient status, and the plan is to analyse three fields per year. So far, digestate application has been prioritised on fields where nutrient demand is inferred through lower yields.

Lodge farm now exports some digestate to neighbouring farms, and aims to sell the liquid fraction for £ 7/t (8.25 €/t) and the solid fraction for £ 24 - £ 30/t (28.25-35.25 €/t).

9.3 Slurry and digestate separation

Description

Slurries, manures and digestates deliver relatively high loads of plant-available P to soils compared with available N, partly owing to the high loss rate of N within animal housing, during storage, and via volatilisation following soil application. Therefore, soils close to animal housing that receive high loadings of these organic fertilisers are often over-loaded with P. It can take a long time for crop off-takes to reduce soil P concentrations back down to optimum levels typically it can take a decade of crop off-take to reduce the soil P index by 1 point.

Excess soil P concentrations represent inefficient use of finite phosphate resources and pose an increased risk of P losses to water – a major driver of freshwater eutrophication. Separation of slurries and digestates can help to target P additions by concentrating P in the solid fraction that can be economically transported further from animal housings. In addition, the organic matter rich solid fraction is useful soil improver that can benefit soils further from animal housing that rarely receive manure inputs (Section 4.2).

Separation of faeces (which contains urease) and urine in animal housing, before storage, reduces hydrolysis of urea and therefore reduces emissions arising during housing, storage and spreading stages of manure management (TFRN, 2011; Burton, 2007; Fanguiro et al., 2008a,b; Møller et al., 2002).

Separation of solid and liquid manure fractions can occur in a pit after exiting animal housing, with a pump to syphon off the liquid fraction. Most N is in the liquid fraction and can be spread nearby for crops, possibly using an umbilical system to minimise compaction. Most P is in solid fractions, and can be transported further (c.85% liquid mass removed) to soils with a lower P index, to soils that would benefit from organic matter additions.

An additional economic benefit of separation is a reduction in the c.15% reduction in volume of slurry (solid fraction removed to manure heap), which allows a smaller storage volume for a given number of animals and storage duration, or a longer storage duration (see Section 9.4).

In general, there are different methods for slurry separation into a nutrient and dry matter rich fraction and a liquid fraction. In particular, there are mechanical screen separators, separation systems based on sedimentation and/or centrifugation, suitable biological treatment systems can be installed and reverse osmosis systems (Sommer, 2002; AgResearch, 2011). The choice of technique depends on the objective of the separation. Therefore the centrifugation is one of the most efficient techniques for the separation of the dry matter and P. However, filtration does not perform best for separating dry matter, N and P. On the other hand the screw press is suitable for the slurry production with high content of dry matter which is then goes for incineration. The decanter centrifuge is the most efficient in retaining P and at the same time producing high dry matter content with low amount of moisture. Nevertheless the performance of the aforementioned separation methods can be improved by using chemical additives. In particular, additives like brown coal, bentonite, zeolite, crystals and efficient microorganisms can be used. Likewise chemical pre-treatments such as flocculation, coagulation and precipitation can be also used in order to improve the separation efficiency (Lichtfouse et al., 2011).

Achieved environmental benefits

Separation of slurry can lead to a range of benefits that are difficult to quantify directly, but that are represented within environmental benefits quantifiable for other BEMPs:

- The liquid fraction can be more easily managed via umbilical systems and injection applicators to deliver N in precise doses to nearby fields, contributing to environmental benefits achievable through precision application (Section 5.3);

- The solid fraction can be delivered to fields further away to soils that:
 - need P additions, contributing to good NMP (Section 5.1);
 - need organic amendments, contributing to good soil structure (Section 4.2);
- Existing slurry storage facilities can hold the liquid fraction for c.15% longer owing to reduced volume, leading to storage benefits outlined in Section 9.4 and precise application timing benefits summarised in Section 5.3;
- Separated liquids have less potential to contaminate grass compared with unseparated slurry (AFBI, undated).

AFBI (undated) note that grass yields per unit of organic N have shown a 25% increase with separated liquid (3mm screen), compared with raw slurry – probably reflecting the higher TAN to organic N ratio in the liquid fraction. In relation to this, the export of fibre rich in less readily available organic N can enable farms in NVZs to achieve higher NUE by delivering a higher fraction of available N within the 170 kg N ha⁻¹ yr⁻¹ threshold.

Appropriate environmental performance indicators

Technical indicators

Technical indicators are explored in more detail under ‘Operational data’, below. Two key parameters are:

- % dry matter in solid fraction
- % increase in nutrient concentrations in respective fractions

Management indicators

- % slurry generated on dairy, pig and poultry farms that is separated prior to storage
- % digestate from AD plants that is separated prior to storage
- Targeted application of liquid and solid fraction in accordance with crop nutrient and soil organic matter requirements

Performance indicators

Key indicators of whole-farm resource efficiency that should reflect benefits of this technique include:

- Nutrient surplus (N and P)
- Nutrient use efficiency (N and P)

Cross-media effects

Electricity use of up to 4 kWh per tonne of slurry results in resource depletion, GHG emissions and acidifying gas emissions associated with electricity generation. In the UK, a lifecycle carbon footprint of 0.59 kg CO₂e per kWh consumed electricity translates into 2.36 kg CO₂e per tonne slurry in the worst case for centrifuge separators, but just 0.59 kg CO₂e per tonne slurry for a screw press.

These effects are significant but likely to be smaller than the benefits of more efficient storage and NMP enabled by separation, considering fertiliser-N has an upstream (production) carbon footprint of approximately 6 kg CO₂e kg⁻¹ N and P₂O₅ a production carbon footprint of approximately 2 kg CO₂e kg⁻¹. Improved NMP of slurry arising from separation could easily increase N and P utilisation in the order of 1 kg each per tonne slurry.

Operational data

The main technical characteristics of the slurry separation techniques are presented in Table 9.16 below (Al Seadi, undated), while technical data from pig and cattle farms are presented in Table 9.17 (Sindhoj et al., 2013).

Table 9.16. Technical characteristics of the slurry separation techniques (Al Seadi, undated)

Slurry separation technique	Each technique separates:		
	Dry matter/fibres	Phosphorus	Nitrogen
Strainer	+	-	-
Sedimentation	+	-	-
Screw press	+	Partly	-
Decanter centrifuge	+	Partly	-
Ammonia stripping	-	-	+
Ultra centrifuge	Partly	+	-
Flocculation/chemical precipitation	-	+	+
Evaporation	-	+	Partly
Membrane technologies e.g. reverse osmosis	-	+	+

Table 9.17. Slurry mechanical separation characteristics; data from pig and cattle farms in Finland and Sweden (Sindhoj et al., 2013)

Processing technology	Type of farm (country)	Processing capacity	Drivers for implementation	Processing costs (£/m ³ y ⁻¹)	Incomes and savings not included
Screw press	Pig farm (FI), 600 sows, 2,300 finishers per year	Max capacity 25 m ³ /hour pig slurry. Farm generates 1,700 m ³ /year	Allocating of manure nutrients on farm, reduce odour, improved properties	2.11	Saved logistic costs, better allocation of nutrients on farm
Centrifuge	Dairy farm with biogas (SE), 450 milking cows	~20,000 m ³ digestate per year	Reduce volume of liquid digestate, lower P concentration in the liquid fraction	1.62	Less costs for liquid manure handling (but costs for solids)

Integration into farm operations

According to AFBI (undated), the mechanical separation operations of slurry in Northern Ireland Dairy Farms meet the following listed principles:

- Unless faeces and urine are separated out directly in animal housing via separate collection systems, a reception tank for the mixed slurry may need to be installed from which separation can occur.
- The separation system needs to be carefully integrated into farm operations, in terms of infrastructure (to minimise costs associated with restructuring or construction work) and in terms of soil and nutrient management.

Technical separation efficiencies

Table 9.18 summarises some key features of different slurry separation techniques.

Table 9.18. Some technical and economic features of different slurry separation techniques

Technique	Capacity (m ³ /h)	Capital cost (€)	P separation efficiency (%)	Dry matter content in solid phase (%)	Energy consumption kWh/t slurry
Sieve bow Brushed screen Drum filer	10-20	10-30	<<30	<25	0.5
Screw augurpress Filter press	4-15	>25	20-40	25-35	1.0
Sieve belt press	4-30	>70	50-75	20-25	0.1
Centrifuge decanter	4-100	>100	60-70	25-30	4.0

NB: Direct separation energy requirement considered only (peripheral equipment energy requirements excluded)
 Source: EC (2013).

Case Study: Slurry separator installation, Fforest Farm, Wales.

Fforest Farm is a 700 acre (283 ha) dairy farm with some 240 cows with around 100 beef cattle that are kept in groups from calves to 26 months before slaughter. Dairy cattle are housed over winter in cubicles with automatic scrapers scraping slurry to channels and subsequently to a reception pit from where it is pumped to a separator. The liquid fraction is then gravity fed to a lined earth banked lagoon which was installed in 2011 at the same time as the separator. The former “tin tank” slurry store was considered to be in poor condition and did not have the capacity required for the 5 months storage as part of the NVZ Action Programme Measures. This has however been retained, in part, to act as a store for the solid fraction from the separator prior to moving to field heaps where it is used on forage ground (Figure 9.6).

The farm is located at around 180 m above sea level with land rising to 380 m, much of the land being in small blocks some of which are located some 7 km distant from the main holding. In view of the distances involved, it was considered more practical and efficient to carry the solid fraction to outlying land, particularly as this was principally maize/fodder ground where there was a higher P & K requirement and where N could be applied through inorganic fertiliser (Figure 9.7).

The liquid fraction is spread by contractor at a rate of 30,000 gallons (136 m³) per hour, and covers an area of 10 acres (4 ha) per hour using a dribble bar applicator. Cost for 2 days spreading is generally £ 4,000 (4,700 €). Slurry is applied after each silage cut as well as on grazing land with a 17 day rotation on the grazing land. The cost of the slurry system was £ 40,000 (47,000 €), comprising £ 24,000 (28,235 €) for the separator and £16 000 (18,823 €) for the lined lagoon.



Figure 9.6. Slurry separator showing the dry pressed material (centre) with pipeline carrying liquid fraction to slurry lagoon (out of view).



Figure 9.7. Slurry separator press.

Benefits realised:

- One of the issues affecting grazing was that P&K values on some of the grazing land close to the Home Farm were too high and cattle were rejecting the sward. By applying the liquid fraction only, the indices are dropping and rejection is no longer a problem.
- P & K nutrient value is now being targeted at the forage Maize, Winter Wheat and Spring Barley crops.
- The applied liquid fraction from the lagoon is quickly absorbed into the ground, plant response time is quicker.
- There is minimal slurry coating on the grass and animals will happily graze fields the day after spreading activities
- The slurry spreading can be undertaken using an umbilical system which avoids traffic through the nearby village and reduces both fuel costs and machinery/tyre wear
- Soil type of the land is predominantly clay and does not lend itself to heavy farm machinery traffic. The umbilical system appears to be the optimum for this type of land.
- From soil analysis undertaken, several grazing fields were found to have elevated P & K levels and as a result cattle would not readily graze this land. Since the installation of the separator, the P & K constituents have effectively been reduced in the liquid slurry resulting in a more palatable sward.
- Due to improved effluent management and revised spreading activities the amount of fertiliser purchased in 2012 was reduced by 28 Tonnes. Cost saving $28 \times \text{£ } 320 = \text{£ } 8,960$ (10,541 €)
- Targeted P & K applications have seen improved yields of Winter Wheat by 0.5 tonnes/ha
- Solids (fibre) is now transported to forage fields rather than unseparated slurry, resulting in more efficient transport and reduced costs for fuel, tyres, labour and fertiliser.
- Reduced soil compaction
- Reduced soil structure damage
- Reduced risk of Cross Compliance breach - Soils
- Reduced Ammonia emissions
- Improved N supply to crop
- Reduced impact on neighbours- transport and odour

- No need for stirring slurry lagoon prior to emptying- previous system required stirring for up to 24 hours

The motor for the slurry pump to the separator has a high power requirement (11 kW) with a further 5 kW power requirement for the screw press pump and this is currently sourced from the National Grid. The slurry pump is rated so highly due to the nature and volume of slurry entering the system particularly over the winter housing period and due consideration must be given to pump selection.

Throughput of slurry through the separator is up to 65 m³/h. The reception pit has capacity for 48 hours slurry production- if motor cannot be repaired/replaced then contingency plan is to tanker from reception pit to slurry lagoon. Other key operational data:

- Slurry store has capacity for 5 months slurry production without separation
- Separation claimed to reduce slurry volume by up to 20%
- Planning Permission required for lagoon but not for separator
- Farm lies within AONB so planning permission usually comes with stringent conditions and there is no likelihood of permission being granted for a wind turbine to offset energy costs
- NVZ Action Programme Measures had to be complied with for new storage facility
- Slurry store had to be compliant with the Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulations (Wales) 2010
- Slurry transport to reception pit is by gravity(slurry channels) which determined siting of the plant
- Utilisation of the existing reception pit and former slurry store reduced costs
- Waste minimisation programme should be undertaken to minimise the amount of clean water entering the slurry system to minimise operation costs
- Slurry store construction had to comply with the SSAFO Regulations

Applicability

Slurry separation is applicable for housed dairy, pig and poultry farms where slurry is produced. The potential reduction in slurry volume would be particularly beneficial where there is limited availability for additional slurry storage, and for farms in NVZ.

Slurry separation is applicable and widely used at biogas production units for separation of anaerobic digestate.

Slurry separation is not applicable to farms where most manure is managed in solid manure systems, such as deep-bedding (many beef-cattle and sheep farms).

Slurry separation may not be economically viable for small farms.

Economics

For the example of Fforest Farm in Wales (above), capital costs of £ 24,000 for the separator and £ 16,000 for the lagoon translated into £ 167 (196 €) per cow. Fertiliser cost savings of £ 8,960 per year translate into a simple payback of 4.5 years.

Grant schemes may be available to encourage framers to install slurry separators, as in the UK (Williams, pers. comm., 2013).

Table 9.19 summarises some key economic data regarding capital investment, depreciation and operating and maintenance costs related to each m³ slurry treated, for different separation techniques.

Table 9.19. Capital and operating costs for different slurry separation technologies

Technique	Investment	Depreciation	Electricity	Maintenance	Additives	Total
€ per treated m³ liquid slurry						
Sieve, screen, drum, etc.	25 000	0.5	0.06	0.25	0	0.81
Screw, augur press	30 000	0.6	0.12	0.30	0	1.02
Sieve belt press	70 000	1.40	0.01	0.70	1.00	3.11
Centrifuge	100 000	2.00	0.48	1.00	Option	2.38
NB: Assumes 0.12 €/kWh electricity						
Source: EC (2013)						

Newell-Price et al. (2011) estimate typical annual costs at 3,000 € and 5,400 € for dairy and pig farms, respectively.

In general, the different separation methods have different investment and operational costs. Given this variability in the costs, as a general remark it should be concluded that sedimentation, mechanical screen separators and centrifugation are simple techniques that are cost effective. On the other hand, biological treatments, evaporation, ultrafiltration and reverse osmosis are more complex methods and increase highly the investment cost (Sommer, 2002).

Driving forces for implementation

The following driving forces were noted by the farmer from the above case study farm:

- Efficient use of nutrients in slurry, reducing fertiliser costs
- Reduced labour and machinery costs compared with previous non-separated slurry management
- Enables longer duration of liquid slurry storage, enabling compliance with NVZ requirement (storage capacity and non-spreading periods)
- A low-cost and easily managed effluent management system compared with e.g. AD (though complementary to AD)
- Allows for soil improvement through targeted application of organic matter in the solid fraction

Reference organisations

- Fforest Farm, Wales,

Reference literature

- AFBI, undated. *Mechanical Separation of Slurry on Northern Ireland Dairy Farms. Technical Note*. DARD, Northern Ireland.
- AgResearch (2011), *Characterising dairy manures and slurries*, Envirolink tools report, publication code: AGRX0901, prepared by: Houlbrooke D., Longhurst B., Orchiston T. and Muirhead R., October.
- Al Seadi T. undated. *Separation of slurry – a potential option for the animal production sector*, University of Southern Denmark, available online at: http://www.staengineering.it/argomenti/reflui_zoot/Teodorita_Al_Seadi%5B1%5D.pdf, accessed January 2015.
- Burton, C.H., 2007. The potential contribution of separation technologies to the management of livestock manure. *Livestock Science* 112, 208–216.

- EC, 2013. *Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry and Pigs. Draft 2 (August, 2013)*. IPTS, Seville.
- Fanguero, D., Coutinho, J., Chadwick, D., Moreira, N., Trindade, H., 2008a. Effect of cattle slurry separation on greenhouse gas and ammonia emissions during storage. *Journal of Environmental Quality* 37, 2322–2331.
- Fanguero, D., Pereira, J., Chadwick, D., Coutinho, J., Moreira, N., Trindade, H., 2008b. Laboratory assessment of the effect of cattle slurry pre-treatment on organic N degradation after soil application and N₂O and N₂ emissions. *Nutrient Cycling in Agroecosystems* 80, 107–120.
- Lichtfouse E., Hamelin M., Navarette M. and Debaeke P. 2011. Sustainable Agriculture Volume 2, e-ISBN 978-94-007-0394-0.
- Møller, H.B., Sommer, S.G., Ahring, B.K., 2002. Separation efficiency and particle size distribution in relation to manure type and storage conditions. *Bioresource Technology* 85, 189–196.
- Newell-Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R., Misselbrook, T.H., 2011. *An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture*. ‘ADAS’ and ‘Rothamsted Research, North Wyke’; Defra Project WQ0106 (Dec. 2011).
- Sindhøj E., Alitalo A., Kassi P., Sipilä I., Tamm K., Rodhe L. 2013. Examples of implementing manure processing technologies at the farm level in the Baltic Sea Region. International Conference on manure management and valorization, poster presentation, December 5-6, Bruges, Belgium.
- Sommer S. (2002). Solid liquid separation of livestock slurry. HELCOM 23/2002 Seminar. Available online at: http://agrienvarchive.ca/bioenergy/download/S1-Sommer_DK.pdf. Accessed January 2015.
- TFRN, 2011. *Draft Guidance document for preventing and abating ammonia emissions from agricultural sources*. WGSR Informal document no. 21.
- Welsh Assembly Government, 2010. *The Water Resources (Control of Pollution) (Silage, Slurry and Agricultural Fuel Oil) Regulations 2010 (SSAFO)*. WAG, 2010.
- Williams, J. (ADAS advisor), personal communication March 2013.

9.4 Appropriate slurry processing and storage systems

Description

Before the use of the slurry e.g. in the field, proper process techniques must be applied. For farmers, the loss of NH_4^+ via the NH_3 emissions from animal housing, manure stores and applied manure will reduce the fertiliser value and amount of the animal manure. Therefore the implementation of a technique that reduces the NH_3 emissions and in parallel maintains a high predictability of the N fertiliser value of manure may contribute to reduce the oversupply of N to crops (Figure 9.8). Therefore the acidification of slurry e.g. in pig houses will decrease the amount of NH_3 emissions from the animal house, the store and after having applied the slurry to the land (Kai et al., 2008).

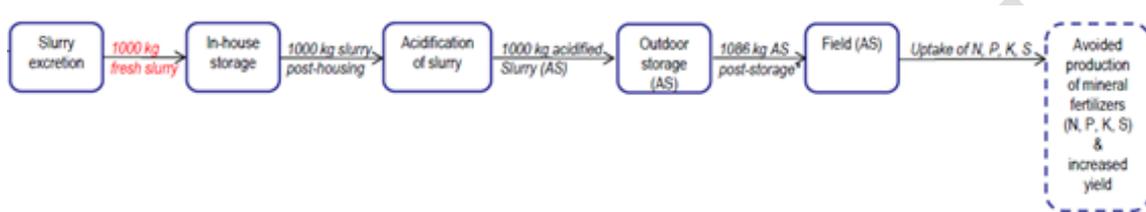


Figure 9.8. Flowchart of the (pig) slurry acidification technique (Hamelin, 2010)

In particular, the application of an acidic reagent results to a lower value of pH (Figure 9.9). This lower pH value contributes to the inactivation of pathogens and/or helps to reduce the ammonia emissions. This process is called slurry acidification and its objective is to reduce the pH value (as it was previously mentioned) as well as to increase the concentration of ammonium ($\text{NH}_4\text{-N}$) at the expense of ammonia (NH_3). Therefore applying this technique a significant reduction in ammonia emissions is achieved.



Figure 9.9. Slurry acidification; tank for sulphuric acid (picture from: <http://www.jhstaldservice.dk>)

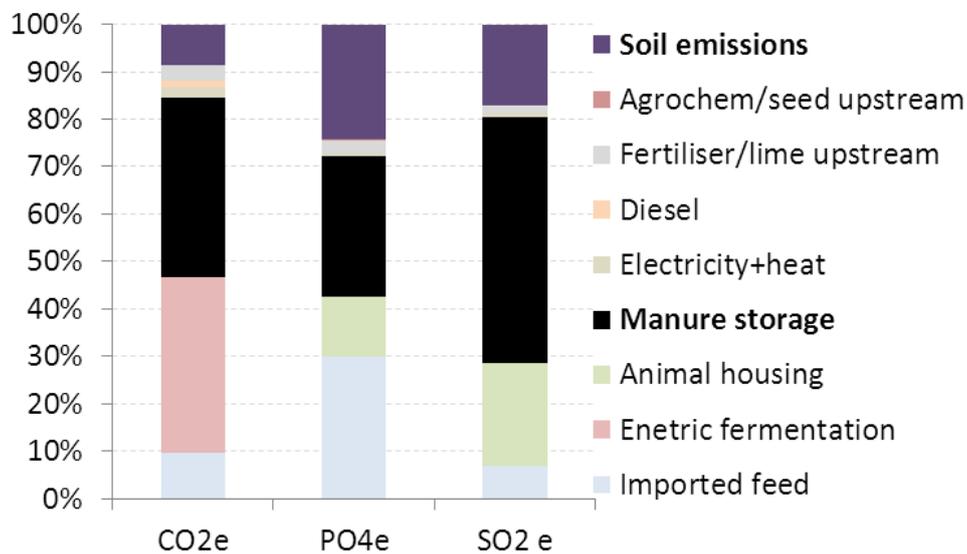
On the other hand, solidification/stabilisation techniques can be implemented but properly modified and adapted on site-specific applications taking always into consideration the end-use of the treated material and the chemical characteristics of the slurry. Laboratory tests should be performed in the slurry in order to define precisely the blend of the chemical additives and eventually reach the required properties of the final material (Ameel, undated).

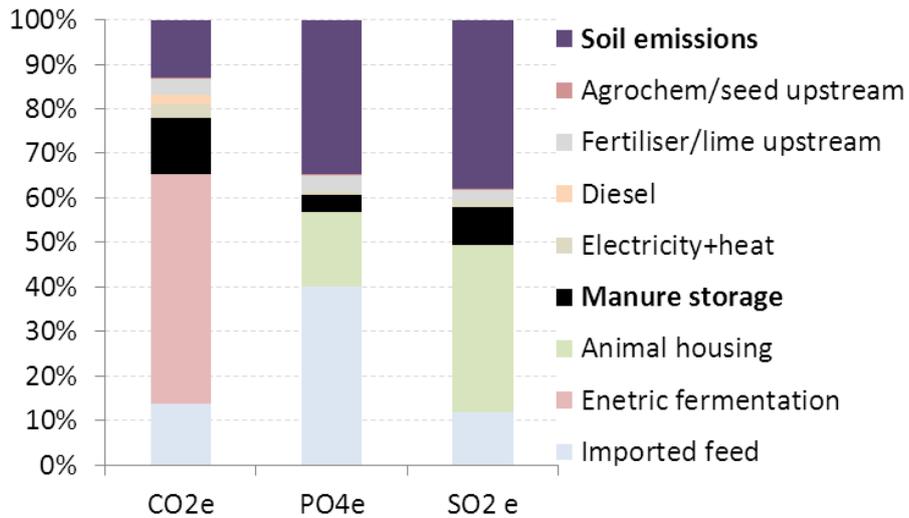
Another important technique regarding the slurry process is the slurry cooling. The slurry cooling technique provides similar characteristics with the geothermal heat generation. In particular, when slurry is being cooled the ammonia levels are lowered in the stable contributing to creating both better

atmosphere and more welfare to the animals and the employees. On technical grounds the ammonia evaporates from the processed slurry (Joergensen, 2009).

All the available best available techniques for the slurries processing are enclosed in the Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry and Pigs (EC, 2013). Likewise, the same document gathers technical, operational data and examples of national regulations regarding the manure storage systems.

The next step is the implementation of proper slurry storage systems. Those storage systems have an important influence on three key environmental burdens arising from farm operations: global warming potential via CH₄ and N₂O emissions, and eutrophication and acidification via NH₃ emissions. Under worst case open lagoon systems, slurry storage can contribute up to 38% of farm system GHG emissions, 30% of farm system eutrophying emissions, and 52% of farm system acidifying gas emissions for a large dairy farm (Figure 9.11). The type of slurry storage system, in particular the surface area exposed to the atmosphere in relation to the slurry volume, strongly influences CH₄ and NH₃ emissions to the atmosphere. Tank stores may develop crust covers that restrict these emissions but increase N₂O emissions (Figure 9.11).





Data for a large dairy farm where animals housed for 10 months of the year.

Source: Bangor University Farm LCA tool

Figure 9.10. The contribution of manure storage, and soil emissions influenced by manure storage, towards total global warming, eutrophication and acidification burdens on a large dairy farm with lagoon slurry storage (top) and tank storage with crust cover (below)

Best practice is to install tall (> 3 m) slurry tanks with a comparatively small exposed slurry surface area (new stores), and to cover slurry with some form of fixed or temporary cover (retro-fit existing stores) (Figure 9.9). By conserving TAN in slurry, efficient slurry storage facilities can lead to higher NUE and lower environmental burdens (and costs) associated with fertiliser production and application, although spreading emissions of NH₃ may increase.



Source: IMPEL (2009)

Figure 9.11. Slurry stores with rigid covers

The capacity of slurry stores in relation to slurry generation (animal numbers) determines the maximum duration of slurry storage, and can have a significant influence on the efficiency and environmental impact of slurry application. In particular, insufficient slurry storage capacity leads to winter application of slurry onto wet soils, when a high proportion of N may be lost via runoff and leaching, and when plant uptake is low. Thus, adequate storage capacity is a second key component of best practice. Best practice measures from Newell-Price et al. (2011) are summarised in Table 9.20.

Table 9.20. Best practice measures listed in the ADAS best practice manual

Measure	Description
Increase the capacity of farm slurry (manure) stores to improve timing of slurry applications	On farms where there is currently limited slurry storage capacity, expand facilities for the collection and storage of slurry, to allow spreading at times when there is a low-risk of runoff and when there is an actively growing crop to utilise nutrients applied in the slurry.
Adopt batch storage of slurry	Store slurry in batches for at least 90 days before land spreading; do not add fresh slurry to the store during this storage period
Install covers on slurry stores	Open slurry stores (tanks or lagoons) are fitted with a cover (either a rigid cover with a vent or a floating flexible cover)
Allow cattle slurry stores to develop a natural crust	Retain a surface crust on stores, composed of fibre and bedding material present in cattle slurry, for as long as possible. In most cattle systems, it is possible to retain an intact crust for the majority of the year.
<i>Source:</i> Newell-Price et al. (2011).	

Summarising, in order to achieve the best environmental performance within farms, farmers should follow the principles below:

- Decrease the surface area where emissions can take place e.g. cover slurry storages and/or increase the depth of the storages;
- Decrease the source strength of the emitting surface e.g. lowering the pH value and
- Install adequate slurry storage capacity to enable optimised timing of slurry application with respect to soil conditions and plant growth requirements.

Achieved environmental benefits

Slurry processing

Acidification

The application of the acidification technique reduces the risk of gaseous emissions and the odour problems. Several researchers e.g. Pedersen, (2004); Ottosen et al., (2009) reported that frequent adjustment of the pH of pig slurry in a pig house (1/3 drained floor and 2/3 slats) reduced the ammonia volatilization process by 70%. Additionally the slurry acidification also results in reduced ammonia volatilization from the slurry storage. Kai et al. (2008) demonstrated that losses from acidified slurries are less than 20% of the related emissions from an untreated uncovered storage facility. The ammonia losses during manure storage are expected to be reduced by 50% as compared with untreated slurry with naturally established floating layer.

Slurry cooling

Applying the slurry cooling technique, the elimination of ammonia from the stables is supported providing the related benefits to the natural and aquatic environment. Likewise when the ammonia evaporation decreases the slurry is containing a higher level of nitrogen, which eventually increases the manures fertilizer value. In parallel, reducing the ammonia emission levels in the farm, the animal welfare is upgraded due to the fact that the animals breathe less harsh fumes with ammonia. Additionally, the evaporation of ammonia can be reduced up to 31% per year (Joergensen, 2009).

Covered slurry stores

Table 9.21 shows the NH₃ reductions achievable through various best- and good- practice options for slurry storage covers, and applicability. Methane emissions are also likely to be significantly reduced by these options. For example, CH₄ emissions from slurry stored in a liquid tank with crust cover are 85% lower than emissions from an uncovered anaerobic lagoon according to IPCC (2006) (Table 9.23).

One the one hand, net farm system benefits may be reduced somewhat through higher NH₃ and CH₄ emissions during subsequent spreading, depending on the spreading techniques applied (see Sections 9.6 and 9.7). On the other hand, net benefits may be increased through high fertiliser replacement following TAN conservation in the slurry.

Life cycle assessment of a large dairy farm system where animals are indoors for 10 months of the year shows that shifting from lagoon storage to tank storage with a crust cover can reduce farm-level GHG emissions by 29%, eutrophying emissions by 25% and acidifying gas emissions by 42% (Bangor University, 2013).

Appropriate slurry storage capacity

Cuttle et al. (2007) estimated the following benefits for increasing slurry storage capacity to 6 months, from an average of three months, under a cool, temperate, wet climate (UK):

- A 25% reduction in slurry P losses to water;
- For arable land, a 10-20 kg N/ha (20-40%) reduction in annual N leaching via optimised application timing, or a 15-30 kg N/ha (30-60%) reduction if fertiliser application rates are reduced accordingly;
- For grassland, a 2-5 kg N/ha reduction in n leaching for dairy farms, and 1 kg N/ha reduction for beef farms.

Table 9.21. Best and good practice abatement measures for cattle and pig slurry storage according to TFRN (2011)

	Abatement measure	NH ₃ reduction (%)*	Applicability
Best practice	Tight lid, roof or tent	80	Concrete or steel tanks and silos. May not be suitable on existing stores
	Plastic sheeting (floating cover)	60	Small earth-banked lagoons
	Replacement of lagoon, etc. with covered tank or tall open tanks (H > 3 m)	30–60	Only new build, and subject to any planning restrictions concerning taller structures.
	Storage bag	100	Available bag sizes may limit use on larger livestock farms.
Good practice	Plastic sheeting	60	Large earth-banked lagoons and concrete or steel tanks. Management and other factors may limit use of this technique.
	Natural crust	40	Higher dry matter slurries only. Not suitable on farms where it is necessary to mix and disturb the crust in order to spread slurry frequently. Crust may not form on pig manure in cool climates.
	Low technology floating covers (e.g. chopped straw, peat, bark, LECA balls, etc.)	40	Concrete or steel tanks and silos. Probably not practicable on earth-banked lagoons. Not suitable if materials likely to cause slurry management problems.
*Relative to open storage reference system Source: TFRN (2011).			

Appropriate environmental performance indicators

Emission factors for different storage systems

Ammonia and CH₄ emission factors for different storage systems will depend on climate and average storage duration (IPCC, 2006). Therefore, relevant national data should be referred to when assessing manure storage options, or at least data from similar climatic zones. Table 9.22 provides some NH₃ emission factors for different manure types and storage systems in the UK.

Table 9.22. Nitrogen emission factors for different storage systems and manure types

Livestock	Manure	Store	Ammonia emission	
			% N	% TAN
Cattle	Slurry	Circular tank	8.3	15.8
		Weeping wall	5.6	10.8
		Lagoon	41.7	79.9
	Farm yard manure		1.1	4.2
Pigs	Slurry	Circular tank	2.7	3.8
		Lagoon	19.5	28.1
	Farm yard manure		2.3	4.6
Poultry	Layer manure		2.3	3.7
	Broiler litter		0.5	0.8

Source: Webb and Misselbrook (2004)

According to Tier 2 methods in IPCC (2006), CH₄ and NH₃ emissions from manure storage can be calibrated according to animal diets, in particular dry matter intake (CH₄) and protein intake (NH₃). However, the IPCC methodology does not differentiate between housing and storage emissions. Methane conversion factors (MCFs) related to different management systems in IPCC (2006) are sufficient to provide practical guidance on more efficient management systems. Relevant N₂O and CH₄ emission factor values are summarised in Table 9.23.

Table 9.23. Emission factors for N₂O and CH₄ for different manure types and storage systems, from IPCC (2006)

Manure management system		N ₂ O-N as fraction of N _{ex}	Methane conversion factor (%)*
Solid storage		0.005	2–4
Liquid slurry	Natural crust cover	0.005	10–20
	No crust cover	0	17–32
Uncovered anaerobic lagoon		0	66–76
Pit storage		0.002	17–32 (3 if < 1 month)
Cattle and swine deep bedding	No mixing	0.01	17–32 (3 if < 1 month)
	Active mixing	0.07	
Composting (in-vessel or static pile)		0.006	0.5
Composting	Intensive windrow	0.1	0.5–1.0
	Passive windrow	0.01	0.5–1.0
Poultry manure (with and without litter)		0.001	1.5

N_{ex} = N excreted indoors by livestock
 *Percentage of total CH₄ production potential based on volatile solids content, expressed as a range for ≤10 °C (northern Europe) to 17 °C (southern Europe) average annual temperature
Source: IPCC (2006)

Management indicators

- Liquid slurry stores are covered
- Capacity of liquid slurry stores (m³), also expressed as the number of overwinter months of storage
- Distance of export to receiving farm (esp. pig, poultry)
- Timing of slurry applications in relation to soil conditions (moisture content) and crop nutrient requirements
- Slurry processing applying suitable methods (those which described above)

Performance indicators

Key indicators of whole-farm resource efficiency that should reflect benefits of this technique include:

- Nutrient surplus (N and P)
- Nutrient use efficiency (N and P)
- kg NH₃ emitted per cow place or per livestock unit per year
- Manure storage CH₄ emissions, kg CH₄ per kg meat/milk

Cross-media effects

Acidification

The used acidic agent may inhibit the growth of some microorganisms or other pathogens. Consequently, the related impacts over pathogens survival must be deeply evaluated (AgroTechnologyAtlas, 2015). Furthermore when applying the acidification technique, the NH₃ emissions decrease but at the same time the N₂O emissions may increase after field application (Fangueiro, 2012).

Moreover, in many cases the application of the slurry acidification may generate additional costs because of increased energy consumption; Pedersen (2004) estimated (under certain circumstances) that the additional net energy consumption is approximately 3 kWh/m³ slurry.

Capped storage reduces dilution, and the consequent higher dry matter content in spread slurry can lead to slower infiltration into the soil and higher NH₃ volatilisation following application. Separation of the solid fraction (Section 9.3) and efficient application methods such as injection (Section 9.6) and trailing shoe (Section 9.7) can minimise this effect.

Natural crust formation on stored slurry (a secondary good practice measure with respect to NH₃ and CH₄ emission) can lead to increased N₂O emission.

Longer storage duration can lead to higher storage emissions of CH₄ and NH₃, contributing to global warming, eutrophication and acidification burdens. These can be minimised by the covering of stores, and are likely to be outweighed by the avoided eutrophication benefits arising from improved timing of slurry application.

Operational data

Slurry processing

The acidification technique decreases the level of CH₄ emissions. The efficiency of this technique (efficiency of the decrease of the CH₄ emissions) depends strongly on the acid material is used. In particular, the efficiency is up to 90% when lactic acid is used, 40-65% with HCl and 17-75% when nitric acid is applied.

In particular, the addition of 4-6 kg concentrated sulphuric acid per 1,000 kg of pig slurry, then the pH value ranges from 5.5 to 6.0. However, it should be noted that the amount of H₂SO₄ depends on the alkalinity of the manure. As far as the energy consumption is concerned, the Infarm plant located in Randers treats 10,000 m³/y using 1.8 kWh/m³ (AgroTechnologyAtlas, 2015).

The technical characteristics of the slurry processing techniques are presented detailed in Table 9.24 (Sindhøj et al., 2013).

Table 9.24. Technical characteristics of the slurry processing techniques (Sindhøj et al., 2013)

Processing technology	Type of farm (country)	Processing capacity	Drivers for implementation	Processing costs (€/m ³ y-1)	Incomes and savings not included
<i>Slurry acidification</i>					
In house	Pig farm (DK) produces 6,500 finishers per year	Max capacity NA, farm generates 3,250 m ³ /year	Ammonia abatement demanded by legislations	6.68	Saved N; S fertilisation unnecessary
During spreading	Fictive pig farm (DK), 3,800 places, typical for DK	Max capacity NA, farm generates 6,000 m ³ /year	Ammonia abatement demanded by legislations	1.04	Saved N; S fertilisation unnecessary
<i>Slurry cooling</i>					
Heat pumps	Pig farm (FI), 1,000 fattening pig places	Max capacity NA, cools 1,200 out of 2,000 m ³ per year	Save energy, decrease emissions	2.99	Saved N and energy

According to Joergensen (2009) the slurry cooling by 1°C results to a reduction of the ammonia vapour by 7%.

Additional measures to reduce storage emissions

Careful control of dietary N (protein) intake can reduce TAN in slurry, and therefore NH₃ losses during storage (Section 8.3).

Ammonia emissions from slurry (and digestate) depend on the chemistry of dissolved ammonia and transfer mechanisms of gaseous ammonia at the slurry surface. Important parameters include: slurry surface area, surface roughness and temperature and wind speed. Emissions during storage can also be reduced by applying the following measures (EC, 2013):

- Installing a smaller container diameter and/or a reduced wind contact area at the slurry-air interface
- Reducing the surface area to volume (SA/V) ratio of the storage. For example, the SA/V of 1,000 m³ slurry store storage can be reduced by 1/3 if the height of the sides is increased from 3 to 5 m. For rectangular storage, the ratio of the height to surface area should be 1:(30–50). However, excessive height of the slurry store represents a possible safety risk.
- Operating at a lower level of fill (wind shielding effect), so long as this does not involve premature slurry spreading.
- Emptying the stores in spring, before the onset of the warm season, so that the least possible slurry quantity is stored during summer when volatilisation losses are high – especially in hot summer climates.
- Frequent transfer of slurry from a housing facility to an outdoor store. Since the temperature of the slurry tends to match the ambient temperature, this technique leads to NH₃ and CH₄ mitigation in cool and temperate regions, but not necessarily in warmer climates.
- The discharge of slurry in open storage containers should be performed as close to the base of such containers as possible (infilling below the liquid surface level).
- Homogenisation and the circulation pumping of slurry should be performed when the wind is blowing away from any sensitive sites requiring protection.
- Maintain a low evaporation rate by avoiding unnecessary stirring.

Other interventions may reduce NH₃ emissions from slurry storage, such as acidification of the slurry. EC (2008) estimated that acidification and eutrophication burdens from meat and dairy production in the EU-27 could be reduced by 14-16 % through liquid manure pH reduction.

Increasing storage duration

Storage duration can be maximised by following good practice with respect to runoff water management. Housing should be drained to avoid overflow onto the yard area where it becomes diluted with rain water, generating a large volume of dirty water that must be sent to slurry stores.

Applicability

The highest levels of management performance referred to in this BEMP incur significant capital expenditure (see below) and apply only to large pig and poultry units, large dairy farms where animals are housed for a large proportion of the year, and to farms with anaerobic digestion units. EC (2013) cite a study that found 50–70% of existing steel slurry tanks in the UK can be readily retro-fitted with tent-type covers.

Best practice is for all farms is to send slurry to a local AD unit with gas-tight digestate storage tanks. This offers an opportunity for small farms to optimise their manure management systems and achieve the highest levels of NUE.

Where there are no opportunities for local AD of slurry, and where farms are too small to implement primary best practice measures, secondary measures, such as sheeting-covers on slurry stores, apply to all farms with liquid slurry systems. All farms should ensure that slurry storage capacity is sufficient to comply with national NVZ requirements, whether or not in an NVZ.

The acidification of animal slurry is an efficient technique that reduces NH₃ emissions from livestock during storage and field application. The application of this technique is implemented using proper additives/acid materials e.g. H₂SO₄. However, in many countries (e.g. Portugal) there are major concerns regarding the potential acid hazards (Regueiro Carrera et al., 2013)

On the other hand, the sulphuric acid addition to manure can have negative impacts for the sustainability of some types of concrete because of a sulphate reaction. Therefore the selection of the suitable concrete type should be made very carefully, while the sulphuric acid manipulation should be performed under safety protocols (AgroTechnologyAtlas, 2015).

Economics

Covered storage investment costs

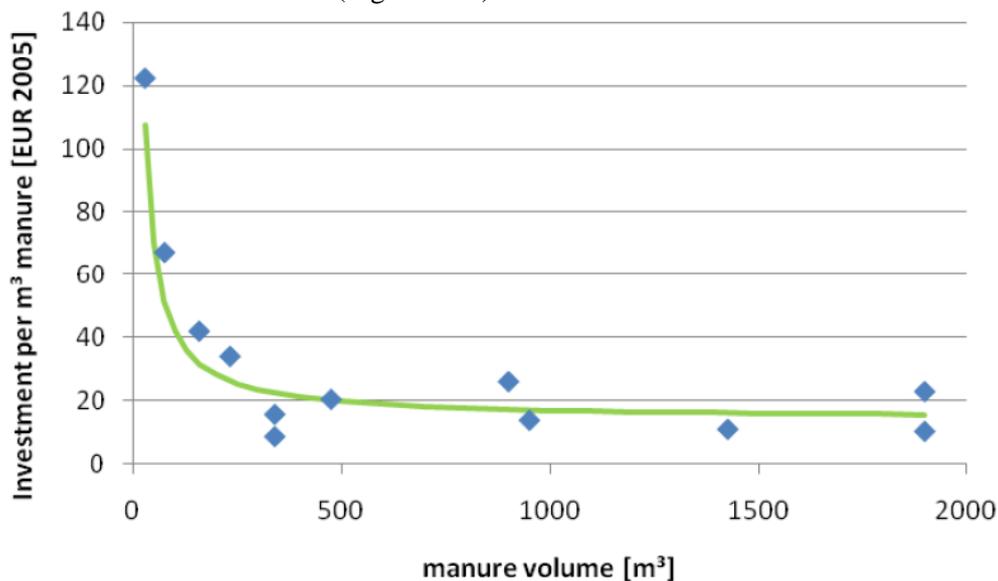
The BREF on intensive pig and poultry production presents useful economic data for baseline uncovered storage and different types of covered storage, at different scales (Table 9.25).

Table 9.25. Annual and investment costs for different types of slurry storage system (EC, 2013)

Usable storage capacity	500 m ³		1,000 m ³	3,000 m ³	5,000 m ³	
	13.7		17.7	27.9	35.5	
Diameter	Annual €/m ³ /y	Investment €/m ²	Annual €/m ³ /y	Annual €/m ³ /y	Annual €/m ³ /y	Investment €/m ³ /y
Uncovered	1.78	NA	1.57	1.29	1.17	NA
Concrete cover	2.74	NA	2.38	1.96	1.82	NA
Tent roof	3.67	100	2.74	2.00	1.74	46
Floating film	2.7	34	2.14	1.66	1.47	16
Light bulk materials	2.03	10.2	1.73	1.43	1.3	7.6
Floating bricks	2.42	39.5	2.11	1.73	1.6	39.5
Straw	2.2		1.86	1.49	1.35	

0.2 m freeboard and residual volume 0.5 m depth assumed, storage over 6 months, expenses calculated per total slurry quantity (2 x capacity).
Source: EC (2013) based on UBA (2010)

TFRN (2011) presented storage investment costs for different scales expressed per m³ capacity, showing a strong reduction in marginal investment costs up to 500 m³ but a small reduction in marginal investment costs thereafter (Figure 9.12).



Source: Klimont and Winiwarter (2011).

Figure 9.12. Size-dependent abatement costs to implement high-efficiency manure storage ammonia-abatement measures

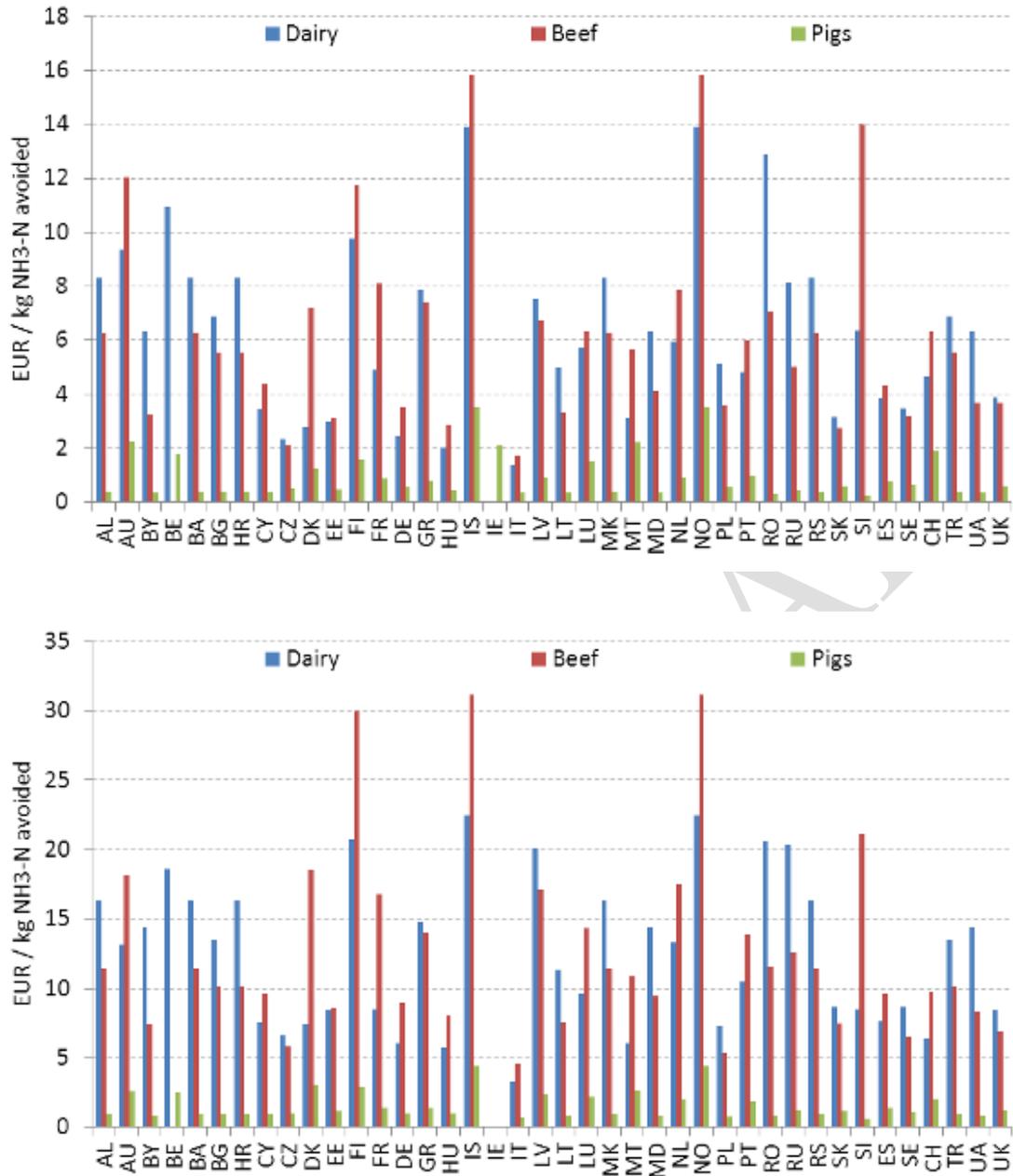
Ammonia abatement costs

Figure 9.13 displays the range of abatement costs calculated across European countries by the GAINS model for low- and high- efficiency slurry cover systems. It is apparent that low efficiency systems such as plastic covers are more cost-effective than high efficiency systems that require major renovation or rebuilding of manure stores. Capping of pig slurry is associated with the lowest abatement costs. In particular, Bittman et al., (2014) presents the following figures for manure covering systems:

- Tight lid cover: 2-4 €/m³/year (emission reduction > 80%)
- Plastic cover: 1.5-3 €/m³/year (emission reduction > 60%)
- Floating cover: 1.5-3 €/m³/year (emission reduction > 40%)

It is important to note that fertiliser-replacement values are excluded from these abatement costs. Where pig slurry can be applied using efficient techniques to match crop demand, the enhanced fertiliser replacement value (1.06 € per kg N) could exceed the abatement cost, resulting in net economic savings for covered storage of pig slurry (Table 9.26).

Furthermore, solid covers can prevent rainwater accumulation in the storage tank, considerably reducing slurry transport and spreading costs. This factor may be particularly important for farmers considering a move from a lagoon to a (possibly covered) tank system of storage. Rainfall of 1000 mm over a year could increase slurry spreading costs by 50% to 100% depending on the depth of lagoon stores (2-3 m).



NB: Values exclude reduce slurry handling costs and increased fertiliser replacement value

Source: Based on data from Winiwarter et al. (2011)

Figure 9.13. Ammonia abatement costs for low-efficiency (top) and high-efficiency (below) slurry cover systems calculated for European countries using the GAINS model

Table 9.26. Net abatement costs calculated from median European abatement costs for slurry cover systems from Winiwarter et al. (2011) minus potential fertiliser replacement value of retained N

	Slurry type	Abatement cost (€/kg NH ₃ -N avoided)	Fertiliser replacement value (€/kg N)	*Net cost (€/kg NH ₃ -N avoided)
High efficiency	Dairy	13.10	1.06	12.04
	Beef cattle	10.50		9.44

	Slurry type	Abatement cost (€/kg NH ₃ -N avoided)	Fertiliser replacement value (€/kg N)	*Net cost (€/kg NH ₃ -N avoided)
	Pigs	1.08		0.02
	Laying hens	3.83		2.77
	Other poultry	3.86		2.80
Low efficacy covers	Dairy	6.33	1.06	5.27
	Beef cattle	5.61		4.55
	Pigs	0.58		-0.48
Median values = median values from European countries calculated using GAINS model. *Assumes that each kg NH ₃ -N avoided replaces one kg fertiliser-N These values exclude potentially large slurry spreading cost savings achievable through volume reduction (avoided rainwater ingress). <i>Source:</i> Based on data from Winiwarter et al. (2011)				

Overall cost effectiveness

For most types of slurry, covered storage is a relatively expensive NH₃ abatement option, but it does also result in considerable reductions in methane emissions. If abatement costs are divided across NH₃ and CH₄, covered storage becomes a more cost-effective mitigation option. The overall cost-effectiveness of covered storage should consider:

- Capital investment and additional operational costs for covered storage
- Enhanced fertiliser replacement value of slurry
- Reduced spreading costs of undiluted slurry
- Ammonia abatement value
- GHG abatement value

If manure can be sent to an on-site or nearby AD unit, this can represent the most cost-effective manure management option owing to renewable electricity and heat revenues and enhanced fertiliser replacement value, if managed well (Section 9.2).

Increasing slurry storage capacity

The cost implications of this aspect of best practice will vary depending on farm type. Taylor (2011) assumed that at present farms have three months storage, and that an additional three months storage capacity would lead to optimised environmental performance (Taylor, 2011). Based on these assumptions, Cuttle et al. (2007) and Taylor (2011) calculated an amortised cost of £ 4/t (4.70 €) slurry over 20 years.

Driving forces for implementation

- Nitrate Vulnerable Zone regulations on slurry storage capacity.
- Regulations on slurry storage infrastructure and emission limits in sensitive areas.
- Reduced spreading costs (covers) and fertiliser costs (covers and capacity).
- Increased effective slurry storage duration achieved by installation of covers.
- Ammonia abatement demanded by legislations.
- Save energy and decrease of the related emissions.

Reference literature

- AgroTechnologyAtlas, 2015. Spreading and other outdoor logistics handling of livestock manure, document 1001: in-house acidification of liquid livestock manures, available online at: <http://agro-technology-atlas.eu/techdescs.aspx?techgroup=1000>, accessed January 2015.

- Ameen M.E. undated. Evaluation of field methods for the solidification/stabilization of contaminated soils and sludges, available online at: <http://www.geocon.net/pdf/paper34.pdf>, accessed January 2015.
- Bangor University, 2013. Farm LCA tool (Styles, D., Gibbons, J., 2013).
- Cuttle, S., Macleod, C., Chadwick, D., Scholefield, D., Haygarth, P., Newell-Price, P., Harris, D., Shepherd, M., Chambers, B. & Humphrey, R., 2007. *An Inventory of Methods to Control Diffuse Water Pollution from Agriculture (DWPA) USER MANUAL*. DEFRA, London.
- EC, 2008. *Environmental Improvement Potentials of Meat and Dairy Products*. IPTS, Seville.
- EC, 2013. *Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry and Pigs*. Draft 2 (August, 2013). IPTS, Seville.
- Hamelin L. 2010. Biogas, slurry separation & acidification: a few LCA perspectives based on recent studies. Syddansk Universitet, Seminar om biogas og gylleseparation, Odense, Denmark, October 14th.
- Fangueiro D. 2012. Sustainable animal slurry management at farm scale: a systemic approach, Kick off meeting ReUseWaste project, Marie Curie action of the EU-FP7-PEOPLE-2011 program., University of Copenhagen, Faculty of Science, 24-26 September.
- IMPEL, 2009. *Comparison Programme on Permitting and Inspection of IPPC Pig Farming Installations in IMPEL Member Countries*. Final report. IMPEL, 2009
- IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>
- Joergensen B. 2009. Slurry cooling. Slurry cooling – A good investment for better environment, work health and welfare, Nordic Folkecenter for Renewable Energy.
- Kai P., Pedersen P., Jensen J.E., Hansen M.N., Sommer S.G. 2008. A whole-farm assessment of the efficiency of slurry acidification in reducing ammonia emissions. *Europ. J. Agronomy* 28, 148-154.
- Klimont, Z., Winiwarter, W., 2011. *Integrated ammonia abatement – Modelling of emission control potentials and costs in GAINS*. IIASA, Laxenburg.
- Newell-Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R., Misselbrook, T.H., 2011. *An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture*. ‘ADAS’ and ‘Rothamsted Research, North Wyke’; Defra Project WQ0106 (Dec. 2011).
- Ottosen L.D.M., Poulsen H.V., Nielsen D.A., Finster K. Nielsen L.P. Revsbech N.P. 2009. Observations on microbial activity in acidified pig slurry, *Biosystems Engineering* 102, 291-297.
- Regueiro Carrera I., Coutinho J., Fangueiro D. 2013. Comparison of different approaches for ammonia emissions minimization by acidification of dairy and pig slurries. Available online: http://www.reusewaste.eu/publications/REGUEIRO_IRIA_ARTICLE_Ramiran15.pdf, Accessed January 2015.
- Sindhøj E., Alitalo A., Kassi P., Sipila I., Tamm K., Rodhe L. 2013. Examples of implementing manure processing technologies at the farm level in the Baltic Sea Region. International Conference on manure management and valorization, poster presentation, December 5-6, Bruges, Belgium.
- Pedersen P. 2004. Svovlsyrebehandling af gylle i slagtesvinestald med drænet gulv. Meddelelse nr. 683, Landsudvalget for Svin, pp. 12.
- Taylor, M., 2011. *Increase the capacity of farm manure (slurry) stores*. COST action information sheet.
- TFRN, 2011. *Draft Guidance document for preventing and abating ammonia emissions from agricultural sources*. WGSR Informal document no. 21.
- UBA, 2010. Water Protection in Cooperation with Agriculture. Umwelt Bundes Amt, Berlin.
- Webb, J., Misselbrook, T.H. (2004). A mass-flow model of ammonia emissions from UK livestock production. *Atmospheric Environment* 38, 2163–2176.
- Winiwarter, W., Klimont, Z., Sutton, M., 2011. *Summary of ammonia abatement costings in GAINS*. Spreadsheet 2b. TFRN.

9.5 Appropriate solid manure storage

Description

Compared with liquid slurry systems, solid farm yard manure storage systems are associated with lower environmental burdens, including significantly lower CH₄ and NH₃ emissions (Webb and Misselbrook, 2004; IPCC, 2006). There is less scope for environmental improvement through management of solid manures, but some aspects of best management practice are described here.

Anaerobic digestion (Section 9.1) or separation of animal excreta in housing, prior to storage (Section 9.3) is best practice for farms with liquid slurry systems. Best practice is to compost or batch store the solid fractions arising from all manure management systems, especially farm yard manure and poultry litter. Best practice measures are summarised in Table 9.27.

Table 9.27. Best practice measures for solid manure management described in Newell-Price et al. (2011)

Measure	Description
Adopt (batch) storage of solid manures	Store 'fresh' solid manure in separate batches (for at least 90 days) before land spreading.
Compost solid manure	Encourage the breakdown of solid manure by active composting. Turn the solid manure windrow twice in the first seven days of composting to facilitate aeration and the development of high temperatures within the windrow.
Site solid manure field heaps away from watercourses/field drains	Where solid manure is stored in a field heap it should not be sited within 10m ⁴² of a watercourse or (effective) field drain.
Store solid manure heaps on an impermeable base and collect leachate	Manure heaps are sited on an impermeable base, with leachate collection facilities.
Cover solid manure stores with sheeting	Solid manure field heaps are covered (e.g. with heavy duty polythene sheeting) in a similar manner to a silage clamp.
<i>Source:</i> Newell-Price et al. (2011).	

However, it should be mentioned that a minimum distance should be kept between the manure storage facility and the watercourse, waterbody etc.

As a general remark, the manure storage facility must be located in well-drained area and the surface water should not enter it. An appropriate effective buffer strip must be constructed between the manure storage facility and the watercourse. Therefore a minimum distance between the manure storage facility and the watercourse must be set, which depends on several factors such as the type of storage, soil type, depth to bedrock, etc. (Linkletter et al., 1999).

Moreover, the location of the manure storage facilities is sometimes unavoidable in places affected by a high water table. Therefore in order to avoid the floatation inside and avoid using high amounts of concrete, it should be good to install groundwater pressure relief drain. (DEFRA, 2010).

The exact distances are listed in the operational data section.

Composting is a controlled aerobic degradation process of organic matter. Compost is more stable than manure, with a low moisture content and most of the initial nutrients (EC, 2013). Composting is based on aerobic microbial metabolism and associated heating over 50°C to inactivate weeds and most pathogens. The composting process allows naturally occurring microflora to degrade cellulose and other carbon compounds in the manure to produce a more friable, stable, and spreadable product with reduced volume (Haygarth, 2011). Composting also sanitises manure and reduces readily

⁴² This distance may have to be increased under certain circumstances e.g. from wind blow or field slope.

available N content from 25% to 10%, thus reducing N losses via volatilisation and leaching following spreading. Faecal indicator organism (FIO) losses are also reduced from compost, rather than manure, spreading.

Batch storage is defined by Newell-Price and Morvan (2011) as the storage of solid manure for at least 90 days before spreading on fields, during which time no fresh manure should be added to the heap. Batch-storage achieves similar results to composting in terms of most of FIO and N loss reductions following spreading (FIO numbers decrease with time of storage).

In either case, the most important environmental protection measures are to locate manure stores away from water courses, to cover them, and to collect and divert any runoff into either an on-site liquid slurry system or back onto the manure heap. Thus, this BEMP covers:

- Composting or batch storage of solid manures
- Covered and appropriately sited storage.

Achieved environmental benefits

The main environmental benefits of composting and batch storage are:

- A reduction in NH₃ and NO₃ losses following spreading – on the assumption that farm yard manure or compost is applied once every three years to the farm field area, Cuttle et al. (2007) estimate a 3 kg N/ha per year (15–30%) reduction in N losses, and no effect on P losses.
- Reduced FIO losses following spreading only if farm yard manure would otherwise be spread following less than three months of storage.

Covered storage will reduce nutrient and FIO leaching from manure and compost piles, thus reducing eutrophication and water pollution risks. Newell-Price et al. (2011) provide an overview of emissions changes from solid manure management measures (Table 9.28).

Table 9.28. Changes in emissions to air and water for measures recommended in Newell-Price et al. (2011)

	Nitrate	Nitrite	Ammonium	Particulates	Solubles	Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Adopt (batch) storage of solid manures	↓	↓	↓	~	~	~	~	↓↓	↓	(↓↑)	↑	~
Compost solid manure	↓	↓	↓	~	~	~	~	↓↓	↓	(↓↑)	↑	↑
Site solid manure field heaps away from watercourses/field drains	↓	↓	↓	↓	↓	~	↓	↓	~	↓	~	~
Store solid manure heaps on an impermeable base and collect leachate	↓	↓	↓	↓	↓	~	↓	↓	↑	(~)	~	~
Cover solid manure stores with sheeting	↓	↓	↓	↓	↓	~	↓	↓	↓	(↓↑)	↑	↑

Source: Newell-Price et al. (2011).

Appropriate environmental performance indicators

Emission factors

Emission factors for different storage systems listed in Table 9.22 and Table 9.23 in the previous section indicate the relative performance of solid manure storage systems in terms of storage emission losses. Of more importance for capturing the effectiveness of this technique are emission factors for

soil application (see Sections 9.6 and 9.7), and faecal indicator organism losses. In summary, the main emission factors of relevance:

- NH₃, CH₄ and N₂O emissions from the storage system (e.g. Webb and Misselbrook, 2004; IPCC, 2006)
- NH₃ and NO₃ emission factors based on manure type and spreading method (e.g. MANNER-NPK: ADAS, 2013)

Management indicators

- Type and capacity of solid manure management system
- Covering of manure or compost heaps
- Hydrological isolation of compost heaps from water courses

Performance indicators

Key indicators of whole-farm environmental performance that should reflect benefits of this technique include:

- Total nutrient losses to waters (kg/ha/y)
- Total faecal indicator organisms in neighbouring water bodies
- Percentage of (%) solid manure fractions stored according to the described principles in this technique

Cross-media effects

Composting and batch storage typically result in 30-50% of the total N in farmyard manure being lost to the atmosphere, either as NH₃, N₂O or N₂. For poultry manures, losses are more typically 20% (Haygarth, 2011; Newell-Price and Morvan, 2011). It is possible to reduce ammonia emissions from composting by reducing aeration intensity and by increasing the amount of straw relative to the amount of dung, but care must be taken to avoid insufficient aeration otherwise N₂O and CH₄ emissions would increase (Haygarth, 2011). Whilst the reduced N availability can reduce N losses following spreading, it can also lead to lower NUE depending on the long-term availability of the organic fraction added.

Operational data

Composting must be closely monitored to ensure that the pile temperature increases to above 55°C for three days after each turn (Haygarth, 2011). Turning of the pile allows mixing and the further degradation of material and ensures that all parts of the pile are treated.

Standard farm equipment can be used to turn the compost piles. Additional concrete stands may need to be constructed for compost piles and batch storage.

Brouwer and Ervin (2002) demonstrated that the minimum separation distance between any proposed livestock facility and any residential area should be 610 m, which is a requirement for the reduction of the produced odours. Moreover, a buffer strip of 30 m between the manure storage facility and the watercourse must be respected with a minimum manure storage facility of 6 months. However, it is noted that the location of the field heaps differs among the EU member states. In Table 9.29 the field heaps for Northern Ireland, Southern Ireland and Britain are presented.

Table 9.29. Rules for solid manure field heap storage in northern and southern Ireland and Britain (Nicholson et al., 2011)

Distances	Northern Ireland	Southern Ireland	Britain
Buffer distance between field heaps and water supply sources serving over 50 people or providing over	50 m	250 m	50 m

Distances	Northern Ireland	Southern Ireland	Britain
10m ³ /day			
Distances between field heaps and certain surface waters	50 m from lakes 20 m from waterways/drains etc.	20 m from lakes	10 m from a surface water/drain
Field heaps storage	Must not be stored within 20 of open field drains or any drain, which has been backfilled to the surface with permeable material	Within 10 m of an open drain	Not be stored within 10 m of and land drain
Storage duration	No longer than 6 months	No longer than 9 months	Up to 12 months

Moreover, the manure should be stored in a compact heap at least 2 m high and carefully located not less than 50 m from any waterbody, public road, domestic well or watercourse and 300 m from any public supply source. It should be also mentioned that the storage is allowed only for the period from 16th of January to 31st of the October in the same year (REPS, 2004)

Applicability

A readily applicable option to farms with solid manures, particularly in areas where there is a high risk of pathogen transfer to water systems (Haygarth, 2011).

Composting has no effect on the proportion of readily available N in poultry manure.

Composting and batch storage are not relevant where fresh manure can be incorporated into soils (nearby tilled soils) during spring, as the latter option can lead to better overall environmental performance (Newell-Price and Morvan, 2011).

Economics

Costs will include operational costs of turning manure using normal (typical) agricultural machinery, plus the construction of a concrete pad, if required (Haygarth, 2011; Newell-Price and Morvan, 2011). Table 9.30 summarises estimated costs for implementation of relevant best practices measures across typical UK farm types, from the ADAS best practice manual (Newell-Price et al., 2011).

Table 9.30. Estimated net cost for different farm types to implement best practice measures

	Dairy	Grazing LFA	Grazing Low	Mixed	In Pigs	Out Pigs	Poultry
	€ per farm per year						
Adopt (batch) storage of solid manures	294	412	647	1,765	2,118		588
Compost solid manure	706	882	1,412	4,118	5,294		2,353
Site solid manure field heaps away from watercourses/field drains	118	176	118	118			
Store solid manure heaps on an impermeable base and collect leachate	294	412	647	1,765	2,118		588
Cover solid manure stores with sheeting	176	176	294	824	1,176		588

Source: Newell-Price et al. (2011)

Moreover, storage costs might range at < 1 €/m³ for low efficiency measures (e.g. 40% reduction), < 5 €/m³ for high efficiency measures (80%) reduction, which correspond to the following abatement figures up to 2 €/kg NH₃-N and 4 €/kg NH₃-N respectively for low and high efficiency measures (Klimont and Winiwarter, 2011).

Driving forces for implementation

- Management of final compost easier than for raw manure
- Reduced risk of water contamination with FIOs
- Minimisation of N losses to air and water following spreading

Reference literature

- ADAS, 2013. *PLANET page for MANNER NPK*. Accessed July 2013: <http://www.planet4farmers.co.uk/Manner>
- Brouwer F., Ervin D.E. 2002. Public concerns, environmental standards and agricultural trade, CABI Publishing, ISBN 0-85199-586-1.
- Cuttle, S., Macleod, C., Chadwick, D., Scholefield, D., Haygarth, P., Newell-Price, P., Harris, D., Shepherd, M., Chambers, B. & Humphrey, R., 2007. *An Inventory of Methods to Control Diffuse Water Pollution from Agriculture (DWPA) USER MANUAL*. DEFRA, London.
- DEFRA, 2010. The water resources (control of pollution) (silage, slurry and agricultural fuel oil) (England) Regulations, "The SSAFO Regulations", guidance notes for farmers, available online: <http://archive.defra.gov.uk/environment/quality/water/waterquality/diffuse/nitrate/documents/201009ssafo-england.pdf>, accessed January 2015.
- EC, 2013. Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry and Pigs. Draft 2 (August, 2013). IPTS, Seville.
- Haygarth, P., 2011. *Compost solid manure*. COST 869 action. Alterra, Wageningen.
- IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>
- Klimont Z., Winiwarter W. 2011. Integrated ammonia abatement – Modelling of emission control potentials and costs in GAINS, Interim report IR-11-027, LIFE project, reference code: EC4MACS LIFE06 ENV/AT/PREP/06.
- Linkletter G.P., Small D., Galloway K. 1999. Guidelines for manure management for Prince Edward island, available online: http://agrienvarchive.ca/bioenergy/download/pei_manure_man99.pdf, accessed January 2015.
- Newell-Price, J.P., Morvan, T., 2011. *Adopt batch storage of solid manure*. COST 869 action. Alterra, Wageningen.
- Newell-Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D., Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R., Misselbrook, T.H., 2011. An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture. ‘ADAS’ and ‘Rothamsted Research, North Wyke’; Defra Project WQ0106 (Dec. 2011).
- Nicholson F., Rolett A., Chambers B. 2011. Review of pollutant losses from solid manures stored in temporary field heaps. ADAS, report for DEFRA project WT1006.
- REPS 2004. Rural environment protection scheme, Farmer's handbook for REPS 3, the department of agriculture and food, available online: http://www.agriculture.gov.ie/media/migration/farmingschemesandpayments/ruralenvironmentprotectionschemereps/ruralenvironmentprotectionschemereps/pastruralenvironmentprotectionschemereps/rep3/rep3_farmershandbook.pdf, accessed January 2015.
- Webb, J., Misselbrook, T.H., 2004. A mass-flow model of ammonia emissions from UK livestock production. *Atmospheric Environment* 38, 2163–2176.

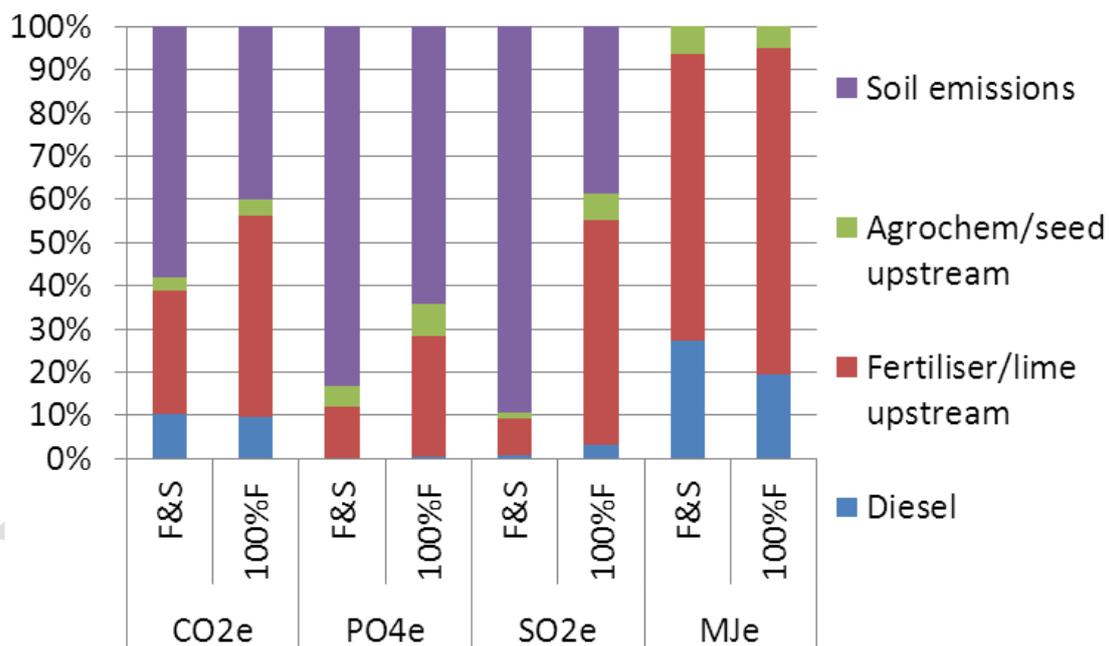
9.6 Injection slurry application and manure incorporation

Description

Surface spread manures and slurries are susceptible to $\text{NH}_3\text{-N}$ losses. Approximately 40% to 60% of TAN in slurry is volatilised following splash-plate spreading (TFRN, 2011), and this can rise up to 80% if a high-trajectory splash-plate spreader is used in warm conditions. Slurry applications are responsible for almost all soil emissions of NH_3 , which contribute 89% of the lifecycle acidification burden arising from spring barley production where 30 tonnes per hectare of pig slurry are broadcast spread (Figure 9.14).

Whilst contributing only half of the total N applied to arable land in the example below, pig slurry application increases the lifecycle acidification burden of barley production by over 320%. Slurry emissions are also responsible for a large share of soil GHG (N_2O) emissions and eutrophying (mainly NH_3 , NO_3 and P) emissions.

There are two ways to apply the slurry injection technique: i. open slot and ii. closed slot. The first one is applied for use in grassland, while the second one is applied either shallow (5-10 cm depth) or deep (15-20 cm). It should be mentioned that the use of the deep injection is rather limited due to the fact that mechanical damage may decrease the herbage yields on grassland. Likewise there is a great risk of nitrogen losses as nitrous oxide and nitrates in some circumstances. Furthermore other technical limitations are the soil depth, soil and clay content, moisture of soil (e.g. a high draught period requires a tractor with large capacity) (FAO, 1999).



Data for spring barley with 30 tonnes per hectare pig slurry application (F&S), or 100% mineral fertiliser application (100%F).

Source: Bangor University Farm LCA tool

Figure 9.14. The contribution of soil emissions, with and without pig slurry application via broadcast spreader, towards total global warming, eutrophication and acidification burdens for spring barley production on a large arable farm

Ammonia emissions from soils occur immediately following slurry or manure application, and can be largely avoided through injection of slurry below the soil surface or incorporation of manures below the soil surface by inversion ploughing or alternative techniques. Best practice is thus:

- Shallow injection application of slurries
- Incorporation of manures within one hour of spreading

In addition, best practice with respect to field nutrient budgeting (Section 5.1) and precise timing of nutrient applications (Section 5.3) should be adhered to. Shallow injection application is particularly suitable for separated liquid fractions of slurries or digestates (Section 9.3), and enables precise dosing and placement (Section 5.3).

Injection spreaders insert slurry into shallow or deep open or closed slots close to crop roots, reducing losses of N from ammonia volatilisation and optimising the placement of nutrients for crop uptake (Figure 9.15).



Figure 9.15. Shallow slurry injection ensures better targeting and less wastage by cutting slits in the ground and injecting the slurry close to the roots of the grass.

Incorporation applies to arable soils only. Injection application of slurries is not possible on steeply sloping, stony, clayey, peaty or shallow soils, in which case trailing shoe or banded application may be preferable (c.f. in the following section).

Achieved environmental benefits

Table 9.31 summarises the NH_3 emission reductions achievable for different methods of slurry injection and incorporation, relative to the reference situation of broadcast application (e.g. via nozzle and splash-plate) to the soil surface without incorporation, based on TFRN (2011). Abatement efficiencies of up to 90% are possible with closed-slot deep injection, and 70% for open slot shallow injection. Immediate incorporation is similarly effective, though will require more energy and may have consequences for soil carbon depending on how incorporation fits into the soil preparation plan (see Chapter 6). Delayed incorporation is less effective.

DEFRA (2004) estimated 70% abatement efficiency for injection application of slurry compared with splash plate application, and a 60% reduction for manure incorporation within 2 hours (30% within 24 hours). More recently, it has been estimated that direct placement of slurry on tillage land can lead to an NH_3 emission reduction of 80% (Misselbrook et al., 2012).

Table 9.31. Best practice abatement techniques for slurry application to land determined by TFRN (2011)

Abatement measure	Land use	NH ₃ reduction (%)	Factors affecting reduction	Limitations to applicability	Cost (€/kg NH ₃ abated)
Injecting slurry (open slot)	Grassland	70%	Injection depth ≤ 5 cm	Unsuitable where: slope >15%; high stone content; shallow soils; high clay soils (>35%) in very dry conditions; peat soils (>25% organic matter content)	-0.5 – 1.5
Injecting slurry (closed slot)	Grassland Arable	80 (shallow slot 5-10 cm)	Effective slit closure		-0.5 – 1.2
Incorporation of surface applied slurry immediately by ploughing	Arable	90%	Efficiency depends on application method and weather conditions between application and incorporation		-0.5 – 1.0
Incorporation of surface applied slurry immediately by non-inversion cultivation		70%			-0.5 – 1.0
Incorporation within 4 hrs		45-65%			-0.5 – 1.0
Incorporation within 24 hrs		30%			0 – 2.0
<p>Slurry defined as flowable manure usually less than 12% dry matter. Material with a higher dry matter content or containing high amounts of fibrous crop residue may require pre-treatment (e.g. chopping or water addition) to be applied as a slurry, and should otherwise be handled as for solid manures Average values across UNECE region. Ranges reflect slight differences in techniques, management, weather conditions, etc.</p>					
<p>Source: TFRN (2011)</p>					

For solid manure, immediate incorporation by inversion ploughing can reduce NH₃ emissions by 90%. Non-inversion incorporation, and delayed incorporation, offer significant but reduced abatement (Table 9.32).

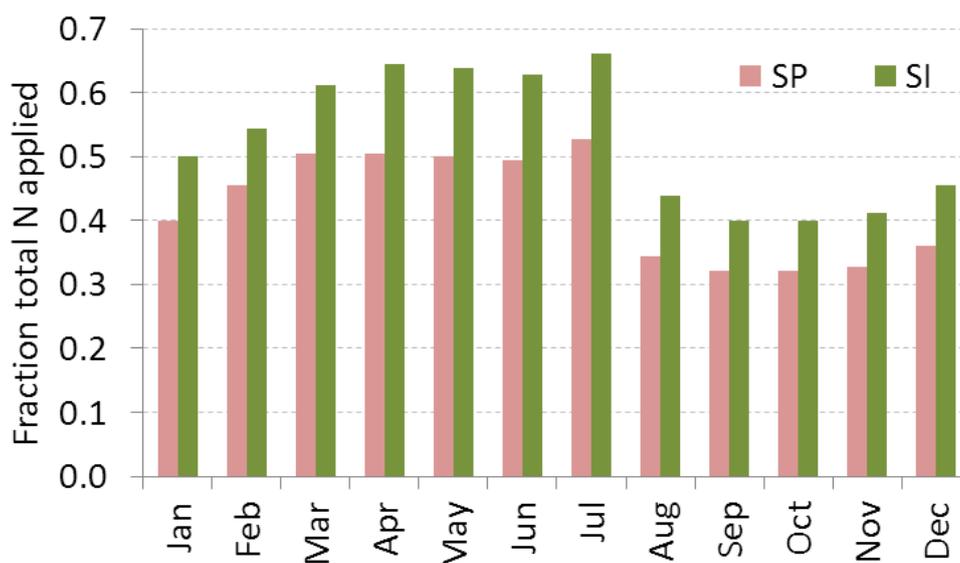
Table 9.32. Effectiveness of manure incorporation techniques determined by TFRN (2011)

Abatement measure	NH ₃ reduction (%)	Factors affecting reduction	Cost (€/kg NH ₃ abated)
Immediate incorporation: ploughing	90	Degree of burying the manure	-0.5–1.0
Immediate incorporation: non-inversion cultivation	60		0–1.5
Incorporation after 4 hrs	45–65	Degree of burying the manure. Efficiency depends on time of day of spreading and weather conditions between application and incorporation	0–1.5
Incorporation within 12 hrs	50		0.5–2.0
Incorporation within 24 hrs	30		0.5–2.0

Source: TFRN (2011)

Example: pig slurry on an arable farm

Nitrogen availability for plant uptake and losses were calculated for shallow injection slurry application and splash-plate application using the MANNER-NPK model (Figure 9.16). Shallow injection resulted in a greater proportion of applied N being available for plant uptake throughout the year when compared to splash plate application.



NB: Based on MANNER-NPK outputs for an arable farm with winter cereals in eastern England, assuming moist medium-textured (sandy-clay-loam) soils and moderate breeze. Assumes slurry application on the 15th of the month across the 12 months of the year for indicative purposes.

Figure 9.16. Calculated N availability for crop uptake following application of 50 t/ha (180 kg total N) pig slurry with splash-plate (SP) and shallow injection (SI) techniques in any given calendar month

Whilst there is conflicting evidence on the effect of slurry application methods on direct N₂O emissions, indirect N₂O emissions arising downwind of NH₃ emissions and downstream of NO₃ emissions (IPCC, 2006) should be reduced. Meanwhile, by increasing the fertiliser replacement value of slurries and manures, efficient application techniques can lead to significant reductions in farm upstream environmental burdens associated with synthetic fertiliser manufacture (Table 9.33).

Table 9.33. Change in ammonia and nitrate losses following application of 50 t/ha pig slurry (180 kg N/ha) in March using shallow injection instead of splash plate

Application method	Crop-available N	NH ₃	NO ₃	Fertiliser N application	Net CO ₂ e
	kg/ha				
Splash plate	81	41	16		
Shallow injection	98	13	20		
Change	+17	-28	+4	-17	-205

Appropriate environmental performance indicators

Spreading technique emission factors

The MANNER NPK tool is available online and is based on algorithms derived from extensive UK studies on ammonia emissions and nitrate leaching arising from organic amendments (ADAS, 2013). Based on data published regarding development of MANNER (DEFRA, 2004), the standard emission factor (EF) for cattle slurry is given as 32.4 % of TAN applied, which is then modified according to soil moisture, land use and slurry dry matter (DM) content at the time of application:

- soil moisture – dry (summer) EF1 = ‘standard’ EF x 1.3; moist (rest of year) EF1 = ‘standard’ EF x 0.7
- land use – grassland EF2 = EF1 x 1.15; arable EF2 = EF1 x 0.85
- slurry DM content – EF3 = EF2 x ((12.3 x DM) + 50.8)/100

Management indicators

- Employ efficient slurry application techniques (injection or immediate incorporation)
 - incorporation
- Calculate plant-available nutrients supplied by application technique type
 - (e.g. MANNER-NPK calculator)
- Analyse slurry for nutrient content (Section 5.3)
- Percentage of (%) volume slurry applied using efficient methods
- (Avoided) fertiliser requirement (kg/ha/yr.)
- Timing of slurry applications in relation to soil conditions (moisture content) and crop nutrient requirements

Performance indicators

Key indicators of whole-farm resource efficiency that should reflect benefits of this technique include:

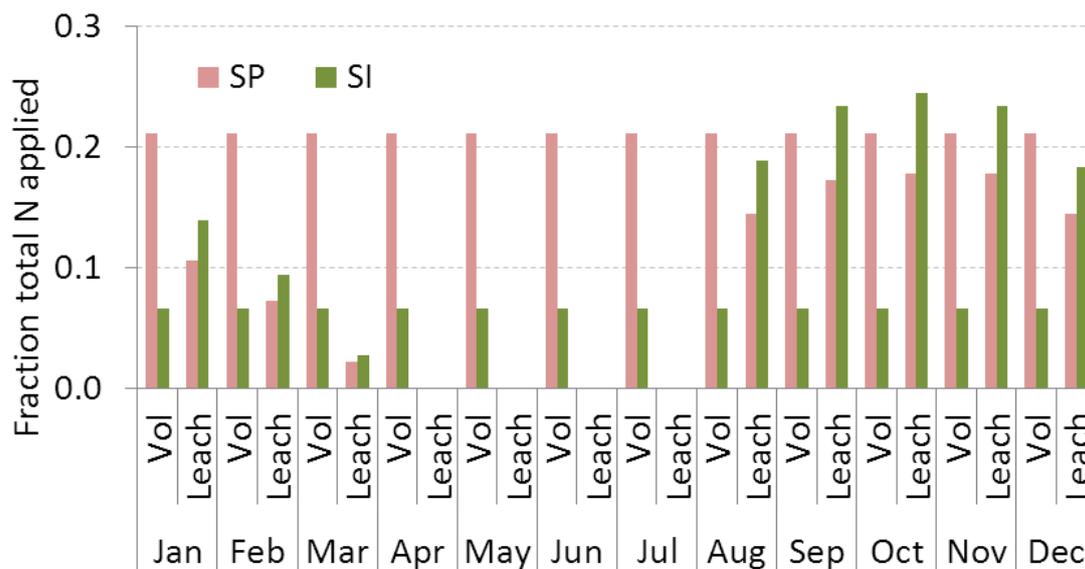
- Nutrient surplus (N and P)
- Nutrient use efficiency (N and P)
- Farm system lifecycle environmental burdens per unit output (e.g. CO₂e per tonne grain)

Cross-media effects

Eutrophication and nutrient balance

Where efforts are made to limit losses of nutrients to the wider environment, it is important to consider all forms of loss together at the farm scale, so as to avoid reducing losses in one form only to increase losses in another.

In the example below (Figure 9.17), splash plate application of slurry resulted in higher volatilisation of N (as ammonia-N) throughout the year compared with shallow injection. Shallow injection resulted in greater N leaching than splash plate application, principally in the autumn, but this represented a much smaller fraction of total N applied than that lost by volatilisation with the splash plate method. In addition, the higher availability of N following shallow injection means that less fertiliser N is applied, so that overall environmental burdens are significantly lower for shallow injection.



NB: Based on MANNER-NPK outputs for an arable farm with winter cereals in eastern England, assuming moist medium-textured (sandy-clay-loam) soils and moderate breeze. Assumes slurry application on the 15th of the month across the 12 months of the year for indicative purposes.

Figure 9.17. Calculated N loss through volatilisation (Vol) and leaching (Leach) following application of 50 t/ha (180 kg total N) pig slurry with splash-plate (SP) and shallow injection (SI) techniques in any given calendar month

GHG emissions

There is no clear evidence on N₂O emission effects arising from injection application of slurries compared with broadcast application. Injection application and manure incorporation require more energy (diesel) than broadcast application. However, total diesel consumption for all operations contributes just 10% to farm system GHG emissions, compared with 28% for fertiliser manufacture and 58% for soil emissions (e.g Figure 9.14) so any increase for slurry and manure application operations is not likely to have a major effect on lifecycle global warming potential. Considering the farm system as a whole, including avoided fertiliser application, and avoided indirect N₂O emissions, it is highly likely that the overall effect of injection application on GHG emissions will be beneficial (i.e. achieve a net lifecycle reduction).

The use of heavy equipment such as injection spreaders at inappropriate times, when soils are wet, can cause soil compaction, with consequent potential risk for water pollution – especially in late winter or early spring (EC, 2013).

Operational data

Spreading requirements

Figure 9.18 provides a simple diagrammatic representation of shallow injection slurry application. Shallow injection application of manures requires more fuel and more time than broadcast application

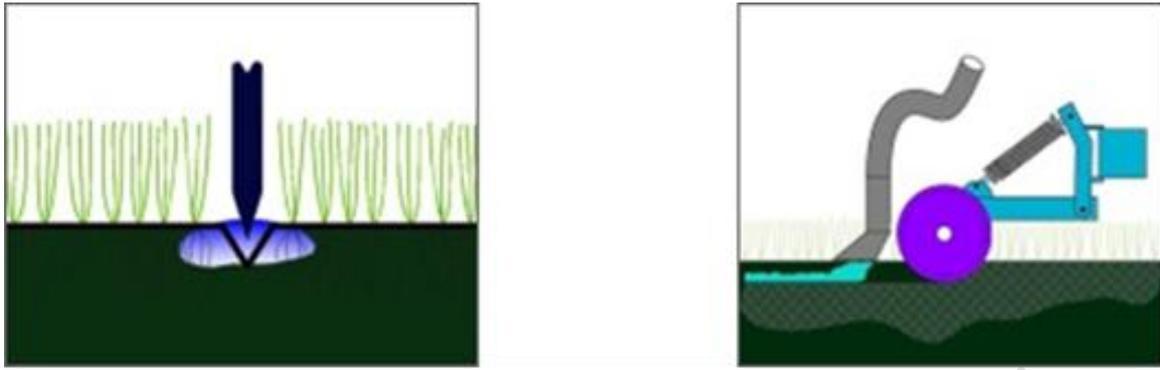


Figure 9.18. Simple schematic of shallow injection application of slurry

Shallow injection application of slurry may be combined with the umbilical hose technique, whereby slurry is fed to the spreader directly from the slurry store. This provides a fast work rate since repeated journeys to and from the store are not necessary, and this saves on fuel and soil compaction, although hoses can cause damage to crops and can potentially encourage spreading under wet soil conditions.

Application rates are determined by flow rate, bout width and forward speed.

$$\text{Forward speed (km/h)} = \frac{\text{Discharge rate (m}^3\text{/s)} * 36\,000}{\text{Bout width (m)} * \text{Application rate (m}^3\text{/ha)}}$$

Incorporation method

The method of incorporation has a significant influence on the efficiency of NH₃ abatement, as demonstrated by data presented in EC (2013) based on a meta-analysis by Webb et al. (2010) (Table 9.34).

Table 9.34. Summary of experimental results on NH₃ abatement through manure incorporation with different equipment

Equipment	Manure type	NH ₃ reduction Mean (range)
Plough	Slurry	92 (78–99)
Disc	Slurry	80 (69–90)
Tine	Slurry	66
Harrow	Slurry	68 (60–69)
Plough	Solid	91 (86–95)
Disc	Solid	63
Tine	Solid	57
Harrow	Solid	90

Source: EC (2013) cite Webb et al. (2010)

Additional environmental protection measures

Areas where spreading should be avoided include buffer zones close to surface waters, near surface or exposed drainage, soil cracked down to field drains, slopes, poorly drained, sandy soils over shallow groundwater, near to springs, boreholes or wells.

EC (2013) note that land spreading of manures should be avoided when the following risk factors are high. Land with a very high risk of run-off (water-saturated, snow-covered, frozen, flooded areas, watercourses, etc.) should be avoided.

In addition, the application of manure should be avoided in periods that are too dry and windy, or when soils are too wet. Optimum conditions to minimise NH₃ volatilisation are cool and humid conditions before or during light rain (TFRN, 2011).

Timing of application should also be as close to the period of crop demand as possible, as highlighted in Chapter 5 with respect to Nutrient Management Plan. Therefore, the farmers should calibrate spreaders for each type of material spread at least once per season. In parallel, should measure the nutrient content of slurries regularly. Ensure a representative sample is taken from material for analysis. This involves taking a number of subsamples (at least five) that are then bulked, mixed thoroughly, then resampled.

- First, agitate slurry – for four hours if slurry is in a large storage lagoon.
- Use an operator’s platform or reception pit and use a weighted bucket on a rope.
- Do not hang over the edge, or enter a below ground sump (gasses).

Dilution of slurries can also reduce volatilisation, though is unnecessary if a best practice application technique is employed. There is a positive linear relationship between slurry DM content (%) and the proportion of TAN lost as ammonia emission. A 50% reduction in in %DM (through dilution) will achieve approximately 30% reduction in ammonia volatilisation.

EC (2013) note the following recommended limits to the spreading rate on higher risk land, based on UK data:

- 50 m³/ha for pig/cattle slurry
- 50 t/ha for dry manure
- 5 – 15 t/ha poultry manure.

Applicability

Injection application of slurries is applicable to all arable and grassland soils. It works best for slurries with a low dry matter content, ideally <6%.

Injection application of slurries is not possible on steeply sloping, stony, clayey, peaty or shallow soils, in which case trailing shoe or banded application may be preferable (see §9.7).

Incorporation of slurries and manures is only applicable on arable soils.

Economics

Spreading costs

Compared with splash plates, injection applicators have slower work rate and higher tractor costs per unit of slurry spread. In addition, machinery, repair costs are higher for band spreaders, due to higher soil/machine contact and more moving parts (EC, 2013). The spreading cost premium, expressed per m³ spread, decreases as annual spreading quantities increase (Table 9.35). Smaller farms may benefit from pooling equipment in cooperatives, or using contractors who are able to cost-effectively invest in expensive spreading equipment.

Incorporating slurry or manures presents an additional cost for ploughing or alternative tillage operations.

Table 9.35. Spreading costs for reference broadcast spreading and injection and incorporation methods according to process capacity (farm or farm cooperative size)

Process capacity (m ³ /y)	1,000	3,000		10,000	30,000	100,000
		High	Low	Low	-	-
Spreading costs (€/m ³ slurry)						
Open slot injector	9.97	4.89	6.16	4.37	4.67	2.89
Closed slot injector	10.38	5.71	7.49	4.96	5.30	3.04
Incorporation < 1 hour	7.43	4.04	5.13	3.86	4.02	3.31
Incorporation < 4 hour	7.10	3.71	4.80	3.53	3.69	2.98

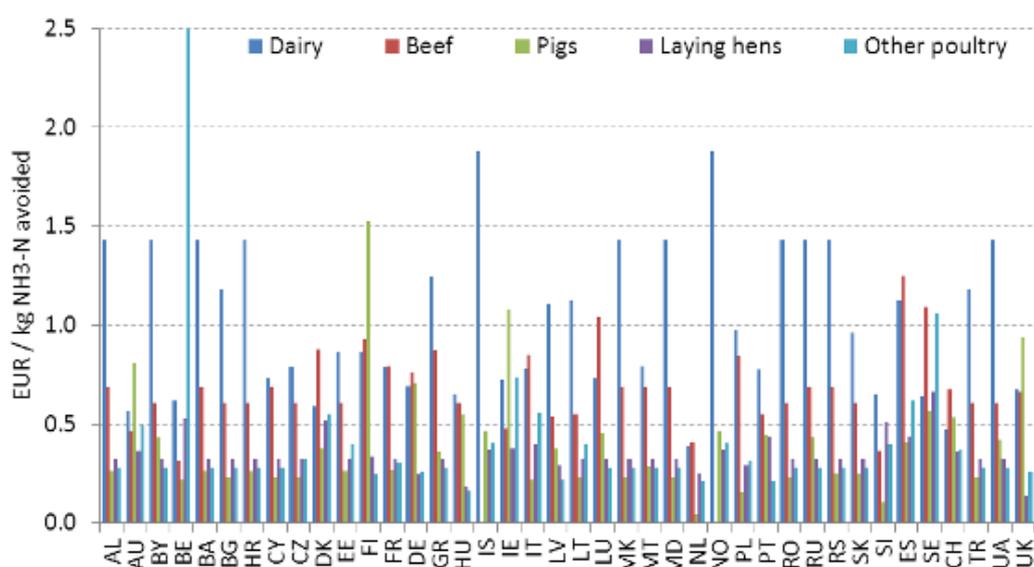
Source: EC (2013).

Klimont and Winiwarter (2011) report recent evidence from Webb et al. (2011) that emphasises the dependence of NH₃ abatement costs on the utilization rate of equipment. For large farms or for

contractors, the investment cost becomes less important. In a cost-optimized approach, small or medium sized farms would rely on contractor work. Labour costs and other country-specific parameters are important: GAINS modelling reported in Klimont and Winiwarter (2011) assumes a labour cost of 0.52 €/m³ manure spread.

Ammonia abatement costs

Table 9.36 summarises net abatement costs for different options. Figure 9.19 shows the wide variation in estimated NH₃ abatement costs for high- efficiency spreading techniques across countries and for different types of animal slurries from GAINS modelling in Winiwarter et al. (2011). Median values are displayed in Table 9.36. Values are lowest in the Netherlands (less than 0.5 €/kg NH₃-N for high-efficiency techniques). As indicated in Table 9.36, replaced fertiliser N is values at over one €/kg N, so that gross abatement costs below this value result in net economic savings (assuming precise NMP is implemented). High-efficiency spreading techniques result in net economic savings for all types of livestock slurries (Table 9.36).



NB: Excludes value of retained N

Source: Based on data from Winiwarter et al. (2011).

Figure 9.19. Ammonia abatement costs for high-efficiency spreading options such as injection calculated for European countries using the GAINS model

Table 9.36. Net abatement costs calculated from median European abatement costs for high efficiency (injection) slurry application techniques minus fertiliser replacement value of retained N (Winiwarter et al., 2011)

Slurry type	Abatement cost (€/kg NH ₃ -N avoided)	Fertiliser replacement value (€/kg N)	*Net cost (€/kg NH ₃ -N avoided)	**Estimated €/m ³ spread
Dairy	0.91	1.06	-0.15	
Beef cattle	0.67		-0.39	
Pigs	0.28		-0.76	
Laying hens	0.33		-0.73	
Other poultry	0.28		-0.78	
Median values = median values from European countries calculated using GAINS model (Winiwarter et al., 2011).				
*Assumes that each kg NH ₃ -N avoided replaces one kg fertiliser-N				

Driving forces for implementation

- Improved N use efficiency
- Restricted total N application rates in NVZs (Nitrates Directive)
- EU ammonia emissions ceiling
- Habitats Directive
- Various national initiatives to restrict N-enrichment of oligotrophic systems, e.g. Danish Agreement on Green Growth which requires for Natura 2000 sites a maximum total N deposition burden of 0.2-0.7 kg N/ha dependent on the number of livestock in the proximity and other sensitive habitats currently with buffer zone protection, a maximum total burden of 1 kg N/ha. For certain non-Natura 2000 areas currently without buffer zone protection, there are State guidelines on maximum over-burden of 1 kg N/ha (Danish Government, 2009).
- Reduced herbage contamination (especially for grassland used for grazing)

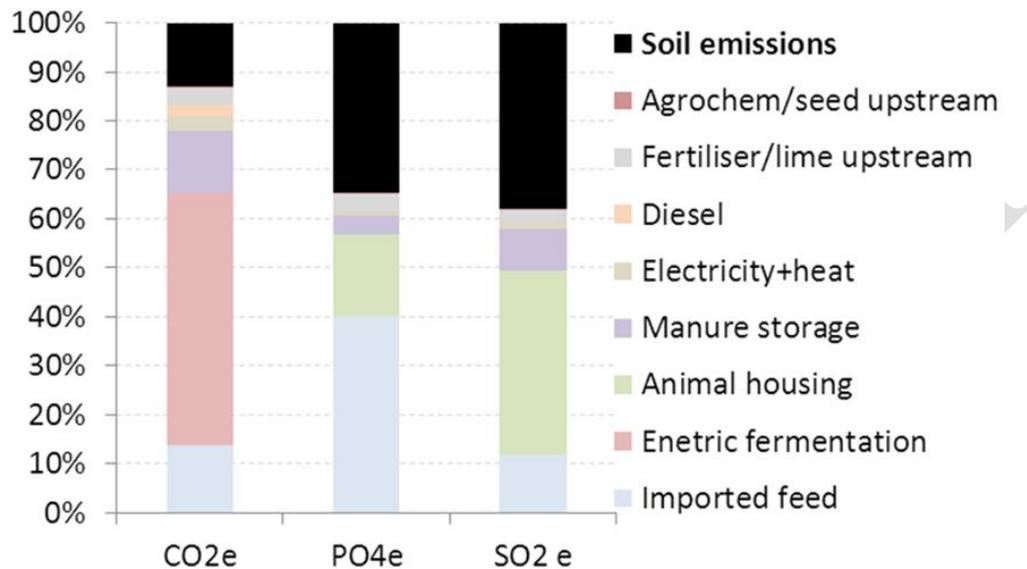
Reference literature

- ADAS, 2013. PLANET page for MANNER NPK. Accessed July 2013: <http://www.planet4farmers.co.uk/Manner>
- Bangor University, 2013. Farm LCA tool (Styles, D., Gibbons, J., 2013).
- Danish Government (2009). *Agreement on Green Growth*. Available at: www.mst.dk/NR/rdonlyres/56A2C35F-2A22-4AF5-A9DE-5AC1101B5E3D/0/DanishAgreementonGreenGrowth_300909.pdf
- DEFRA, 2004. Research project KT0106 MANNER-Policy Support Model, Final Report. Defra, London, UK. 34 pp.
- FAO, 1999. Proper Manure Application to Land. Food and Agriculture Organization of the United Nations, available online: <http://www.fao.org/ag/againfo/programmes/en/lead/toolbox/Index.htm>, accessed January 2015.
- EC, 2013. *Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry and Pigs. Draft 2 (August, 2013)*. IPTS, Seville.
- IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from <http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>
- Klimont, Z., Winiwarter, W., 2011. *Integrated ammonia abatement – Modelling of emission control potentials and costs in GAINS*. IIASA, Laxenburg.
- Misselbrook, T.H., Gilhespy, S.L., Cardenas, L.M. (Eds.) (2012). *Inventory of Ammonia Emissions from UK Agriculture 2011*. DEFRA, London.
- TFRN, 2011. *Draft Guidance document for preventing and abating ammonia emissions from agricultural sources*. WGSR Informal document no. 21.
- Webb, J., Pain, B., Bittman, S., and Morgan, J. 2010. The impacts of manure application methods on emissions of ammonia, nitrous oxide and on crop response - A review, *Agriculture, Ecosystems and Environment*, 137: 39-46. doi: 10.1016/j.agee.2010.01.001.
- Winiwarter, W., Klimont, Z., Sutton, M., 2011. *Summary of ammonia abatement costings in GAINS*. Spreadsheet 2b. TFRN.

9.7 Injection slurry application to grassland

Description

Slurry applications are responsible for almost all soil emissions of NH₃, which contribute towards 38 % of the lifecycle acidification burden arising on intensive dairy farm systems (Figure 9.20). Slurry emissions are also responsible for a large share of soil GHG (N₂O) emissions and eutrophying (mainly NH₃, NO₃ and P) emissions.



Data for a large dairy farm where animals housed for 10 months of the year.

Source: Bangor University Farm LCA tool

Figure 9.20. The contribution of soil emissions towards total global warming, eutrophication and acidification burdens on a large dairy farm with tank storage of slurry

Band spreading of slurry reduces the surface area of slurry exposed to the air compared with splash plate application by placing slurry in narrow bands on the crop canopy. A development of band spreading is the trailing-shoe application system in which a metal shoe parts the herbage and slurry is deposited in bands on the soil surface, with the minimum of herbage contamination. Trailing shoe reduces slurry N losses from ammonia volatilisation and results in less contamination of grass for grazing and/or silage making. Livestock can be returned to pasture sooner and palatability (grazing efficiency) is maximised. Figure 9.18 provides a simple schematic representation of trailing shoe and injection application of slurry.

Achieved environmental benefit

Ammonia abatement efficiencies

DEFRA (2004) estimated that the following abatement efficiencies for trailing shoe and band spreading application of slurry compared with splash plate application:

- Trailing shoe – abatement efficiency of 60%
- Band spreading – abatement efficiency of 30%.

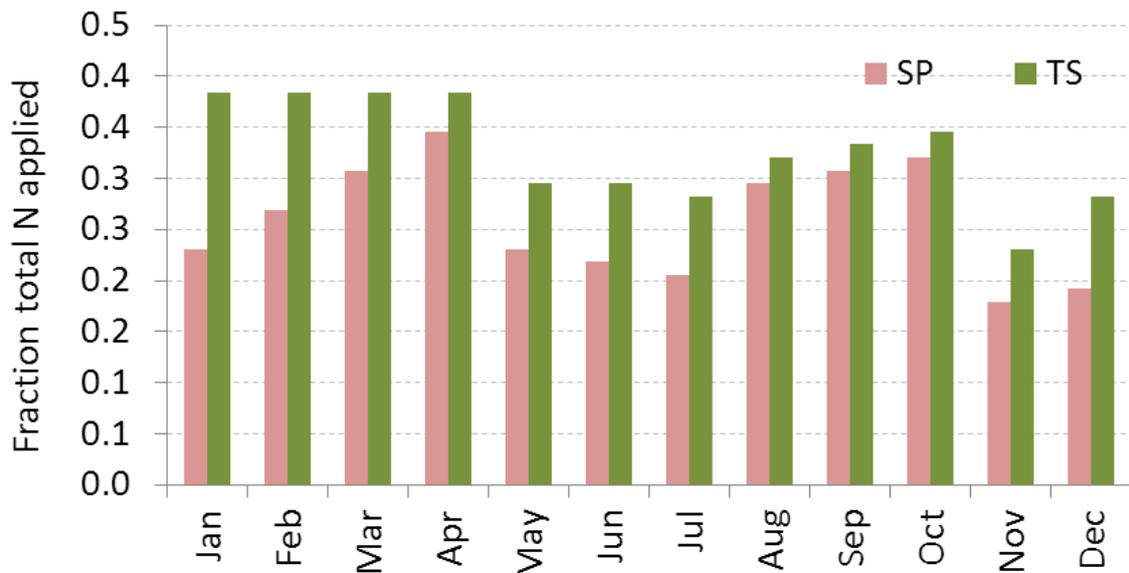
These correspond closely with average abatement efficiencies for these application methods, compared with broadcast application, calculated for the UNECE region (Table 9.37).

Table 9.37. Best practice abatement techniques for slurry application to land determined by TFRN (2011)

Abatement measure	Land use	NH ₃ reduction (%)	Factors affecting reduction	Limitations to applicability	Cost (€/kg NH ₃ abated)
Bandspreading slurry with a trailing hose	Grassland Arable	30-35%	More crop canopy will increase reduction, depending on placement precision and the extent of herbage contamination.		-0.5 – 1.5
Band spreading with trailing shoe	Grassland Arable (pre-seeding) and row crops	30-60%	More crop canopy will increase reduction, depending on placement precision and the extent of herbage contamination	Not suitable for growing solid seeded crop or	-0.5 – 1.5
<p>Slurry defined as flowable manure usually less than 12% dry matter. Material with a higher dry matter content or containing high amounts of fibrous crop residue may require pre-treatment (e.g. chopping or water addition) to be applied as a slurry, and should otherwise be handled as for solid manures Average values across UNECE region. Ranges reflect slight differences in techniques, management, weather conditions, etc.</p> <p><i>Source:</i> TFRN (2011).</p>					

MANNER-NPK is a practical software tool that is widely used by farmers and advisers in the UK to provide a quick estimate of crop available nitrogen, phosphate and potash supply from organic manure applications. It has N transformation/loss modules covering ammonia volatilisation, nitrate leaching and nitrous oxide/di-nitrogen emissions and organic N mineralisation. It also estimates manure phosphate, potash, sulphur and magnesium supply and N availability estimates for following crops through the mineralisation of organic N.

Trailing shoe technique results in a greater proportion of applied N being available for plant uptake throughout the year when compared to splash plate application (Figure 9.21), thus maximising crop response to a given level of N input and associated soil emissions.



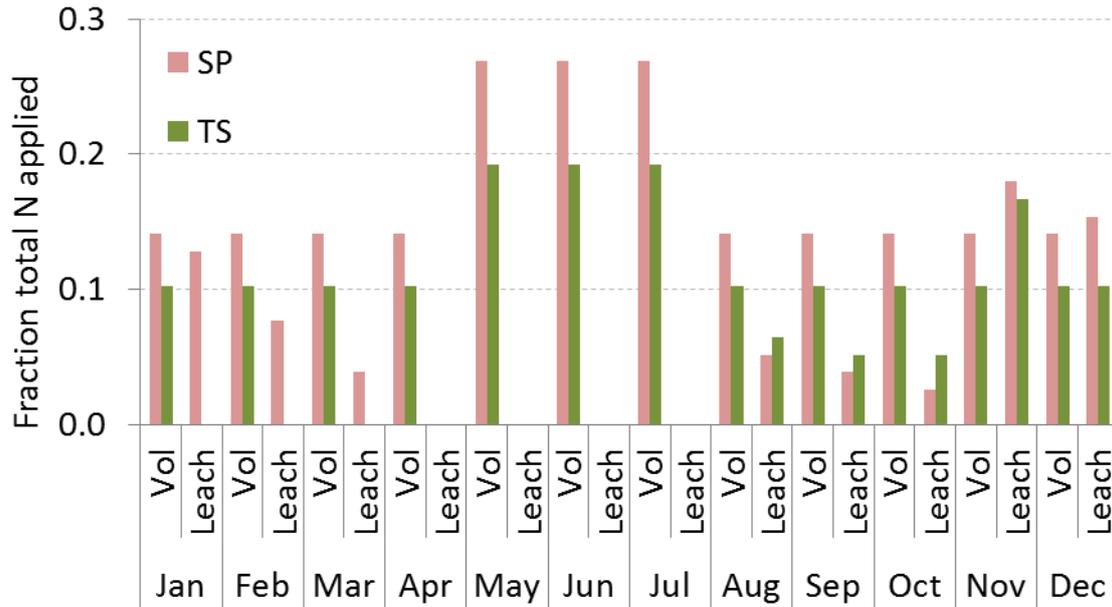
NB: Based on MANNER-NPK outputs for grassland in south-western England, assuming moist medium-textured (sandy-clay-loam) soils and moderate breeze. Assumes slurry application on the 15th of the month across the 12 months of the year for indicative purposes.

Figure 9.21. Calculated N availability for crop uptake following application of 30 t ha⁻¹ (78 kg total N) cattle slurry with splash-plate (SP) and trailing shoe (TS) techniques in any given calendar month

In addition, compared with the traditional splash plate method, the trailing shoe technique reduces the amount of slurry N loss via volatilisation throughout the year and via leaching losses, for most of the year. The example given in Figure 9.22 is for cattle slurry on dairy and beef farms.

Overall environmental benefit

Thus, overall, trailing shoe application results in lower NH₃ and NO₃ emissions per hectare and higher crop-available N following slurry application (Table 9.38). Therefore, to achieve the same yield, less synthetic fertiliser is required leading to additional lifecycle benefits from avoided fertiliser manufacture and avoided fertiliser application emissions.



NB: Based on MANNER-NPK outputs for grassland in south-western England, assuming moist medium-textured (sandy-clay-loam) soils and moderate breeze. Assumes slurry application on the 15th of the month across the 12 months of the year for indicative purposes.

Figure 9.22. Calculated N loss through volatilisation and leaching following application of 30 t ha⁻¹ (78 kg total N) cattle slurry with splash-plate (SP) and trailing shoe (TS) techniques in any given calendar month.

Table 9.38. Change in ammonia and nitrate losses following application of 30 t/ha cattle slurry (78 kg N/ha) in February using trailing shoe instead of splash plate

Application method	Crop-available N	NH ₃	NO ₃	Fertiliser application	Net CO ₂ e
	kg per ha				
Splash plate	21	13	27		
Trailing shoe	30	10	0		
Change	+9	-4	-27	-9	-89

Case study farm use of trailing shoe technique

On a Welsh dairy farm described below, slurry application with trailing shoe equipment has provided much more flexibility with respect to the timing of slurry application, and has improved the placement of slurry to minimise run-off risk. It has also improved yields through more uniform and predictable grass growth across the grazing area.

Owing to improved fertiliser replacement value of slurry following trailing shoe application, fertiliser usage has reduced on grazing land and on fodder maize land, by up to 50%.

In addition, trailing shoe application places slurry on to the ground and does not coat grass, making it more palatable to livestock. Earthworm numbers appear to have improved as there is now a “refuge” between slurry trails which aids soil aeration. In general, the visual appearance of the grazing leys has improved considerably since the introduction of the new spreading system with more even grass colour and growth (Figure 9.23).



Figure 9.23. Trailing shoe assembly fed by umbilical system showing clean placement of slurry.

Appropriate environmental performance indicators

Spreading technique emission factors

The MANNER NPK tool is available online and is based on algorithms derived from extensive UK studies on ammonia emissions and nitrate leaching arising from organic amendments (ADAS, 2013).

Based on data published regarding development of MANNER (DEFRA, 2004), the standard emission factor (EF) for cattle slurry is given as 32.4 % of TAN applied, which is then modified according to soil moisture, land use and slurry dry matter (DM) content at the time of application:

- soil moisture – dry (summer) EF1 = ‘standard’ EF x 1.3; moist (rest of year) EF1 = ‘standard’ EF x 0.7
- land use – grassland EF2 = EF1 x 1.15; arable EF2 = EF1 x 0.85
- slurry DM content – EF3 = EF2 x ((12.3 x DM) + 50.8)/100

Management indicators

- Employ efficient slurry application techniques (banded or trailing shoe application)
- Calculate plant-available nutrients supplied by application technique type (e.g. MANNER-NPK calculator)
- Analyse slurry for nutrient content (Section 5.3)
- Percentage of (%) volume slurry applied using efficient methods
- (Avoided) fertiliser requirement (kg/ha/yr)
- Timing of slurry applications in relation to soil conditions (moisture content) and crop nutrient requirements

Performance indicators

Key indicators of whole-farm resource efficiency that should reflect benefits of this technique include:

- Nutrient surplus (N and P)
- Nutrient use efficiency (N and P)
- Farm system lifecycle environmental burdens per unit output (e.g. CO₂e per tonne grain)

Cross-media effects

Trailing shoe application can result in some additional N leaching throughout the year, compared with splash plate application, owing to the greater quantity of N delivered to the soil. Nonetheless, this effect is of lesser importance than avoided NH₃ emissions (Figure 9.222).

The rate of slurry application may be reduced somewhat, and therefore fuel consumption increased, relative to splash-plate application. However, no significant additional fuel costs were reported for the Rhual dairy farm case study of trailing shoe implementation (described below).

Some farms utilise an umbilical system where a flexible hose is pulled up and down the field which reduces transport cost and may reduce nuisance in terms of transport along the highways and through residential areas (see Figure 9.23). Soil compaction is also reduced with umbilical systems and there is less soil damage/rutting than with a conventional spreader.

A cross media effect of crust-busting to enable use of trailing shoe application systems, especially with umbilical systems, is the significant increase of ammonia volatilisation from storage areas.

Operational data

Umbilical hose

The use of an umbilical hose, whereby slurry is fed to the spreader directly from the slurry store, provides a fast work rate since repeated journeys to and from the store are not necessary and this saves on fuel and soil compaction but hoses can cause damage to crops and potentially can result in spreading under wet soil conditions (Martin Price, 2013).

Application rates are determined by flow rate, bout width and forward speed.

$$\text{Forward speed (km/h)} = \frac{\text{Discharge rate (m}^3\text{/s)} * 36,000}{\text{Bout width (m)} * \text{Application rate (m}^3\text{/ha)}}$$

Spreading exclusion zones

Areas where spreading should be avoided include:

- Buffer zones close to surface waters
- Near surface or exposed drainage systems
- Soil cracked down to field drains
- Steep slopes
- Poorly drained soils
- Sandy soils over shallow groundwater
- Near a spring, borehole or well.

Spreading should be avoided during or before forecast heavy rain, snow, frozen soil, wet soil, warm humid conditions (odour control).

Slurry nutrient management

Calibrate spreaders for each type of material spread at least once per season. Analyse slurry at least annually (also Section 5.3). Ensure a representative sample is taken from material for analysis. This involves taking a number of subsamples (at least five) that are then bulked, mixed thoroughly, then resampled.

- First, agitate slurry – for four hours if slurry is in a large storage lagoon.
- Use an operator's platform or reception pit and use a weighted bucket on a rope.
- Do not hang over the edge, or enter a below ground sump (gasses).

Applicability

Trailing shoe application systems can be utilised at most farms that are producing slurry. If the farmer does not have their own tanker, contractors have the spreading equipment necessary and can typically spread at a rate of 1.6 – 4.0 ha/hour depending upon pump rates if using an umbilical system.

One potentially limiting factor for trailing shoe application is slurry "thickness". Contractors using an umbilical system require a "thin" consistency, whereas tanker based systems can cope with "thicker" slurries.

Crusting of lagoons is an issue that has caused problems in the past. In order to break this crust, stirring can be a time consuming activity. There are some bacteriological products available to farmers that can break down the crust but the norm is to use a tractor mounted stirrer in a lagoon or a power take-off driven stirrer mounted as a propeller in a steel tower or the use of a “jetting” action via the reception pit pump.

Economics

Equipment costs

For the Rhual dairy farm case study, the trailing shoe slurry tanker cost £ 28,000, in the order of £ 15,000 more than for a conventional “splash plate” slurry spreader. There was no need to up-rate tractor in this case (140 HP tractor is used as before on previous splash plate tanker).

From UK, the approximate investment costs for trailing shoe machines, without the tractor, are reported (prices February 2009, at the exchange rate of €/\$ = 0.88) between 32,000 € and 46,500 € for a tanker mounted machine and 15,500 € for an umbilical mounted machine (EC, 2013). A trailing hose system with the same capacity as broadcast spread system is judged to have an additional price of approximately 15,000 €. Yearly annual running costs are considered around 1 €/m³/year (from 0.9 to 1.1 €/m³/year) (EC, 2013).

Spreading costs

Compared with splash plates, band spreaders have slower work rate and higher tractor costs per unit of slurry spread. In addition, machinery, repair costs are higher for band spreaders, due to higher soil/machine contact and more moving parts (EC, 2013 cite Webb et al. 2010).

Overall spreading costs for different spreader types and annual spreading capacities are displayed in Table 9.39.

Table 9.39. Spreading costs for reference broadcast spreading, trailing hose and trailing shoe application methods according to process capacity (farm or farm cooperative size)

Process capacity (m ³ /y)	1,000	3,000		10,000	30,000	100,000
		High	Low	Low	-	-
Spreading costs (€/m ³ slurry)						
Broadcast spreader	6.61	3.22	4.31	3.04	3.19	2.49
Trailing hose	8.76	3.99	5.08	3.38	3.32	2.57
Trailing shoe	9.68	4.63	5.87	4.11	4.10	-

Source: EC (2013)

Experimental data on grass yields following different slurry application methods suggests that the net benefits of band spreading or trailing shoe application compared with broadcast application may be greater than indicated by TAN conservation as modelled in MANNER-NPK and similar tools. Research at AFBI-Hillsborough (Frost et al., 2006), Northern Ireland demonstrated a yield increase in grass silage resulting from band spread or trailing shoe (Table 9.39) equivalent to mineral fertiliser N of 79 kg/ha, on average, compared with splash plate application. Reduced sward contamination and delivery of N closer to roots may explain some of this benefit. .

Table 9.40. Silage DM yields as affected by differing slurry delivery techniques.

Time of application	Method of application (Grass yield, t DM/ha)			
Slurry application date	No slurry	Splash plate	Band spread	Trailing shoe
May 21	4.26	4.88	5.09	5.63
May 29	3.87	4.60	5.70	5.47
June 4	4.04	4.06	5.33	5.30

Source: Frost et al. (2006).

Replacement of splash-plate spreading with more precise trailing shoe application means that smaller buffer zones are permitted alongside watercourses (6 metres rather than 10 metres for conventional spreaders), so that field margins and yields in those areas can benefit from organic manure additions.

Overall emission abatement costs

Research (Webb et al., 2010) showed that the value of manure N conserved via a reduction in ammonia emissions makes the use of trailing shoe or injection equipment either low- or no-cost (Table 9.41). Oenema et al., (2012) report costs of a range of low-emissions techniques are in the range -0.5 to 1.5 €/kg NH₃-N saved (Table 9.41). However, the net abatement costs are presented in BEMP 1.3.

Table 9.41. Cost benefit of trailing shoe and injection techniques

Application method	Surface	Trailing shoe	Slot injection
Slurry m ³ /ha	30	30	30
N applied kg/ha	108	108	108
Ammonia emission kg N/ha	20	8	6
Abatement %	0	60	70
N conserved kg/ha	0	11.9	13.8
Value of conserved N £/30 m ³ (April 2012 prices)	0	11.5	13.4
Value of conserved N uptake £/m ³ slurry	0	0.38	0.45
Additional contractor cost for abatement £/m ³ slurry		0.42	0.42
Net cost £/m³ slurry		0.40	-0.03

Source: FAS (2012) referencing Webb et al. (2010)

Driving forces for implementation

The main driving forces for slurry separation and trailing shoe slurry application at the Rhual case study dairy farm were:

- Need to comply with NVZ Action Programme Measure for minimum storage capacity (5 months).
- Desire to expand dairy herd in the short term whilst also allowing for future expansion as additional land becomes available, within NVZ constraints.
- Recognition that the full nutrient value of on-farm produced wastes not being utilised, and thus there were opportunities for improved business efficiency.
- Improved pasture palatability because of reduced contamination means more grazing days (shorter hold-off period).

In addition to reduced fertiliser costs and associated exposure to price volatility, and the Nitrates Directive referred to above, a number of other regulations drive the use of efficient slurry application equipment:

- EU ammonia emissions ceiling
- Habitats Directive
- Initiatives to restrict N-enrichment of low-N habitats/ systems, e.g. Danish Agreement on Green Growth which requires for Natura 2000 sites, a maximum total N deposition burden of 0.2 - 0.7 kg. N/ha dependent on the number of livestock in the proximity and other sensitive habitats currently with buffer zone protection, a maximum total burden of 1 kg N/ha. For certain non-Natura 2000 areas currently without buffer zone protection, there are State guidelines on maximum over-burden of 1 kg. N/ha (Danish Government, 2009).

- The Water Resources (Control of Pollution) Silage, Slurry and Agricultural Fuel Oil Regulations (Wales) 2010 (“SSAFO Regulations”)

Reference organisations

Advice/Guidance is provided by the following organisations:

- DEFRA/ADAS reports and tools such as PLANET and MANNER NPK software
- UNECE and TFRN best practice for reducing ammonia emissions

Reference literature

- ADAS, 2013. PLANET page for MANNER NPK. Accessed July 2013: <http://www.planet4farmers.co.uk/Manner>
- Bangor University, 2013. Farm LCA tool (Styles, D., Gibbons, J., 2013).
- Dairyman, 2014. Slurry application technique website. Last accessed February 2014: <http://www.interregdairyman.eu/en/dairyman/show/Comparison-of-different-slurry-application-techniques.htm>
- Dairyman, 2013. Slurry management website. Last accessed December 2013: Fertiliser www.interregdairyman.eu/about-dairyman/innovations/slurry-and-fertilizer-management/
- Danish Government, 2009. *Agreement on Green Growth*. Available at: www.mst.dk/NR/rdonlyres/56A2C35F-2A22-4AF5-A9DE-5AC1101B5E3D/0/DanishAgreementonGreenGrowth_300909.pdf
- DEFRA, 2004. *Research project KT0106 MANNER-Policy Support Model, Final Report*. Defra, London, UK. 34 pp.
- EC, 2013. Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry and Pigs. Draft 2 (August, 2013). IPTS, Seville.
- Environment Agency Wales, 2010. *Silage, slurry and agricultural fuel oil storage. The Water Resources (Control of Pollution) Silage, slurry and agricultural fuel oil Silage, Slurry and Agricultural Fuel Oil Regulations 2010 (SSAFO)*. Publ. Environment Agency Wales, Cardiff.
- Frost, J.P., Caskie, P., Mulholland, M., 2006. *Alternative slurry spreading systems*. AFBI Technical Note for Slurry Event, June 2006.
- Misselbrook, T.H., Gilhespy, S.L., Cardenas, L.M. (Eds.), 2012. *Inventory of Ammonia Emissions from UK Agriculture 2011*. DEFRA, London.
- Oenema, O., Velhof, G., Klimnot, Z., Winiwarter, W., 2012. *Emissions from agriculture and their control potential. TSAP Report # 3, version 2.1*. Ed. M. Amann. EU DG Environment contract ENV C.3./SER/2011/0009. 47 pp.
- Price, M. (2013). Personal communication 27.03.2013
- Smith, K.A., D.R. Jackson, T.H. Misselbrook, B.F. Pain, and R.A. Johnson. 2000. Reduction of ammonia emission by slurry application techniques. *Journal of Agricultural Engineering Research* 77:277-287.
- TFRN, 2011. *Draft Guidance document for preventing and abating ammonia emissions from agricultural sources*. WGSR Informal document no. 21.
- Webb, J., Pain, B., Bittman, S., and Morgan, J. 2010. The impacts of manure application methods on emissions of ammonia, nitrous oxide and on crop response - A review, *Agriculture, Ecosystems and Environment*, 137: 39-46. doi: 10.1016/j.agee.2010.01.001.
- Winiwarter, W., Klimont, Z., Sutton, M., 2011. *Summary of ammonia abatement costings in GAINS*. Spreadsheet 2b. TFRN.

9.7.1 Trailing shoe application case studies

Dairy farm case study

Rhual Dairy Farm in Mold, Flintshire (UK), invested in a trailing shoe slurry application system in 2011. The farm partnership decided that in order to maximise benefit available from farm produced slurry it was necessary to invest in machinery and sufficient storage capacity to enable more effective management of the farm wastes. The farm is a 240 ha holding of owned and rented land supporting a 350 cow milking herd plus 100 followers. Problems in the past using conventional “splash plate” slurry spreading equipment had resulted in coating of grass, sward rejection by grazing stock and variation in spreading patterns and volumes. With the imposition of the NVZ Action programme measures, it was decided that additional storage in the form of a second, above-ground steel slurry tower and the purchase of a trailing shoe tanker/spreader would enable much more efficient use of nutrients.

As a result, the management improvements have seen a significant reduction in bought in fertiliser as shown below for the grazing land:

- 2010: 124.1 tonnes
- 2011: 117.1 tonnes
- 2012: 84.6 tonnes
- 2013: likely to be less than the 2012 figure

These savings translate into significant cost savings compared with the 2010 baseline:

Fertiliser savings 2012	39.5 tonnes @ £320/tonne = £12,640
Fertiliser savings 2011	7.0 tonnes @ £270/tonne = £1,890
Total savings to date	£14,530

The farmer has used the PLANET computer software to assist with fertiliser recommendations with regular soil testing being undertaken on a rotational basis to confirm the decision making process.

Consideration had been given to purchasing a slurry injector however, as with most contractors in North Wales, these were found to be expensive to maintain (broken discs etc.) particularly given the limited soil depth at many sites and caused some problems on heavier ground where stock were uprooting clods of grass/soil resulting in a poor surface and, in some cases, stock injury.

As the farm is in close proximity to a residential area, it was considered that the use of the trailing shoe system would reduce odour problems compared to conventional splash plate spreading as well as reducing ammonia emissions by as much as 80% and thus providing additional nutrient source to the target crop. One factor that was critical to using the system was ensuring that there was around 2 inches (5 cm) of grass cover to minimise N loss. Whilst this is not difficult on grazing land for cattle this was a critical factor for careful management where sheep were grazing.

The farm now has over 6 months slurry production capacity provided by the two slurry towers as well as a Low Rate Irrigation system that can be utilised for the spreading of milking parlour wash water year round as permitted by the NVZ Action Programme Measures. If the slurry is considered to be getting too “thick” then the parlour wash water can be directed to the slurry tower reception pit.

The slurry reception pit has over 48 hours capacity (as required under the terms of the SSAFO Regulations) with a number of waste minimisation practices being employed to reduce the amount of clean, uncontaminated roof and yard water entering the slurry storage system. These include the installation of guttering on all the farm buildings with a maintenance programme to ensure that any damage (e.g. from snow slides or machinery) is repaired, water harvesting roof water to use for washing down collecting yards, installation of simple “sleeping policeman” type barriers to keep

clean and foul water apart. With the average cost of water per cow per annum running at around £70 (EUR 82) it is important to utilise as much rainwater as possible to keep a check on rising water costs.

In terms of slurry storage capacity, the farm is fully compliant with the NVZ Action Programme Measures and, indeed, those Measures have prompted the farmer to make changes to improve farm efficiency and viability. Financial assistance of 40% for the additional storage was provided in part through the Welsh Government as part of the Catchment Sensitive Farming/NVZ grant scheme.

FINAL DRAFT

10 IRRIGATION

Introduction

Between 1960 and 2010, global water consumption has more than doubled and currently stands at 1,970 cubic kilometres per year (km³/y). Over that period, industrial water use has tripled, and the rise in population has led to five times higher domestic water consumption. But the greatest portion of that water consumption is the result of agricultural irrigation (Figure 10.1), which has almost doubled over the last 50 years and is currently estimated at about 1,403 km³/y. This rise in water consumption has increased the frequency and intensity of periods of abnormally low flow in streams by 30% globally, largely due to use of water for irrigation (Wada et al., 2013).

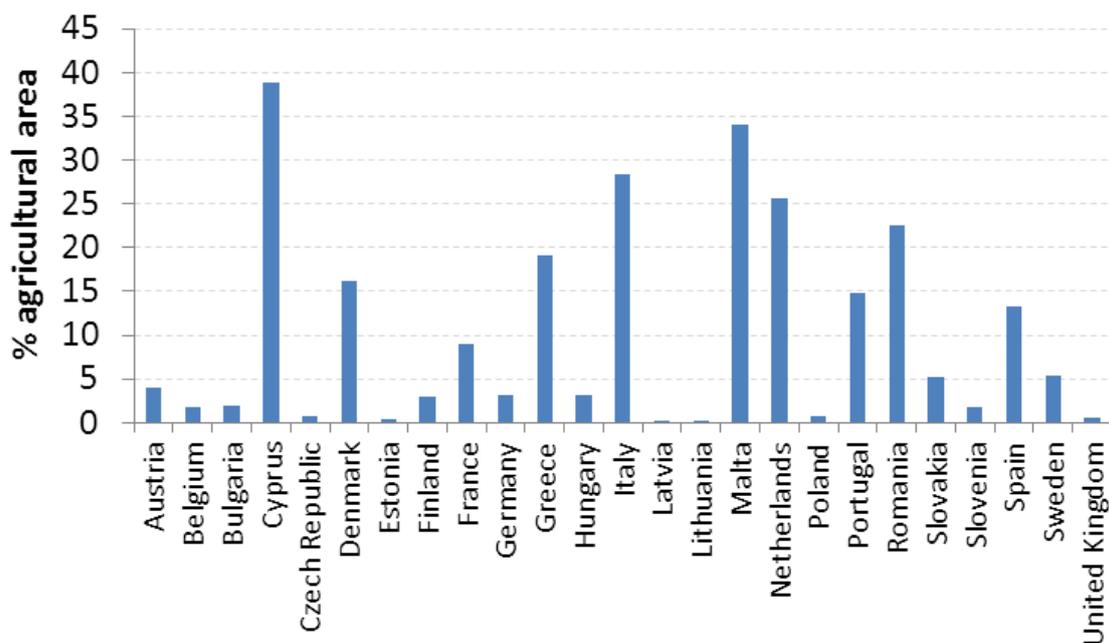


Figure 10.1. Percentage of agricultural area equipped for irrigation across EU member states in 2011
FAO Stat (2013).

Irrigated agriculture is a major water consumer and accounts for about two thirds of the total fresh water used by human activities. However, irrigation is very important to allow high levels of productivity of agriculture, especially in water stressed areas such as the Mediterranean basin. Much of the food production (about 40%) in the Mediterranean area is associated with irrigation. The amount of water used is such that irrigation accounts for 72% of the current freshwater withdrawals across the Mediterranean area (UNESCO, 2006). Since 1990s, increasing drought in the Mediterranean area of Europe has forced the implementation of additional irrigation, increasing the proportion of the total cultivated area that is irrigated. Ayman (2013) estimates that areas receiving supplemental irrigation have gradually increased to becoming more than 50% of the rainfed agricultural area. This situation is getting worse because the water demand of irrigated agriculture is related to climate dependent crop evapotranspiration, which will increase in the Mediterranean region as a result of climate change.

It is therefore crucial that the irrigation efficiency in agriculture is improved by adopting irrigation strategies that save water and maintain satisfactory yields, while contributing to the preservation of the biodiversity of the irrigated and nearby area (Feres and Evans, 2006; Patané et al., 2011).

In this chapter techniques to minimise the irrigation demand are analysed, as well as the methodology for calculating the crop water requirements, which is an important element when installing an

irrigation management system. Efficient existing irrigation management techniques are also presented (systems that already have been implemented by various companies and that have achieved significant water savings as well as crop yields increase). This information is structured in four BEMPs:

1. Agronomic methods for optimising irrigation - Soil management and crop water requirements
2. Optimisation of irrigation delivery
3. Management of irrigation systems
4. Efficient and controlled techniques

Reference literature

- Ayman A.H. (2013), Protected cultivation for improving water-use efficiency of vegetable crops in the NENA region, in: Good Agricultural Practices for greenhouse vegetable crops - Principles for Mediterranean climate areas, study title, ISBN 978-92-5-107649-1.
- Fereres E. and Evans R.G. (2006), Irrigation of fruit trees and vines, *Irrigation Science*, 24, 55–57.
- Patanè C., Tringali S., Sortino O. (2011), Effects of deficit irrigation on biomass, yield, water productivity and fruit quality of processing tomato under semi-arid Mediterranean climate conditions, *Scientia Horticulturae*, 129, 590-596.
- UNESCO (2006), Non-renewable groundwater resources: A guidebook on socially sustainable management for water-policymakers. IHP-VI, Series on Groundwater 10, 103.
- Wada, Y., van Beek, L. P. H., Wanders, N., et al. (2013). Human water consumption intensifies hydrological drought worldwide. *Environmental Research Letters*. 8 (3):1-14. DOI: 10.1088/1748-9326/8/3/034036; available online at: <http://iopscience.iop.org/1748-9326/8/3/034036>.

10.1 Agronomic methods for optimising irrigation - Soil management and crop water requirements

Description

The soil contains mineral and organic materials, which are valuable for the growth of the plants. In particular, soil acts as a storehouse for plant nutrients, as a habitat for soil organisms and plant roots and as an important factor that should be taken into account in the calculation of the crop/plant water requirements (FAO, 2002).

The soil texture and its physico-chemical characteristics/properties determine the amount of the water should be delivered to the plant as well as setting the main parameters for establishing the irrigation scheduling strategy.

Towards the establishment of an efficient irrigation system, the following parameters should be taken into consideration:

- Soil management
- Crops selection
- Precise calculation of crop water requirements
- Irrigation scheduling and
- Water quality

Soil management

The soil's moisture-holding capacity, intake rate and depth are the principal criteria affecting the type of system selected. As a general rule, sandy soils have high intake rates and low soil moisture storage capacities and may thus require a different irrigation strategy as compared with the deep clay soil that has low infiltration rates but high moisture-storage capacities. In addition, sandy soils require smaller and more frequent applications of water, while clay soils are irrigated less frequently and to a larger depth. Moreover, the mix of sludge/mud in a soil influences characteristics like crusting and erodibility and should be considered in each design and decision. Therefore the distribution of soils may vary widely over one specified field, while it is an important limitation on some methods of applying irrigation water (FAO, 1989).

Soil management influences highly the water requirements and the irrigation frequency. In particular, tillage practices like deep ploughing can modify the soil properties affecting water infiltration and soil permeability rates. As a general rule, fine textured soils hold more water than coarse-textured soils. The medium-textured soils have more water available for plant use compared to clay soils (FAO, 2002).

Evaporation of water from the soil is reduced when tillage is reduced due to the fact that with more residue less solar energy reaches the soil surface and wind speed (air movement) is reduced at the soil surface. When the soil surface is wet, evaporation from an uncovered soil, soil without crop residue or crop canopy, will occur at a rate that equals the atmospheric demand. Water that is deeper in the soil cannot be transported quickly enough through this dry surface soil to satisfy atmospheric demand.

If the soil is covered the residue insulates the soil from solar radiation and reduces air movement at the soil surface. Therefore the evaporation rate from a residue covered surface compared to an uncovered soil is reduced. In case of a drought period occurs, the surface moisture under the residue will continue to slowly evaporate. A few days after the wetting incident, evaporation from the covered surface can exceed that of the uncovered surface (UNL, 2014).

Soil holding capacity is improved by adding organic matter, applying a proper cropping choice and cultivation methods and selecting crops according to their Water Use Efficiency (WUE). WUE is defined as crop yield per mm of water use. In general, practices that improve the yield per 'drop' will eventually improve the WUE. Therefore in order to ensure high crop yields, the capture and storage of rainfall in the soil and the ability of the crop to utilise soil moisture must be maximised, whilst the

severity of water deficits during key stages of crop development should be minimised. Crop and grassland WUE are influenced directly by (LEAF, 2013):

- Selecting properly the variety of the crops
- Timing of cultivations and drilling
- Drilling rate
- Avoiding compaction by livestock and machinery
- Soil structure and influence on root development
- Canopy management

And indirectly by:

- Minimising the effects of weeds and diseases that compete for soil moisture and limit the potential of the crop and grassland to access and efficiently use available soil moisture.
- Minimising wastage of the crop, avoiding field and storage losses, such as Dry matter losses minimised etc.

Another way to reduce evaporation losses of soil water is to add a cover of plant residues on the soil surface. Practices that increase shading of the soil surface, and physical structures that concentrate rainwater (or by modifying the micro-climate generally), encouraging also percolation to deeper layers, also reduce the evaporation losses. In hot windy conditions, wasteful transpiration losses may be the result of weeds or excessive crop transpiration and is reduced by applying suitable weed practices or windbreaks respectively. Therefore the soil cover acts as an insulating layer that eliminates the wind effects and minimise the temperature of the surface soil. The thicker the layer of trapped air, the greater will be the insulating effect. Nevertheless the amount of residues required to reduce evaporation losses is considerable greater than the quantity needed to ensure that most rainfall infiltrates where it falls.

One of the most important ways to reduce water evaporation from the soil surface is to get the water as deep into the profile as feasible. Therefore it is important for managing soils that have substantial cracking to understand how cracks are created and how the water is moved into them.

Crop selection

Given the fact that the crop water needs and the growing period differ, crop type is a principal factor that influences the irrigation water requirements. Therefore crops with high daily water needs and a long total growing season require much more water than those with relatively lower daily needs and shorter growing seasons. Concluding, a key element towards reducing irrigation needs is selecting those crop varieties with common characteristics or selecting those that have lower water demand but still provide sufficient added value. For instance, the plants respond differently to salinity; some crops produce acceptable yields at much higher soil salinity compared to others.

Water quality

The water quality is one of the most important factors for the calculation of the gross irrigation water, which is the amount of water (volume of water) to be delivered at each crop. This volume depends on the water quality because when water with high levels of salinity is used then extra volume (amount of water) is required to avoid salt accumulation in the root zone. In some areas water supplies are often limited and thus water for irrigation of low quality is used. Especially in southern areas of Europe e.g. Mediterranean countries the water supplies are limited whereas the quality is low because of their physical and chemical parameters like pH, salinity and alkalinity. For instance, the presence of high soluble salts concentration in the water used for irrigation purposes is one of the limiting factors in the crop production (De Pascale et al., 2013).

The irrigation water characteristics are classified as below (De Pascale et al., 2013):

- Surface waters e.g. from rivers, canals, natural or artificial lakes
- Subterranean water e.g. springs, wells etc.
- Wastewater e.g. urban and industrial drains etc.

Subterranean water and wastewater may be of marginal quality for irrigation purposes because of the presence of dissolved salts and causing health hazards respectively. The parameters that characterise the quality of the water for irrigation purposes are listed below:

- Physical: temperature, soil particles, impurities etc.
- Chemical: gaseous substances, pH, soluble salts, sodium and chloride concentration etc.
- Biological: algae, bacteria, various micro-organisms

In the next paragraphs each parameter is briefly described.

Physical

Low water temperature contributes to the modification of the soil temperature reducing thus the root activity in terms of water and nutrients uptake of the plant. In addition water stress may cause water stress by increasing the gap between transpiration and water uptake. Likewise water at very low temperatures cause disorders and can be stored in basins in order for the temperature to rise. On the other hand, water at temperatures over 35°C can affect the quality of the final product (Langridge, 1963; Wierenga et al., 1971; De Pascale et al., 2013). Any other materials like particles or in general suspended solids may cause problems to the equipment used for irrigation purposes. In particular, the suspended solids may block the equipment used e.g. drip emitters. This problem should be tackled taking also into consideration the distribution method used. For instance, the micro-irrigation systems have a high number of distribution points with small-diameter tubes, which are becoming easier blocked. In fact, these materials do not affect the crops/plants, but final products are becoming stained leading to their depreciation (De Pascale et al., 2013).

Chemical

The pH is an indicator for detecting the acidity or basicity of a water. The optimal pH values range between 6.5 and 7.5, although the minimum acceptable value is 5. Values out of the aforementioned range can cause damages to the cultivated plants/crops. At the same time, alkalinity is a relative measurement of water's capacity to resist a change in pH or its ability to change the pH of the growing media. In particular, water for irrigation with high alkalinity may raise the pH of the growing media over time and thus require more acid to lower the pH of the water to an acceptable level (as was set above). Moreover, one of the most important characteristics of the irrigation water is salinity, which is an evidence of high salt's concentration. Therefore, in order to define the suitability of irrigation water the salt concentration, the relative ration of sodium to the other cations and the concentration of specific ions, which may be toxic to the plants, should be investigated and/or measured. The use of irrigation water with high content of salt concentration affects the relationship between soil, water and plant restricting the normal physiological activity and productive capacity of the crops (De Pascale et al., 2013).

The most readily available water is in the upper root zone, which is considered as a low salinity area. When the crop uses water the upper root zone becomes depleted and the zone of most readily available water changes toward the deeper parts as the time interval between irrigations is extended (FAO, 1994).

Following an irrigation system, the most readily available water is in the upper root zone - a low salinity area. As the crop uses water, the upper root zone becomes depleted and the zone of most readily available water changes toward the deeper parts as the time interval between irrigations is extended. These lower depths are usually more salty. The crop does not respond to the extremes of low or high salinity in the rooting depth but integrates water availability and takes water from wherever it is most readily available. Irrigation timing is thus important in maintaining a high soil-water availability and reducing the problems caused when the crop must draw a significant portion of its water from the less available, higher salinity soil-water deeper in the root zone. For good crop production, equal importance must be given to maintaining a high soil-water availability and to leaching accumulated salts from the rooting depth before the salt concentration exceeds the tolerance of the plant.

The salinity in the lower root zones becomes less important when the upper part of the root zone is well delivered. Nevertheless, in periods where irrigations are extended and the plant needs to uptake more amount of water in the upper part from the lower root zone, then the salinity parameter in the water quality may be a significant problem. In particular, during prolonged drought a high crop water demand occurs where absorption and water movement towards the roots may not be fast enough to supply the required water towards the roots resulting to a strong water stress. The reduced yields and/or plant damage can be the main consequences from a shortage of water for a significant period of time. However it should be clearly mentioned that plants have different tolerance on drought e.g. 8-10 fold range in salt tolerance of different agricultural crops (FAO, 1994).

Biological

The presence of some particular ions can cause significant toxicity problems to the plants. The toxicity problems arise when elements in the irrigation water build up in the plant tissue surface to such an extent that may cause yield reductions. Such elements are chlorine, sulphur, boron, sodium and ammonium. In particular, high concentrations of sodium (Na) are linked with salinity problems, whereas concentrations of sulphur (S) and chlorine (Cl) can create toxicity problems and influence negatively the growth of the plant (De Pascale et al., 2013).

Crop water requirements

Crops need water for transpiration and evaporation and thus the crop water need is also called evapotranspiration. The evapotranspiration rate is the amount of water that is lost to the atmosphere through the leaves of the plant and the soil surface.

In order to estimate the water requirement the first step is to measure the evapotranspiration rate. The reference rate E_{To} is the estimate of the amount of water that is used by a well-watered grass surface, which is roughly from 8 to 15 cm in height. E_{To} represents the maximum evapotranspiration that can happen. Nevertheless, the water requirement is usually less than E_{To} as other factors must be taken into account e.g. growth stage of the plant, leaf size and coverage that provides shade to the ground, etc.). Taking into account the abovementioned factors the E_{To} is converted to E_{Tc} through the K_c coefficient (, the so-called crop-specific coefficient. Summarising, the main equation that is used under standard conditions (e.g. no under stress) is $E_{Tc} = K_c * E_{To}$ (Sela, 2015). The crop water need is expressed in mm/time (e.g. day, month etc.) and depends on the local climate, crop type and growth stage (Sela, 2015).

Table 10.1: Reference K_c values for some crops⁴³ (FAO, 1998; Pardossi and Incrocci, 2008)

Crop	K_c ini	K_c mid	K_c end
Small vegetables	0.7	1.05	0.95
Legumes	0.4	1.15	0.55
Perennial vegetables	0.5	1.00	0.80
Fibre crops	0.35		
Oil crops	0.35	1.15	0.35
Wheat	0.3	1.15	0.35
Sugar cane	0.4	1.25	0.75
Watermelon	0.4	1	0.75
Tomato	0.6	1.15	0.8
Olive	0.65	0.7	0.7

Irrigation scheduling (IS)

Water balance method

⁴³ Table 10.1 lists K_c values for some major crops; the full data for crops and trees can be found in FAO (1988) and Pardossi and Incrocci (2008) together with other important data for crops.

This method consists of three basic steps: i. the available water (AW) in the root zone, which is estimated from soil texture and rooting depth, ii. allowable water deficit (AWD), which is selected depending on crop species, growth stage, soil water capacity and the irrigation system's pumping capacity and iii. soil water balance is measured every day to assess water deficit. In particular, irrigation is implemented whenever AWD is exceeded (Pardossi and Incrocci, 2011). The main difficulty is to determine the ET. The ET is calculated by the equation P-M (Penman-Monteith) or by the classical "two-step approach" $ET = ET_0 * K_c$, where the knowledge of k_c and ET_0 is required. In particular, in commercial vegetable production, ET is calculated using the measured data from weather stations, whereas the crop coefficients are specific values depend on growth stage, climatic conditions and management practices, which are derived either experimentally or retrieved in the relevant literature. Therefore k_c values (figures 2 and 3 and table 5, in the operational data section) for vegetable crops have been reported for different crops and for different growing conditions (Pardossi and Incrocci, 2011).

In vegetable soil cultivations irrigation is essential and should supplement rainfall during the growing season, while is obligatory in greenhouses and soilless cultures. In general vegetables produce high value crops that make more profitable use of irrigation water than other agricultural commodities. For instance, Cooley et al., (2008) and Pardossi and Incrocci (2011) reported that field crops in California accounted for 56% of the total irrigated area resulting to a consumption of 63% of total water use and generating 17% of California's crop revenue. On the other hand, for the same area and same period, vegetables covered 16% of irrigated land and consumed 19% of applied irrigation water, whilst the crop return was estimated to be approximately 39%.

The under-irrigation is responsible for yield loss and low quality products, while over-irrigation increase the energy costs for water pumping, increase the crop's susceptibility to diseases, results to water loss and contributes to high environmental pollution because of the nutrient leaching. The poor management of drip irrigation was the reason for incidents of nutrient leaching in greenhouse tomato in Almeria. This problem was caused because farmers established IS strategy based on experience and not on actual crop water need (Thompson et al., 2007). In addition, the precise scheduling also results to more regulated deficit irrigation because of the better management of the water stress according to the crop water requirements (FAO, 2000; Jones, 2004; Pardossi and Incrocci, 2011).

The main principle of the IS strategy is the determination of the amount of water irrigation needed at a given crop at any time during the production cycle. The IS strategy focus is to avoid crop damage and to ensure that all the irrigation water applied is uptaken by the crop.

Soil water balance and/or direct measurement of soil moisture level are the main methods for setting an efficient IS strategy. In soilless cultures the EC of the nutrient solution contained or drained out from the substrate may be measured and decided if could be an irrigation decision-making variable (Pardossi and Incrocci, 2011).

The soil moisture content gathers the most advantages because it has high accuracy and easy applicable. Furthermore there are many irrigation controllers that are connected with soil moisture sensors. Some sensors measure bot moisture content and salinity of the growing media, while provide simultaneously the possibility of controlled fertigation. However, it should be mentioned that because of the spatial variability of the soil, many sensors have to be installed and connected with the irrigation controller e.g. via wireless network (Pardossi and Incrocci, 2011).

Soil Moisture Sensors - SMS

The Soil Moisture Sensors (SMS) are used to set the frequency and the dose needed of the irrigation applied of the growing media. The soil dielectric sensors are valuable tools for smart water application technology in agriculture and horticulture. The SMS technology is combined with appropriate controllers, which are available on the market, that are interfaced to one or more SMSs. The aforementioned technology is applicable both in soil and soilless cultures. In some cases, some devices have a 'start and stop' control by using one or more SMSs buried in and underneath the root

zone in order to monitor the water movement into the deeper layers and hence to minimise the potential percolation losses (Pardossi and Incrocci, 2011). Soil dielectric sensors are cheap and need less maintenance as compared with traditional water-filled tensiometers. On the other hand, granular matrix sensors are cheap and can be used over a wide range of pressure e.g. 0-85 kPa (Pardossi et al., 2009; Pardossi and Incrocci, 2011). The 5TE (Decagon Devices) or WET (Delta-T Device) are used for the simultaneous measurements of temperature and pore water Electrical Conductivity (EC) in soil or soilless media, offering also the possibility for controlled fertigation. Therefore, the concentration of the nutrient solution is adjusted on the basis of measuring EC in the root zone (Pardossi and Incrocci, 2011).

Achieved environmental benefits

The establishment of an integrated water irrigation strategy leads to significant water savings. Furthermore the soil fertility is also increased influencing the yields and the quality of the planted crops. In addition the water quality is also increasing/improving due to the minimisation of the salinity because of the maintenance of the soil humidity up to certain acceptable levels.

Appropriate environmental performance indicators

The indicators are classified and listed according to the multiple aspects of this technique

- Match crops to available water or vice versa (Y/N)
- Percentage (%) change in irrigation demand (m³/yr, m³/ha/yr)
- Water footprint (blue water component) (L/tonne crop)
- Local/regional groundwater level (depletion)

Cross media effects

No cross media effects have been identified for this technique.

Operational data

Water quality

When water with high alkalinity is present then the farmer should use acid-type soluble fertilisers rather calcium based products. Water is classified as brackish when the salt content is approximately 2 g/l (or 2,000 ppm) or more. Salinity is measured using analytical or electrical conductivity methods (De Pascale et al., 2013). Salinity is expressed either as the total content of salts dissolved in the unit of volume e.g. g/l, or as concentration of mineral salts measured in ppm when analytical measurement methods are applied. In case of electrical conductivity measurement methods, salinity is expressed as deciSiemens per metre (dS/m)⁴⁴ at 25°C. Summarising, water cannot be used for irrigation purposes when salinity exceeds either 2 g/l (or 2,000 ppm), or 3 dS/m or measured at 25°C for analytical and electrical conductivity methods respectively (De Pascale et al., 2013)⁴⁵.

The general rules for controlling the irrigation water quality are to control the pH value within a range of 6.5 and 7.5, alkalinity range of 0.75-2.6 meq/l (being generally smaller when plants are younger) and salinity should be < 2 dS/cm. However, especially for the salinity, salts composition should be assessed carefully because some elements/compounds may cause toxicity in plants. As far as the toxicity is concerned, the critical concentrations of some particular elements can create significant problems to the plant growth. For instance, the chloride hazard of irrigation water is presented in Table 10.2 (De Pascale et al., 2013), while the study performed by De Pascale et al., (2013) present in detail the optimal parameters of the water quality for irrigation.

⁴⁴ More information about measuring salinity can be found in the literature e.g. De Pascale et al., (2013)

⁴⁵ It should be clarified that: 3 dS/m is a very high salinity but it could be used for some crops; on the other hand, 2.0 dS/m is much beyond the maximum salinity tolerated by ornamentals and legumes.

Table 10.2. Chloride hazard of the irrigation water (De Pascale et al., 2013)

Chlorides (meq/l)	Chlorides (ppm)	General notes
< 2.0	< 70	Generally safe for all plants
2.1-4.0	71-140	Sensitive plants usually show slight to moderate injury
4.1-10.0	140-350	Moderately tolerant plants usually show slight to substantial injury
> 10.0	> 350	Severe problems

Selection of adapted crops

Matching closely the crops with the available water, the yields and the quality throughout the season/harvest are improved. In parallel, careful matching of crop requirements and selection of equipment ensure that irrigation is in line with the actual water demand. During peak demand periods, it may be necessary to anticipate increases in soil moisture deficit by irrigating above a crop's immediate needs, as long as this does not bring the soil above field capacity (Ashley et al., 1998).

The crops matching and the optimisation of the cultivation location contribute to the increase of the content of organic substance in the soil and improve the water availability and soil water holding capacity, reducing the erosion potential and the surface outflow of nutrients (UBA, 2010). The crop matching must be implemented in such a way that the organic substances are balanced as much as possible, while minimising or avoiding the surface runoff and soil erosion potential. Therefore the use of pesticides and fertilisers is minimised, while the yield increases.

A typical example of matching crops is the cultivation of vegetable and potato crops. Both cultivations require irrigation in order to ensure the crops production according to market demand. However, the different characteristics of the plants, in particular, crop water requirements provide difficulties in setting an optimised irrigation strategy. Therefore, in order to establish an optimised irrigation strategy, farmers and growers have to take into consideration the water requirement of each crop and the soil type, and demonstrate the efficient use of it. In particular, farmers and growers must match their potential crop requirements with an appropriate source of water at the right time (DEFRA, 2007). Table 10.3 illustrates approximate values of seasonal crop water needs for different crops/plants (AFED, 2010).

Table 10.3. Approximate values of seasonal crop water needs (AFED, 2010)

Crop	Water requirements (mm/total growing period)
Alfalfa	800-1,600
Banana	1,200-2,200
Barley/oats/wheat	450-650
Bean	300-500
Cabbage	350-500
Citrus	900-1,200
Cotton	700-1,300
Maize	500-800
Melon	400-600
Onion	350-550
Peanut	500-700
Pea	350-500
Pepper	600-900
Potato	500-700
Rice (paddy)	450-700
Sorghum/Millet	450-650
Soybean	450-700
Sugar beet	550-750
Sugarcane	1,500-2,500
Sunflower	600-1,000
Tomato	400-800

Soil management

Organic matter in soil provides several benefits. Initially, it acts as a significant source of nutrients and secondly it improves the soil structure as well as minimises the erosion. The organic matter does not add any new nutrients but releases nutrients in soil and thus to the cultivated crops/plants through the decomposition process. Therefore the amount of nutrients must be maintained constant and in particular the adding rate of nutrients (organic matter additions) must be equal to the rate of decomposition. When the decomposition rate is higher than the rate of additions then the effects from the organic matter to the cultivated plants/crops are reduced (Agri-facts, 2000). When planning and setting the parameters of an irrigation system, sufficient system capacity should exist in order to meet the crop water-use values. Hence, implementing the conversion from crop water-use to a system capacity, it is possible to result in an unnecessarily oversized system. Consequently, water amounts for irrigation are reduced by assuming some crop water requirements that are provided by stored soil water or rainfall during peak crop water use periods. Accounting for stored soil water and rainfall assumes that the irrigation scheduling system may fall short of supplying crop water needs during years when timely rainfall does not occur. In case that the capacity of the system is reduced, it is then uncertain whether the system can prevent crop stress from occurring (Kranz et al., 2008). Available water is the water held in the soil between existing soil-moisture content and wilting point. Water in excess of field capacity (approaching saturation) will drive air from the soil, depriving roots of oxygen needed for respiration. If root respiration is limited, then root growth and function are curbed, resulting in restricted rooting depth and increased stress on the plant (Ashley et al., 1998). The amount of water that the soil is capable to retain depends on its texture and structure. The important factors are i. the Field Capacity (FC), which represents the upper limit of the available water in the soil and ii. the Permanent Wilting Point (PWP) that describes the point where the plant cannot extract any more water. Eventually, the Available Water Capacity (AWC) is described by the following equation: $AWC = FC - PWP$ (DEFRA, 2007). Regarding the AWC, the typical values are illustrated in Table 10.4 (DEFRA, 2007). For example, sandy soils hold less water because their texture permits water to drain down the soil profile, resulting to low AWC value. On the other hand, clay soils are equally porous by volume and they are able to retain more water against gravity and thus they have larger AWC value (DEFRA, 2007). Likewise, FAO (2002) and USDA (1991) classified different soil texture according to the available soil moisture (Table 10.5).

Table 10.4. AWC values of soils in UK divided in three categories: i. low, ii. medium and iii. high (DEFRA, 2007).

A LOW	
AWC < 12.5% of the soil In most cases the land is naturally well drained and fields lack perimeter ditches	Coarse sand Loamy coarse sand Coarse sandy loam
B MEDIUM	
AWC 12.5-20% of the soil	Sand Loamy sand Fine sand Loamy fine sand Clay Sandy clay Silty clay Clay loam Sandy clay loam Silty clay loam Fine sandy loam Loam
C HIGH	
AWC > 20% of the soil	Very fine sandy loam Loamy very fine sand Very fine sandy loam Silty loam and peaty soils

Plant available water capacity is the maximum amount of water held in the soil that the crop can use. To ensure that plant stress is minimized, available water capacity should be maintained above the 50% of the available level (Kranz et al., 2008). Hence, a clay loam soil holds approximately 0.2 m of plant available water, while a fine sand holds only 0.1 m. Therefore the extra water stored in the clay loam soil increases the amount of available water to the plant during peak water use periods, allowing the system capacity to be decreased (Kranz et al., 2008; FAO, 2002).

On the other hand, a soil is considered as saturated when the entire pore is filled with water. The term field capacity refers to amount of water that can be held by the soil after the effects of gravity stop. The period will vary depending on the texture of the soil: lighter textured soils drain faster than heavier textured soils. The values in local soil databases need to be continuously updated and refined in order to fit better with the actual field conditions. However, in the field, the actual values may vary from site to site, season to season and even within the season (FAO, 2002). An important factor/indicator of the irrigation scheduling is the Soil Moisture Deficit (SMD), which shows the moisture status of the examined/given soil. Once the water is lost from the soil by evapotranspiration, the water content is reduced and a soil moisture deficit increases. The lower values of the SMD (in a given crop) is called 'critical SMD' and results to in potentially lower yields. Summarising the SMD values should be monitored and irrigation must be applied in order not to reach the critical level/value (SMD) (DEFRA, 2007).

Table 10.5. Classification of soil moisture conditions according to ‘feel and appearance’ method (USDA, 1991; FAO, 2002)

Available soil moisture	Soil moisture condition	Texture			
		Course: Fine sand Loamy fine sand	Moderate coarse: Sandy loam Fine sandy loam	Medium: Sandy clay loam Loam, silt loam	Fine: Clay loam Silty clay loam
0-25	Dry	Loose. Will hold together if not disturbed. Loose sand grains on fingers	Forms a very weak ball. Aggregated soil grains break away easily from ball	Soil aggregations break away easily. No moisture-staining on fingers. Clods crumble with applied pressure	Soil aggregations easily separate. Clods are hard to crumble with applied pressure
25-50	Slightly moist	Forms a very weak ball* with well-defined marks. Light coating of loose and aggregated sand grains remains on fingers	Forms a weak ball with defined finger marks. Darkened colour. No water-staining on fingers	Forms a weak ball with rough surfaces. No water-staining on fingers. Few aggregated soil grains break away	Forms a weak ball. Very few soil aggregations break away. No water stains. Clods flatten with applied pressure
50-75	Moist	Forms a weak ball with loose and aggregated sand grains remaining on fingers. Darkened colour. Heavy water-staining on fingers. Will not form into a ribbon**	Forms a ball with defined finger marks. Very light soil water-staining on fingers. Darkened colour. Will not slick	Forms a ball. Very light water-staining. Darkened colour. Pliable. Forms a weak ribbon between thumb and forefinger	Forms a smooth ball with defined finger marks. Light soil water-staining on fingers. Ribbons form with thumb and forefinger
75-100	Wet	Forms a weak ball. Loose and aggregated sand grains remain on fingers. Darkened colour. Heavy water-staining on fingers. Will not ribbon	Forms a ball with wet outline left on hand. Light to medium water-staining on fingers. Makes a weak ribbon between thumb and forefinger	Forms a ball with well-defined finger marks. Light to heavy soil water coating on fingers. Ribbons form	Forms a ball. Uneven medium to heavy soil water coating on fingers. Ribbon forms easily between thumb and forefinger
Field Capacity (100)	Wet	Forms a weak ball. Light to heavy soil-water coating on fingers. Wet outline of soft ball remains on hand	Forms a soft ball. Free water appears briefly on surface after squeezing or shaking. Medium to heavy soil-water coating on fingers	Forms a soft ball. Free water appears briefly on soil surface after squeezing or shaking. Medium to heavy soil-water coating on fingers	Forms a soft ball. Free water appears on soil surface after squeezing or shaking. Thick soil-water coating on fingers. Slick and sticky

* A ball is formed by squeezing a soil sample firmly in one's hand.

** A ribbon is formed by squeezing soil between one's thumb and forefinger.

Crop water requirements and irrigation scheduling

The different crops have significant differences in height, in leaf and stomata properties whereas the evapotranspiration (ET_c) from full grown well-watered crops differs from ET_o (see Description section for further explanation). In particular, parameters like the close spacing of plants and taller canopy height and roughness of many full grown agricultural crops, may cause these crops to have K_c values larger than 1. The K_c factor values⁴⁶ for several plants/crops are illustrated in Figure 10.2, and is often 5-10% higher than the reference (where K_c = 1.0), and even 15-20% greater for some tall crops such as maize, sorghum or sugar cane (FAO, 1998). Figure 10.3 illustrates the typical range of K_c values during the four growth stages of the plants (FAO, 2002), while Table 10.3 illustrates the seasonal water requirements of the most important field crops (FAO, 1986).

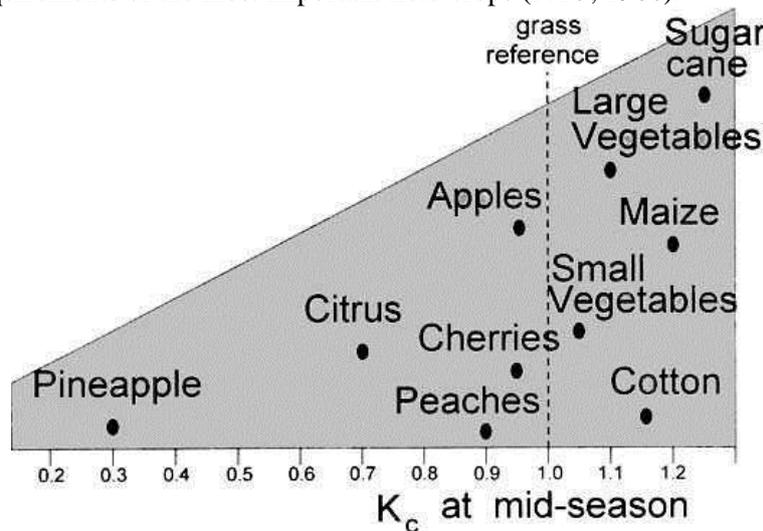


Figure 10.2. K_c values for different crops (FAO, 1998)

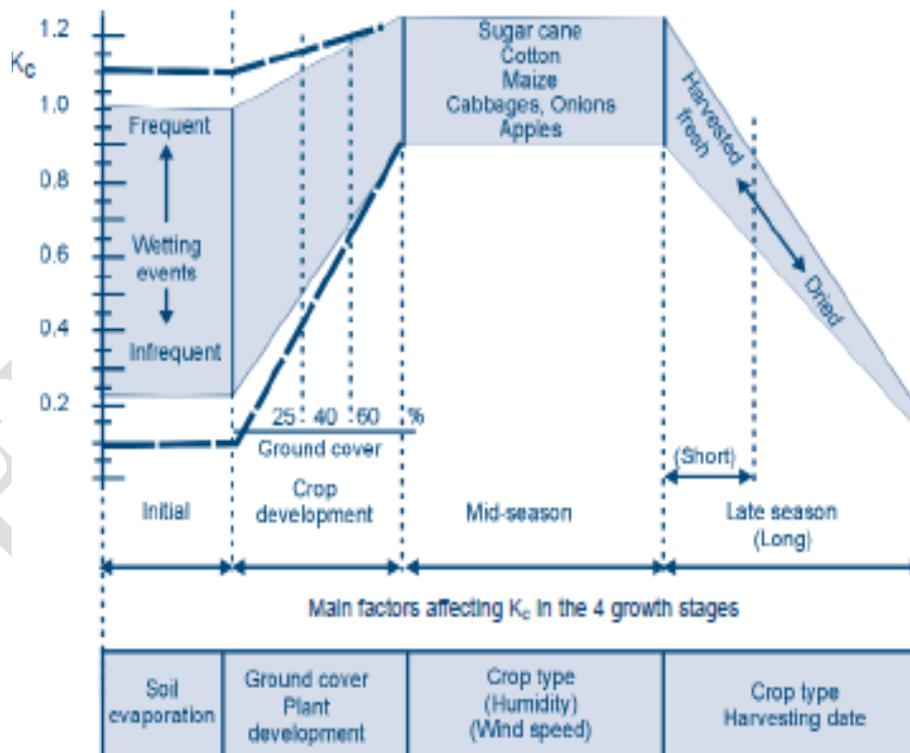


Figure 10.3. Typical K_c ranges for the four growth stages (FAO, 2002)

⁴⁶ For more K_c values and other relevant data for the determination of the crop water requirements can be found at FAO (2002).

Crops need different amounts of water at different stages of their growth cycle. In addition, local climatic and soil conditions influence the availability of water to crops. Applying a proper irrigation scheduling system soil reservoir is managed such that optimum amount of water is available when the plants need it. Towards establishing an efficient irrigation scheduling system the crop water requirements should be precisely determined at different growth cycles, the moisture content of the soil and the soil water capacity as well as the weather conditions. The principal factors that should be taken into account during the establishment and operation of an irrigation scheduling system are listed in Table 10.6 (SAI, 2010).

Table 10.6. Summary of irrigation scheduling system (SAI, 2010)

Scheduling method	Notes
Set time	Maintain the frequency of irrigation but change the set time to maintain a constant soil moisture Use of climate data to modify the operating time on a weekly basis
Irrigation cycle	Monitor the soil moisture at the first irrigation set and initiate an irrigation cycle once the soil moisture trigger level has been reached Use of climate data to determine when the crop has used up the amount of water applied by the system during one irrigation set. Irrigation is initiated when this trigger level has been reached

The farmer can establish an irrigation scheduling strategy by assessing the average temperature in the farm location, the crop, the soil texture and the use of some datasets obtained by FAO. Therefore the farmer can determine the amount of the irrigation water, the required intervals and irrigation depth through four basic steps (SAI, 2010).

Step 1: Estimate the net irrigation depth (mm)

The net irrigation depth is determined by checking the amount of water given per irrigation application taking into account the applied irrigation practice (Table 10.7) (SAI, 2010).

Table 10.7. Appropriate net irrigation depths (SAI, 2010)

	Shallow rooting crops (30-60 cm)	Medium rooting crops (50-100 cm)	Deep rooting crops (90-150 cm)
Shallow and/or sandy soil	15	30	40
Loamy soil	20	40	60
Clayey soil	30	50	70

However, if appropriate local data regarding the root depth lack, then Table 10.8 provide an estimation of the length of the crop root zone (SAI, 2010).

Table 10.8. Appropriate root depth (mm) (SAI, 2010)

Shallow rooting crops (30-60 cm)	Crucifers (cabbage, cauliflower, etc.), celery, lettuce, onions, pineapple, potatoes, spinach, other vegetables except beets, carrots, cucumber.
Medium rooting crops (50-100 cm)	Bananas, beans, beets, carrots, clover, cacao, cucumber, groundnuts, palm trees, peas, pepper, sisal, soybeans, sugar beet, sunflower, tobacco, tomatoes.
Deep rooting crops (90-150 cm)	Alfalfa, barley, citrus, cotton, dates, deciduous orchards, flax, grapes, maize, melons, oats, olives, safflower, sorghum, sugarcane, sweet potatoes, wheat.

Step 2: Estimate the gross irrigation depth (mm)

It is calculated using the net irrigation depth and the efficiency of the applied irrigation system. Equation (1) illustrates the related calculations (SAI, 2010):

Gross irrigation depth (mm) = $100 \times (\text{net irrigation depth}) / (\text{irrigation efficiency}) + (\text{extra irrigation depending on water quality e.g. leaching fraction})$ (1)

Step 3: Calculate the number of irrigation applications over the total growing season

The number of the irrigation applications needed over the total growing season can be estimated/calculated by dividing the net irrigation water volume over the growing season by the net irrigation depth per application. Table 10.9 summarises the water requirements of individual crops and typical yields and efficiencies (SAI, 2010):

Table 10.9. Crop water requirements and typical yield and efficiency (SAI, 2010)

Crop	Crop water need (mm in total growing period)	Typical yield and efficiency
Coffee	Water requirements 1,500-2,500 mm/year	Average of 1 100 kg/ha with varieties producing 2 400 kg/ha under good growing conditions
Sugar cane	Water requirements 1,500-2,500 mm/year	Good range yields in the humid tropics of a totally rain fed crop: 70-100 t/ha cane, in the dry tropical and subtropics with irrigation 110-150 h/ha cane; sugar content at harvest is usually between 10-12% of the cane fresh weight
citrus	Water requirements 900-1,200 mm/year	Good yields of citrus are: orange 25-40 t/ha and year; grapefruit 40-60 t/ha and year; lemons 30-40 t/ha and year; mandarin 20-30 t/ha and year

Step 4: Calculation of the irrigation interval in days

The irrigation interval in days is calculated by dividing the total growing seasons in days by the number of irrigation applications over the total growing seasons (SAI, 2010).

Applicability

The selection of the appropriate agronomic methods in an integrated irrigation plan is applicable in every farm.

Economics

The major costs of irrigation scheduling are the direct costs of equipment, management time for routine calculations and control measurements, as well as the cost of expertise (FAO, 1996).

Driving forces for implementation

- Increase the quality and yields of the fields
- Better management of the water resources and of the soil management
- Careful selection of the crops in a given area

Reference Organisations

The application of plant-based Irrigation Scheduling (IS) is more practical and affordable in greenhouse soilless culture systems where climate and crops are generally more uniform as compared with open field. Therefore in the aforementioned systems, farmers use small size electronic weighing lysimeters to measure on a minute-to-minute basis, ET and the volume and EC of the drainage water. Applied examples of this technique are found commercially in Italy (see Reference Organisations)

De Pascale et al., (2013) summarise the recommended limits for constituents in reclaimed water for irrigation as well as summarise the optimum values of the parameters that influence the water quality for irrigation. DEFRA (2007) summarise best irrigation practices applied in UK for different crops and cultivations.

Reference literature

- AFED (2010), Water Efficiency Handbook, Chapter 5, Agriculture, Available online: http://www.afedonline.org/water%20efficiency%20manual/PDF/6chapter%205_Agriculture.pdf, accessed 18 September 2014.
- Agri-facts (2000), Soil organic matter, Agri-facts, Alberta, Agriculture food and rural development, practical information for Alberta's Agriculture Industry, Agdex 536-1.
- Ashley R.O., Neibling W.H. and King B.A. (1998), Irrigation scheduling, Using Water-use tables, Cooperative Extension System, Agricultural Experiment Station, CIS 1039.
- Cooley H., Christian-Smith J. and Gleick P.H. (2008), More with less: Agricultural water conservation and efficiency in California: A special focus on the Delta, Pacific Institute, ISBN: 1-893790-17-7., available online: http://www.pacinst.org/wp-content/uploads/sites/21/2013/02/more_with_less3.pdf, accessed 23 September 2014.
- De Pascale, Orsini F. and Pardossi A. (2013), Irrigation water quality for greenhouse horticulture, in Good Agricultural practices for greenhouse vegetable crops, principles for Mediterranean climate areas, FAO, E-ISBN: 978-92-5-107650-7.
- DEFRA (2007), Irrigation best practice – a water management toolkit for field crop growers, available online: <http://www.ukia.org/pdfs/A%20Water%20Management%20Toolkit%20for%20Field%20Crop%20Growers.pdf>, accessed 23 September 2014.
- FAO (1986), Irrigation water management: irrigation needs, training manual no. 3, by Brouwer C. and Heibloem M., available online: <ftp://ftp.fao.org/agl/aglw/fwm/Manual3.pdf>, accessed 23 September 2014.
- FAO (1989), Guidelines for designing and evaluating surface irrigation systems, FAO Irrigation and Drainage paper 45 by W.R. Walker, ISBN-92-5-102879-6.
- FAO (1994), Water quality for agriculture, by R.S. Ayers and D.W. Westcot, FAO irrigation and drainage paper, 29 Rev.1, ISBN 92-5-102263-1.
- FAO (1996), Irrigation Scheduling: From Theory to Practice, in proceedings from: Proceedings, ICID/FAO Workshop on Irrigation Scheduling Rome, Italy, 12-13 September, edited: Water Reports 8, ISBN 92-5-103968-2
- FAO (2000), Deficit irrigation practices, Food and Agriculture Organization of the United Nations ISBN 92-5-104768-5.
- FAO (2002), Crop Water Requirements and Irrigation Scheduling, Irrigation Manual Module 4, Developed by Andreas P. Savva and Karen Frenken.
- Jones H.G. (2004), Irrigation scheduling: Advantages and pitfalls of plant-based methods, J. Expt. Bot. 55, 2427–2436.
- Kranz W.L., Irmak S., van Donk S.J., Yonts C.D. and Martin D.L. (2008), Irrigation Management for Corn, University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources, G1850, available online: <http://www.ianrpubs.unl.edu/epublic/live/g1850/build/g1850.pdf>, accessed 23 September 2014.
- Langridge (1963), Biochemical aspects of temperature response, Ann. Rev. Plant Physiol., 14, 441–462.
- LEAF (2013), Simply sustainable water, six simple steps for managing water quality and use on your land, available online: <http://www.leafuk.org/resources/000/691/685/SSW.pdf>, last accessed 18 September 2014.
- Pardossi A. and Incrocci L. (2011), Traditional and New Approaches to Irrigation Scheduling in Vegetable Crops, HortTechnology 21(3), 309-313.

- Pardossi A., Incrocci L., Incrocci G., Malorgio F., Battista P., Bacci L., Rapi B., Marzioletti p., Hemming J. And Balendonck J. (2009), Root zone sensors for irrigation management in intensive agriculture, *Sensors*, 9, 2809-2835.
- Pardossi A., Incrocci L., Malorgio F., Battista P., Bacci L., Rapi, B., Marzioletti, P., Hemming, J. and Balendonck, J. (2009), Root zone sensors for irrigation management in intensive agriculture, *Sensors (Basel Switzerland)* 9, 2809–2835.
- Pardossi A., Incrocci I. (2008), Farm level optimal water management: Assistant for irrigation under deficit, *Crop database, Project FlowAid, FP6-2005-Global-4, Priority II.3.5, Water in Agriculture: New systems and technologies for irrigation and drainage.*
- SAI (2010), Water conservation technical briefs – TB6 Irrigation Scheduling, available online: <http://www.saiplatform.org/uploads/Library/Technical%20Brief%206.%20Irrigation%20Scheduling.pdf>, accessed 22 September 2014.
- Sela G. (2015), Water Requirements of Crops, Smart fertilizer, available online: <http://www.smart-fertilizer.com/articles/water-requirements-of-crops>, last accessed January 2015.
- Thompson, R.B., Martínez-Gaitan C., Gallardo M., Giménez C. and Fernández M.D. (2007), Identification of irrigation and N management practices that contribute to nitrate leaching loss from an intensive vegetable production system by use of a comprehensive survey, *Agr. Water Mgt.* 89, 261–274.
- UBA (2010), Water protection in cooperation with agriculture, Federal Environment Agency, UBA, available online: www.umweltbundesamt.de, accessed 23 September 2014.
- UNL (2014), Agricultural Irrigation Management: Reduce the need for irrigation: maintain crop residue, reduce tillage, University of Nebraska–Lincoln, available online: <https://water.unl.edu/cropwater/reduceneed>, accessed 23 September 2014.
- USDA (1991), National Engineering handbook Section 15, Irrigation, United States Department of Agriculture.
- Wierenga P.J., Hagan R.M. and Gregory E.J. (1971), Effects of irrigation water temperature on soil temperature, *Agron. J.*, 63, 33–36.

10.2 Optimisation of irrigation delivery

Description

The selection of the proper irrigation delivery system is an important aspect. The efficiency rates of each different irrigation delivery system vary significantly. In particular, the efficiency rate for furrow irrigation systems ranges from 20 to 25%, for sprinkler systems from 50 to 70% and for drip irrigation from 80% to 90%. In addition, where the water resources are limited, sprinkler and drip methods are suitable because they can increase the irrigated area by 20% to 30% and 30% to 40%, respectively as compared with furrow irrigation (Tognoni et al., 2002; De Pascale et al., 2011). In the following paragraphs, the systems of drip irrigation and low pressure sprinklers are described in detail.

The drip irrigation systems consist of a head control unit, main and sub-main pipelines, hydrants, manifolds and lateral lines with drip emitters or drippers. This system is suitable for intensive cropping patterns like vegetables, fruit trees, flowers, etc. that are planted in rows but it is not recommended for field crops and forage crops. However, it is applicable with low efficiency rates (Phocaidis, 2007). In sprinkler irrigation systems, spacing for overlapping is a very important and crucial factor in order to ensure that a uniform precipitation over the irrigated area is achieved. Nevertheless in drip irrigation, the non-uniformity comes from pressure variations along the lateral pipelines, variability in the emitters occurring during manufacture and blockage of the emitters due to irrigation water impurities (ADAS, 2013).

In drip irrigation, water goes onto the soil at very slow rates e.g. 1-20 l/hour through appropriate plastic pipes of small diameters fitted with outlets called emitters or drippers. The water is applied close to plants in which the roots grow is wetted, unlike surface and sprinkler irrigation where the whole soil profile is getting wetted. The drip irrigation application is more frequent e.g. 1-3 days as compared with other methods. Therefore, the soil moisture level is significantly increasing, creating the conditions where the plants can flourish (FAO, 2001). The suitability of the drip irrigation is illustrated in Table 10.10 (FAO, 2001):

Table 10.10. Suitability of the drip irrigation (FAO, 2001)

Parameters	Plants	Technical details
Crops	Row crops e.g. vegetables, soft fruit, vine crops	One or more emitters are provided for each plant
Slopes	Any farmable slope	The crop is planted along the contour lines and the lateral water supply pipes are laid along the contour: target is to minimise changes in emitter discharge as a result of land elevation changes
Soils	For most soils is suitable	On clay soils must be applied slowly to avoid surface water ponding and runoff On sandy soils higher emitter discharge rates are needed to ensure adequate lateral wetting of the soil
Irrigation water		

Regarding the irrigation water quality, one of the main problems that have to be tackled is the blockage of the emitters. The waterways diameters of the emitters ranging from 0.2-2.0 mm and blockage incidents can be appeared if the water is not clean or it is not free of sediments. Therefore, in case of sediment presence or algae, fertilizer deposits and/or dissolved salts which are accumulated in the waterways and can cause potential blockages, the irrigation water must be filtered before the use (FAO, 2001). On the other hand, drip irrigation is suitable for water with high saline content or poor quality water. In addition, dripping water to individual plants increases the efficiency in water use of

this system making this irrigation system efficient and suitable for cases where water is scarce (FAO, 2001).

The main components of the drip irrigation system are the pump unit, which takes water from the source and provides the right pressure for delivery into the pipe system, the control head that consists of valves and controls the discharge and the pressure in the entire system, the mainlines and the laterals, that supply water from the control head into the fields and the emitters which distribute the water to the plants.

Sprinkler irrigation

Four types of Centre Pivot low pressure sprinkler Irrigation Systems exist, which are listed below:

1. Low energy precision application
2. Low pressure in canopy
3. Low elevation spray application
4. Medium elevation spray application

The aforementioned listed systems are low pressure sprinkler and use fixed sprinkler applicators or nozzles or drop tubes or a combination of both to apply water. In fact, the centre pivots equipped with high or medium pressure, whereas at sprinklers heads low pressure is applied. Special attention should be given in order to match water application rates to soil intake rates minimising water runoffs. Therefore these practices can be combined with other cultural systems that prevent runoffs during irrigation or regulate rainfall events (e.g. creation of a furrow along the field, which acts as a water collector) (TWBD, 2004). The typical operation range of low pressure sprinklers is 0.6 – 2 bar. Most of them are placed under a category commonly known as spray nozzles or emitters that deliver water at a fixed (round) pattern of 360°. The nozzles or emitters are installed upright on the top of the pivot pipeline or inverted on drop pipes below the pipeline. Given the low pressure operation, the energy requirements are less for the sprinklers, whereas have a relatively small wetted radius resulting to a higher application rate (TWBD, 2004). The low pressure sprinklers are installed on flat fields or on fields with relatively small slopes e.g. less than 5°. In addition, they are suitable for coarse soils (sandy loam, sand), which have high infiltration rates. However, these systems are not suitable for relatively large fields (TWBD, 2004). The suitability of the sprinkler irrigation is illustrated in Table 10.11 (FAO, 2001):

Table 10.11. Suitability of the sprinkler irrigation (FAO, 2001)

Parameters	Plants	Technical details
Crops	Row, field and tree crops where water can be sprayed over or under the crop canopy Large sprinklers are not recommended for delicate crops e.g. lettuce	Large drops create damage to the crops
Slopes	Applicable to every kind of slope	The lateral pipes supplying water to the sprinklers should always be laid out along the land contour whenever possible because pressure is minimised and sprinklers provide a uniform irrigation
Soils	Suitable for sandy soils with high infiltration rates, not suitable for soils which easily form a crust	The sprinkler operating pressure is always lower than the soil infiltration rate to avoid ponding and runoff;
Irrigation water	Clean water free of suspended sediments	

Each irrigation media had advantages and disadvantages. Farmers should know which method suits better the local conditions as well as the cultivations. Therefore conditions like soil type, slope of the

field, local climate and water quality and quantity play an important role on choice of the irrigation method (Table 10.12).

Table 10.12. Characteristics that should be taken into account on choice of irrigation method (Brouwer, 1998; ADAS, 2013)

Condition	Impact
Soil type	Sandy soils have a low water storage capacity and a high infiltration rate and thus they need frequent but small irrigation applications, especially when the sandy soil is also shallow; therefore sprinkler or drip irrigation are more suitable. On loam or clay soils surface irrigation is most suitable. In case of different variety of soil types, sprinkler or drip irrigation are recommended because they will ensure an optimum water distribution.
Slope	Sprinkler or drip irrigation are preferred above surface irrigation on steeper or unevenly sloping lands as they require little or no land levelling. An exception is rice grown on terraces on sloping lands.
Climate	In windy areas drip or surface methods are preferred. In areas of supplementary irrigation, sprinkler or drip irrigation may be more suitable than surface irrigation because of their flexibility and adaptability to varying irrigation demands on the farm.
Water availability	Water application efficiency is generally higher with sprinkler and drip irrigation than surface irrigation and so these methods are preferred when water is in short supply.
Water quality	Surface irrigation is preferred when water contains much sediment. The sediments can cause problems such clogging the drip emitter or sprinkler irrigation system. In case that water contains dissolved salts, drip irrigation is recommended, as less water is applied to the soil than with surface methods.

Cross media effects

In principle by selecting the two types of irrigation systems, the WUE is increased significantly and also the water losses are minimised. Therefore no cross media effects have been observed selecting the above mentioned irrigation systems.

Appropriate environmental performance indicator

At crop level, the Water Use Efficiency (WUE) is measured as the transformation efficiency of water through the cultivation system into yield, according to the following equation (De Pascale et al., 2011).

- $WUE = \frac{yield}{W} = \frac{biomass}{E+T+losses} * Hi$, where W is the global amount of water available (natural rainfall and irrigation), T is transpiration, E is evaporation, losses is the amount of water lost at any level of the process and Hi is the harvest index (according to the crop species).
- Uniformity of the irrigation emitters (%): (wetted area)/(total area of the field)
- For drip irrigation: (number of emitters)/(field surface)

Operational data

The sprinkler irrigation systems are movable and can be easily transferred from one field to another. One irrigation machine can easily cover 25 ha and each model can be modified for variable flow and irrigation strip width. The field should have a regular/normal shape, the soil texture should have high infiltration rate (>15 mm/h), provides good internal drainage performance as well as sufficiently water holding capacity. The irrigation water can come from a tube-well, a river or a small water tank, but being clean from any suspended solids and/or other impurities (Phocaidés, 2007; ADAS, 2013).

Overlapping in sprinkler systems is essential to the design of effective sprinkler irrigation systems, and the sprinkler spacing should not exceed 65% to 70% of the sprinkler diameter coverage under light to moderate wind conditions, and 50% in strong wind conditions (Phocaides, 2007). Therefore, simulation of sprinkler distribution patterns especially in windy conditions is the basis for decision-support models for sprinkler systems in the development and application of optimum irrigation management strategies, and this has evolved significantly over the past two decades.

With a sprinkler, sprayed water breaks up into small drops between with a size of 0.5 and 4.0 mm. The small drops fall close to the sprinkler mechanism, while the larger ones fall close to the edge of the wetted circle. Large drops can damage delicate crops and soils and so in such conditions it is best to use the smaller sprinklers. The drop size of each sprinkler is controlled by the pressure and the nozzle size. The size of the drops changes according to the applied pressure, so when pressure is low the drop size increases. Hence, in order to avoid crop and soil damages, small diameter operating nozzles are used at or above the normal recommended operating pressure (FAO, 2001).

In drip systems, the drippers and/or the lateral spacing are directly related to the crop planting and spacing. The number of drippers depends on the crop and its rooting system e.g. vegetable develop the rooting system in the first 30 cm depth of the soil profile below the emission point while tree develop it beyond 50 – 60 cm (ADAS, 2013). The emitters are usually spaced more than 1 m apart with one or more emitters used for a single plant such as a tree. In case of row crops, more closely spaced emitters are used to wet a strip of soil. Moreover drip irrigation is mainly used in horticulture (BEMP 12.2) where higher yields, improved WUE and higher produce quality have been reported as compared with other irrigation methods for different vegetable crops according to the relevant literature (e.g. De Pascale et al., 2011; Unlu et al., 2006).

This system operates at low flow rates and low pressures (<1.5-2 bar) and provides localized distribution of the water, normally in proximity of the plant or the root zone. Regarding the installation of an efficient micro-irrigation system, several technical parameters should be taken into account. The different component (emitters, tubing etc.) and different types of emitters have different operating pressures and flow rates. The emitters are classified in two main categories: on-line drippers and in-line drippers. In the first case, drippers are attached to the polyethylene tube transporting water to crops from the supply tubing and they can be installed on different diameters allowing operational flexibility. Drip lines can be laid on the ground or suspended. In-line drippers mounted within the tubing (drip line) are an integral part of the polyethylene pipe. Normally, they are placed along the row of the crop or under the mulch.

Moreover, according to the installation type, the micro-irrigation systems are classified according to their flow rates and the operating pressure. The different categories are listed in Table 10.13 including also technical operational details, while Figure 10.4 presents the variation of flow rate of different types of drippers with the operating pressure (Barbieri and Maggio, 2013).

Table 10.13. Drip irrigation systems (Barbieri and Maggio, 2013)

System	Operating pressure (bar)	Flow rate (l/h)	Comments
Drip lines	1.5 – 2	0.5 – 4	<ul style="list-style-type: none"> • Polyethylene pipe; diameter of 0.15-0.20 mm is used • Holes at a fixed distance • Drip lines with drippers at regular intervals of 40-50 cm • Better distribution uniformity (DU), suitable for long-term crops
Drippers	1 - 4	2 – 20	<ul style="list-style-type: none"> • Polyethylene pipe; diameter of 16-25 mm is used

System	Operating pressure (bar)	Flow rate (l/h)	Comments
			<ul style="list-style-type: none"> Dipper spacing and flow rates are selected according to the plants spacing and crop water requirements Light drip lines are equipped with emitters that permit uniform water distribution thanks to built-in labyrinth system that reduces both the pressure and the speed of the water.
Emitters	1 - 3	6 – 30	<ul style="list-style-type: none"> Less clogging incidents
Capillary tubes	1 – 2.5	0.7 – 70	<ul style="list-style-type: none"> Polyethylene pipe; diameter of 20-25 mm is used Capillaries; diameter of 0.5-1.5 mm is used
Micro-mini sprinklers	1.5-2.0	-	<ul style="list-style-type: none"> Holes from where water is injected: 0.8-2.3 mm The sprinklers are mounted directly on the main pipe or on branches; differences occur

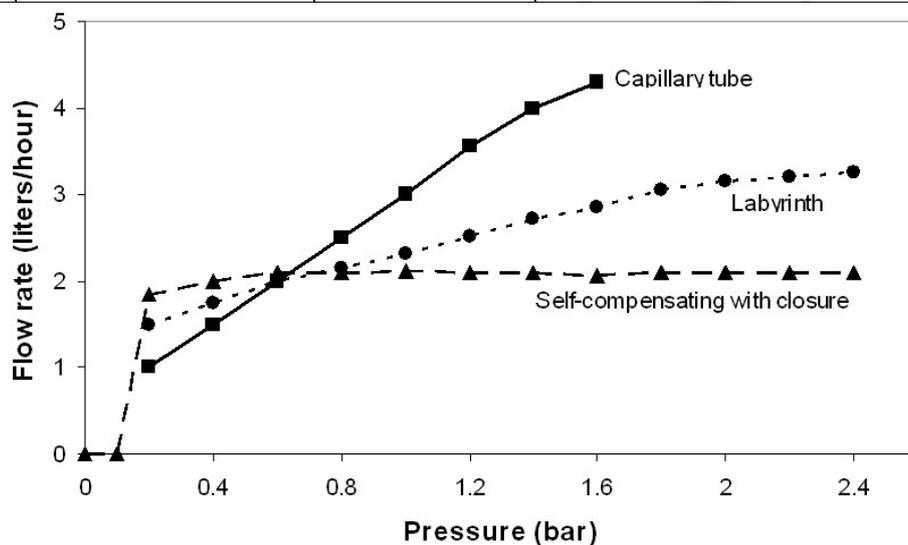


Figure 10.4. Variation of flow rate of different types of drippers with the operating pressure (Barbieri and Maggio, 2013)

Applicability

Low Pressure Center Pivot (“LPCP”) Sprinkler Irrigation Systems are applicable to both arid and humid areas, most soil types and can be used for irrigating a wide variety of crops. These systems are used by farmers for crops/plants like cotton, alfalfa and other hays, pasture, chile, corn, silage, and other non-orchard crops (TWBD, 2004). The uniformity of the low-pressure sprinklers irrigation system is affected by the design factors such as: nozzle type and diameter, operating pressure and spacing layout (Osman et al., 2014). In addition, wind speeds influence the uniformity of sprinkler irrigation systems. However, it should be noted that many centre pivot sprinkler systems are designed to operate on low-pressure drop tubes below the centre pivot lateral and close to the drop canopy. Given the fact that wind speed is reduced close to the canopy, installing low-pressure sprinkler emitters just above the crop canopy, the amount of water losses are eventually reduced and the uniformity is increased (Irmak et al., 2011).

Economics

Gogo (2011) reported that the initial cost of drip irrigation in area of Eastern England is higher than sprinkler, although the total irrigation cost for drip irrigation is economically viable due to the savings on the operation costs.

Driving forces for implementation

The selection of the best irrigation methods together with appropriate decision support tools result to precise irrigation, increasing significantly the efficiency in irrigation management.

Reference literature

- ADAS (2013), New irrigation application technologies, Cranfield University, available online at: <http://web1.adas.co.uk/cranfield/Documents/New%20irrigation%20application%20technologies.pdf> accessed 8 September 2014.
- Brouwer C., Prins K., Kay M. and Heibloem M. (1988), Irrigation water management: Irrigation Methods, Training Manuals n°5, Food and Agriculture Organization of the United Nations.
- De Pascale <http://horttech.ashspublications.org/content/21/3/301.full> - aff-1 S., Dalla Costa <http://horttech.ashspublications.org/content/21/3/301.full> - aff-2 L., Vallone S., Barbieri G. and Maggio A. (2011), Increasing Water Use Efficiency in Vegetable Crop Production: From Plant to Irrigation Systems Efficiency, HortTechnology 21(3), 301-308.
- FAO (2001), Irrigation water management: irrigation methods, Food and Agriculture Organisation of the United Nations, available online: <http://www.fao.org/docrep/s8684e/s8684e00.htm#Contents>, accessed 9 September 2014.
- Gogo E. (2011), A Comparative Analysis of Spray and Trickle Irrigation Systems in Eastern England, MSc Thesis, School of Applied Sciences, Cranfield University, p. 64.
- Irmak S., Kranz WL. And Eisenhauer D.E. (2011), Irrigation efficiency and uniformity, and crop water use efficiency, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln cooperating with the Counties and the United States Department of Agriculture, paper number EC732.
- Osman M., Bin Hassan S. and Wan Yusof (2014), Effect of Low Pressure on Irrigation Uniformity of Solid Set Sprinkler Irrigation System, Applied mechanics and materials, 567, 26-31.
- Phocaidis A. (2007), Technical handbook on pressurized irrigation techniques, 2nd Edition Food and Agriculture Organization of the United Nations (FAO), p. 195.
- Tognoni F., La Malfa G., Barbieri G., Serra G., Maggio A., Leonardi C. (2002), Some aspects of the vegetable industry in Italy, Acta Hort. 582, 121–133.
- TWBD (2004), Water conservation implementation Task Force, Water Conservation, Best Management Practices Guide, Texas Water Development Board, Report 362.
- Unlu M., Kanber R., Senyigit U., Onaran H. and Diker K. (2006), Trickle and sprinkler irrigation of potato (*Solanum tuberosum* L.) in Middle Anatolian Region in Turkey, Agr. Water Mgt. 79, 43–71.

10.3 Management of irrigation systems

Description

The monitoring of the soil moisture is essential to support growers, optimise yield, reduce environmental impacts and manage the irrigation water in a sustainable way. Hence and also according to BEMP 10.1 over and/or under-irrigation incidents are avoided resulting to better management of the installed irrigation system (Figure 10.5) (Orlandini et al., 2008).

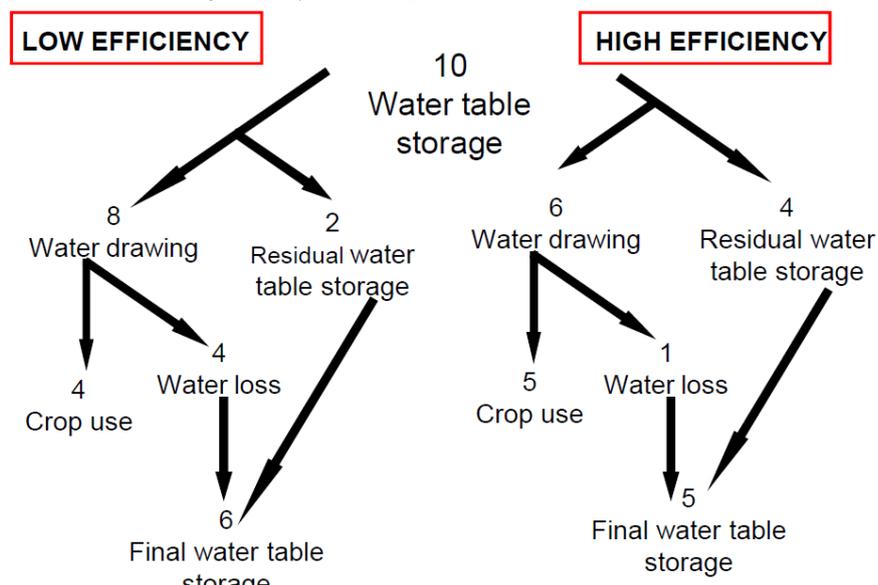


Figure 10.5. Characteristics of high and low efficient irrigation systems (Orlandini et al., 2008)

Towards a sustainable management of an irrigation system, two elements should be taken into account: i. water storage capacity and ii. water distribution efficiency or avoidance water losses by installing pipelines or through changes in operation and management. Both elements are covered under this BEMP.

Water storage capacity

The water storage capacities vary according to each type of soil texture. In particular, soil parameters are key elements for an efficient irrigation management. The soil water storage capacity is expressed as the total amount of water that is stored in the soil within the plants' root zone and is determined by the soil texture and the crop rooting depth. When deeper rooting depth exists, a larger volume of water stored in the soil is meant and therefore the water capacity increases. Furthermore, knowing the soil water storage capacity, the irrigation scheduling is properly set. For instance, the amount of water applied at one time on a sandy soil, is different from the amount of water applied on a loam soil for the same time. The reason is the different soil water capacity between sandy and loam soils. Therefore applying more amount of water to the soil that can be stored results in a loss of water to deep percolation and leaching of nutrients beyond the root zone. Plants can extract a specific amount of the water stored without being stressed. The soil water storage capacity is increased by increasing the organic matter content, the effective soil depth and/or having fallow periods. The increase of the organic matter content to the soil impacts the water holding capacity of the soil. When the upper part of the soil contains more organic matter content, more water is stored.

In particular, leaving higher levels of crop residue and doing less tillage, the soil water balance is increased by increasing the amount of water that infiltrates the soil from irrigation or precipitation, and decreasing the amount of water that runs off the soil surface. Moreover, the rate of evaporation of water from the soil and the amount of irrigation water needed to grow a crop are both reduced.

The practices that influence the increase of water holding capacity focus on the increase of effective soil depth. The effective soil depth may be limited due to the presence of compacted soil layers (e.g. hard pans, plough pans). By removing those layers, or by adding planting pits, the roots of the plants have more accessibility to larger amount of soil creating conditions for water storage⁴⁷.

Water distribution efficiency

The water distribution efficiency is affected by water losses through evaporation and transpiration, by undesired vegetation and leakage through water control structures in the distribution system. The efficiency is increased by lining canals, waterways and channels with impermeable materials like bricks or other similar materials. Likewise high-density polyethylene materials can be used in irrigation channels as a cheap lining material. Pipes may be laid for water conveyance in farms or wherever possible to reduce or eliminate the water distribution losses. Water losses in canals can be almost eliminated by installing pipelines and changing the operation and management of the water distribution system.

Water application efficiency varies considerably by different irrigation method. High application efficiency reduces erosion, deep percolation and return flows. In general, drip and sprinkler irrigation provide high efficiency rate (see also BEMP 10.2), whereas the application rate is equal to the soil water infiltration rate.

The sprinkler irrigation system should have a uniform distribution pattern. In particular, the volume of water applied can be changed either by altering the total time the sprinkler operates, by altering the pressure at which the sprinkler operates and in case of a centre pivot sprinkler by adjusting the moving speed of the system. As a general rule, the uniformity of the system is affected either by operating the system out of the design pressures or by using non-well maintained equipment.

The selection of the irrigation system should be designed properly in order to meet the crop water requirements. However, the system capacity should take into account parameters like evapotranspiration rate, crop rooting depth, available holding capacity of the soil, crops to be grown (because irrigation system is linked with the crops), water delivery capacity and available sources of water. Moreover topography parameters should also be taken into consideration like, shape, size and field slope and steepness. A sprinkler system is designed to apply water uniformly without run-off and/or erosion. Furthermore the application rate of the sprinkler system is matched to the intake rate of the most restrictive soil in the field and when the application rate exceeds the soil intake rate, the water will run off the field or relocate within the field.

Run-off Harvesting

The run-off is collected from the sloping surfaces. The run-off is collected from a large area (usually form a large area within a field) and is concentrated in a smaller cropping area. However, it is not recommended that the slope of the catchment area does not exceed 5%. Bare catchment areas result to more amount of run-off but work should be done in order to avoid potential soil erosion or other similar land problems. They can left also under natural vegetation and may sometimes be sown to short-season crops, but the amount of collected water will be less than under bare soils. Nevertheless, diversion ditches are probably necessary upslope of the area used for run-off harvesting to prevent excessive damage by run-off. The concentrated run-off is collected from narrow channels like footpaths, cattle tracks or other residential areas and/or roads.

Irrigation management system

The irrigation systems operation should follow the crop water requirements, taking into account parameters like timing and the amount of irrigation water applied. Therefore it is required as a minimum to measure accurately the soil-water depletion volume and the volume of irrigation water applied and the uniformity of the water applied.

⁴⁷ More information can be found at: http://www.fao.org/ag/ca/training_materials/cd27-english/sm/soil_moisture.pdf

Achieved environmental benefits

The efficient water distribution results in significant environmental benefits.

Applicability

This BEMP is fully applicable in field and horticultural crops in all the different cultivation types.

Appropriate environmental performance indicators

The appropriate environmental indicators for the management of irrigation systems are listed below (EPA, 2003):

- application efficiency (on farm): $(W_{\text{stored}}/W_{\text{applied}})*100\%$
- irrigation efficiency (on farm): $(W_{\text{beneficial}}/W_{\text{applied}})*100\%$
- conveyance efficiency (to farm): $(W_{\text{delivered}}/W_{\text{diverted}})*100\%$

where: W_{diverted} is the total water diverted or pumped into an open channel or pipeline at upstream end, $W_{\text{beneficial}}$ is the average amount of water beneficially used, W_{applied} the average amount of the water applied and W_{stored} is the average amount of water infiltrated and stored in the plant root zone.

Maximum soil water deficit (MSWD) is the amount of water stored in the soil that is readily available to the plant and in particular the irrigation should be applied when this moisture amount has been removed from the soil. Afterwards, the same amount of water should be added through the irrigation system, representing the maximum value that can be applied at one time, in order to avoid the risk of deep percolation. The MSWD is expressed as the Soil water Storage (mm) * Available coefficient of the water to the crop (AC %). The Soil Water Storage is determined by the crop rooting depth (mm) multiplied by the available water storage capacity of the soil (AWSC – mm/m) (British Columbia, 2002).

For the storage efficiency, the proper indicator is presented below (Majumdar, 2013):

$Es = 100 \frac{Ws}{We}$ where, Es is the storage efficiency, Ws is the amount of water actually stored in root zone soil from the water applied and We is the amount of water needed to meet the soil water depleted in the crop root zone.

Water storage efficiency is considered important in areas where under-irrigation is implemented in order to save some amount of water because of its scarcity or its high price (Majumdar, 2013).

Operational data

Infiltration rate and field capacity are two important hydrological variables that depending on the soil texture (Table 10.14 and Table 10.15).

Table 10.14. Infiltration rates and field capacity for different soil textures (Orlandini et al., 2008)

Texture	Infiltration (mm/h)	Total porosity (%)	Field capacity (%)	Wilting point (%)	Water availability (%)
Sand	50 (25-250)	38 (32-42)	9 (6-12)	4 (2-6)	5 (4-6)
Loam-sandy	25 (12-75)	43 (40-47)	14 (10-18)	6 (4-8)	8 (6-10)
Loam	12.5 (8-20)	47 (43-49)	22 (18-26)	10 (8-12)	12 (10-14)
Loam-clayey	8 (3-15)	49 (47-51)	27 (23-31)	13 (11-15)	14 (12-16)
Slime clayey	2.5 (0.3-5)	51 (49-53)	31 (27-35)	15 (13-17)	16 (14-18)
Clayey	0.5 (0.1-10)	53 (51-55)	35 (31-39)	17 (15-19)	18 (16-20)

Table 10.15. Infiltration rates (mm/h) (Orlandini et al., 2008)

	Infiltration rate (mm/h)
Very slow	< 1
Slow	1-5
Moderately slow	5-20
Moderate	20-63
Moderately rapid	63-127
Rapid	> 127

Cross media effects

There are no cross-media effects applying these techniques.

Economics

It is very difficult to obtain economic figures about the efficient distribution of water. Those values ranged according to various criteria, e.g. pricing of the water in areas or scarcity of water.

Driving forces for implementation

The efficient management of an irrigation management system is the main important driving force for implementation of this BEMP.

Reference literature

- EPA (2003), National Management Measures for the Control of Nonpoint Pollution from Agriculture, Chapter 4F-Irrigation water management, available online: http://water.epa.gov/polwaste/nps/agriculture/upload/2003_09_24_NPS_agmm_chap4f.pdf, last accessed 11th September 2014.
- British Columbia (2002), Soil water storage capacity and available soil moisture, water conservation factsheet, Ministry of Agriculture, Food and Fisheries, Order No. 619.000-1, Agdex: 550.
- Orlandini S., Marta A.D., Natali F. (2008), Water use in Italian agriculture: analysis of rainfall patterns, water storage capacity and irrigation systems, Cost Action 734, available online: http://www.adagio-eu.org/documents/meeting_jojs/04_S_Orlandini_wateruse_italian_agriculture.pdf, last accessed 11th September 2014.
- Majumdar D.K. (2013), Irrigation water management, principles and practice, Second Edition, PHI learning Private Limited, ISBN-978-81-203-4826-4.

10.4 Efficient and controlled techniques

Description

Field application efficiency is considered as the ratio between the water used/applied in the field or used by a crop and the total amount of water delivered to the field, or to that crop. Therefore, the performance of a water irrigation system can be monitored by indicating how well the water is delivered to the crops. The efficiency of furrows, sprinklers and drip systems was measured 55%, 75% and 90% respectively (Dworak et al., 2007; EEA, 2012).

Figure 10.6 illustrates the applied irrigation systems in Europe in 2003. In Spain, the irrigated area (hectares) was decreased approximately 28% for the period 2002-2008, while drip irrigation increased from 1.1 to 1.6 million hectares (EEA, 2012).

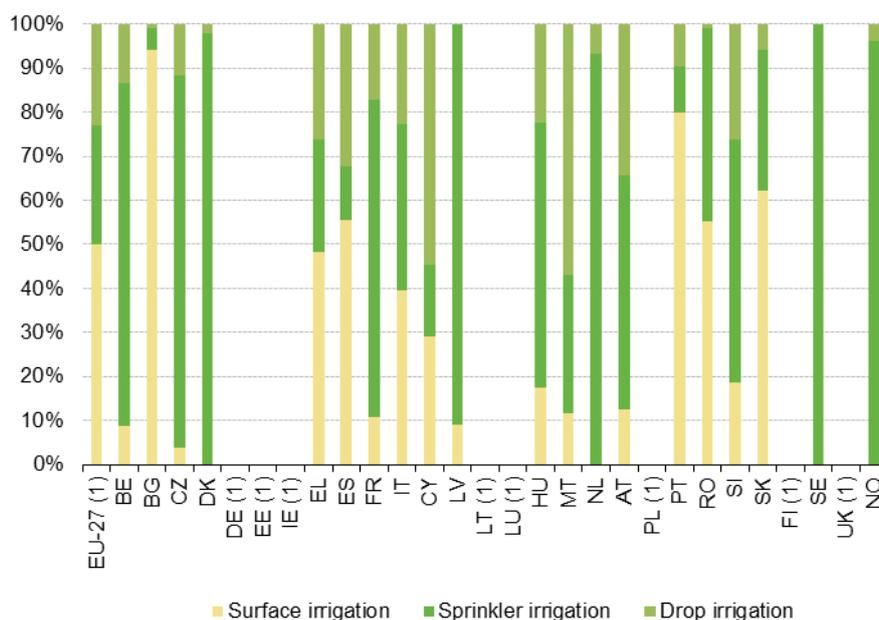


Figure 10.6. Irrigation systems in Europe for the year 2003 (Eurostat, 2003)

In this BEMP, applied efficient and controlled irrigation techniques are presented. In particular, techniques like Deficit Irrigation (DI), which minimises irrigation demand as well as other practices already implemented by companies, are presented in detail. In the following paragraphs the selected techniques are described. Apart from the listed practices below, it should be mentioned that in order for the farmers to be able to achieve efficient and controlled water irrigation consumption, water meters should be installed.

Deficit Irrigation

The frame of DI is that the crops are exposed to a specific level of water stress either during a certain period or throughout the whole growing season and the yield reduction is lower compared with the achieved water savings (Eck et al., 1987; Patané et al., 2011). The efficiency of the DI is measured by the Water Use Efficiency (WUE) or crop Water Productivity (WP), which is expressed by the reduction of the water applied with watering or by reducing the number of the applied irrigations. Additionally, the DI is applied together with the application of appropriate irrigation schedules and also because of the crop sensitivity to water deficit during growing season changes with the phenological stage (Istanbulluoglu, 2009).

Most of the horticultural production is located in the Mediterranean area where high conditions of day-light and high temperature exist. In those areas an efficient irrigation strategy must be applied.

The effects of the DI are crop-specific and the climate conditions of the examined cultivated area, the crop and soil type/characteristics are the main parameters for the calculation/estimation of the amount of the water required. However, it is recommended to assess the impact of DI strategies with multi-years open field experiments before implementing the most suitable irrigation strategy (DI) for a given crop in a specific location.

DI is implemented by two different strategies: i. Regulated Deficit Irrigation (RDI) and ii. Partial Root Drying (PRD). RDI is a method based on the observation that plant/crop growth is not more sensitive to water stress caused by drought than to transpiration increasing thus the WUE indicator. On the other hand, the soil water status must be monitored frequently in order to identify the limit values of the water stress in which the yield is not reduced.

Before applying DI, it is necessary to calculate/estimate/define the water crop requirements (Feres and Soriano, 2007), which are presented detailed in BEMP 10.1.

Techniques already implemented by companies

Pepsico UK

Pepsico UK together with Cambridge University developed an appropriate tool (i-crop) that helps farmers to produce more by using less water. This tool incorporates soil moisture and local weather data. Farmers can access the information online and to be informed about the frequency of the irrigation and the amount of water is needed. More specifically, the i-crop tool relates Soil Moisture Deficit (SMD) to local weather station data in order to identify the appropriate crops and set the irrigation timing/scheduling (Pepsico, 2012).

The developed tool is based on the four listed aspects (PepsiCo, 2012): i. New varieties, focused on varieties that provide better yields, require less fertiliser and provide higher drought tolerance. ii. Precision agronomy, which focus on how and where to grow the crops. iii. Modified agronomy, irrigation and fertilizers indicating that drip irrigation is the best irrigation method and providing advice for application of fertilizers. iv. Cool farm tool, which measures the performance and develops what of scenarios if needed.

Supplementary information from the aforementioned technique are summarised under the operational data section.

Marks & Spencer

Moreover, nowadays a few corporate organisations compile water use assessments, but in a different non-conventional way. In the past, companies/organisations were implementing water footprint studies in a stand-alone basis, although the new approach is to address the environmental impacts of the water use from a water stewardship perspective (RPA, 2011; EEA, 2012). The UK retailer, Marks & Spencer, uses a three-tiered approach, and targets the development of a sustainable supply chain (Marks & Spencer, 2011). The three steps of this methodology are presented in detail in the Operational Data section of this BEMP.

Aarhus University – RMD technique

In Denmark, Aarhus University developed an irrigation method based on the Partial Root zone Drying method (DI related). Applying this method, the crops watering takes place on first one side and then on the other side; by alternating sides each week (or certain period according to the crop type, climate data and soil characteristics) the plants receive a certain portion of water, but leaving them a bit drought-stressed. Appropriate sensors are installed on root zone of each plant in order for the optimised operation of the described method (SAFIR, 2009). The continuous, accurate measurement of flow facilitates charging the water on the basis of consumption as well as encourages farmers to use efficiently the water for irrigation purposes. The principle is the same with domestic water meters where households are charged according to their actual water consumption. The irrigation water must be measured in each field and set for optimum management. Several studies proved that the measurement results to better irrigation water management. Moreover, it should be mentioned that a measurement at a diversion, lateral or farm delivery point corresponds to each field if the water is not

split and used further on other separate fields. Most water meters measure flow rate, which is then converted to volume or depth unit according to the farmers' needs (Zhang et al., 2013).

Achieved environmental benefits

The controlled irrigation techniques provide significant environmental benefits. Some representative environmental benefits of the aforementioned techniques are presented below.

It is reported in the literature that the total energy savings can reach 20% by applying improved management measures (like application water meters, irrigation scheduling and/or other irrigation controlled techniques) as compared with other traditional irrigation methods (Zhang et al., 2013).

Regarding the potatoes cultivation by PepsiCo UK, in 2011 water usage was reduced by 8% and yield increased by 13%. These figures achieved by applying drip irrigation systems in surface more than 300 ha and in water stressed areas/regions and implementing new varieties of potatoes.

The development of the PRD irrigation method by the Aarhus University reduces the water consumption by 20% without decreasing the yield. However, it should be noted that if the plants are irrigated in the conventional way, (on both sides of the plant at the same time), but with the same reduction in the amount of water, then the yield will be less (SAFIR, 2009), thereby providing evidence for the effectiveness of the PRD itself.

Deficit irrigation

Through the application of the aforementioned techniques, water savings from irrigation are achieved. Furthermore the nutrient efficiency (N) is increasing, influencing positively the yield of the cultivated plants/crops.

In addition, reduced pollution because of fertilisers leaching is achieved and smaller amounts of products for plant protection are used. Moreover, energy savings are performed due to the lower amount of energy required for pumping the water. Finally, the crop yield increases maintaining quality at a high level (less risk of plant stress due to waterlogging or water deficit between successive irrigation). Applying DI techniques, reductions in nitrate leaching to groundwater are achieved (Quemada et al., 2013). DI is applicable as an important tactical measure for reducing the amount of water for irrigation when the water availability is scarce, although it cannot be used as a strategic practice over long time periods (Fererres and Soriano, 2007). It should be also mentioned that the use of efficient and controlled techniques reduce the overexploitation of water resources and their salinization.

Appropriate environmental performance indicators

The appropriate environmental indicators are summarised below (based partially on Burton, 2010):

- Percentage of (%) crop requiring irrigation (by crop and climate region)
- Water consumption m^3/ha or m^3/t produced for different crop types related to annual water balance
- Type of water used (green or fresh) according to the applied water footprint methodology
- Volume of water abstracted (m^3/ha), in case of drillings
- Drip irrigation installed
- Yield or marketable value of products per unit water abstracted (kg/m^3 or $\text{€}/\text{m}^3$)
- Percentage of (%) crop area requiring irrigation (by crop and climate region)
- Irrigation efficiency: is the ratio between the water stored in the soil depth exploited by plant roots to the water applied by the irrigation system. The major causes for reduced IE are drainage of excess irrigation water to soil layers deeper than the depth of active roots. All cropping system have a lower IE than 100 percent, apart from closed soilless systems, in which water loss due to

uncontrolled seepage and periodical discharge of recycling irrigation water can be less than 5% provided high quality irrigation water is available.

Cross media effects

There are no cross-media effects applying these techniques.

Operational data

Deficit irrigation

Before applying an irrigation plan based on DI, soil characteristics in the field should be investigated. Hence, soil texture and structure, field water capacity problems, number and thickness of the soil layers in the underground, the crop/plant characteristics (i.e. rooting depth) should be investigated/measured (Figure 10.7). In addition, chemical analyses of the soil must be performed in order to identify potential chemical and/or nutrient problems like acidity, salinity, nutrient deficiency etc. (Stikic et al., 2010).



Figure 10.7. Identification of the soil characteristics before applying DI strategy (Stikic et al., 2010)

Tomato under RDI and PRD cultivation

The optimal irrigation period includes the period from blossoming (3-4 weeks old small plants) until the final harvest. Figure 10.8 illustrates the water feeders distance in the cases of PRD and RDI, in particular, the plant spacing in the row (0.5 cm) and the dripper spacing, which is 1 m for PRD and 0.5 cm for DI. The PRD shifting is performed when soil water content on the dry side was 30% lower than on the wet side. The irrigation is applied when the average daily temperature is higher than 26.5°C or when air temperature is higher than 40°C.

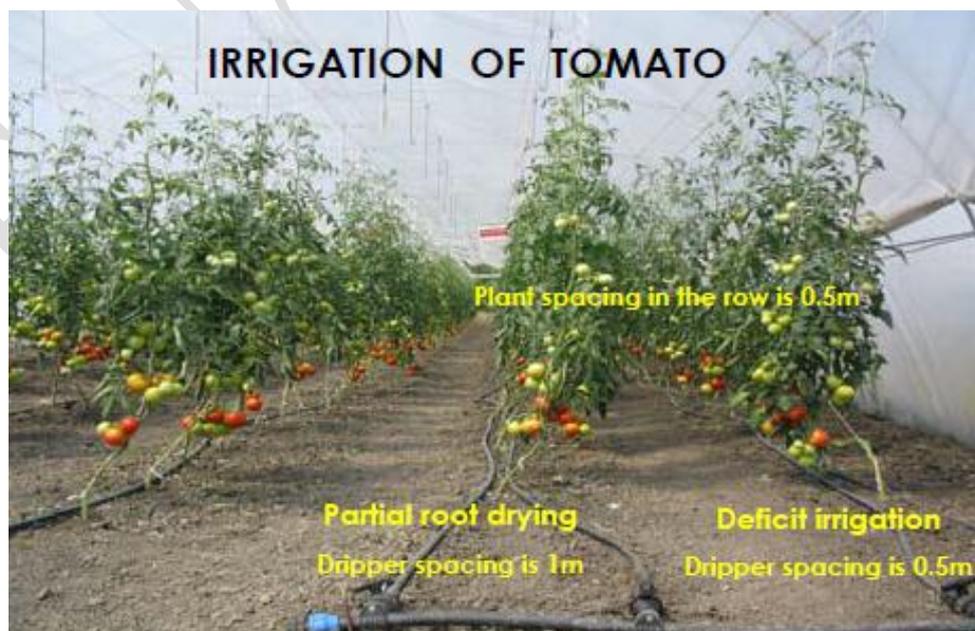


Figure 10.8. Irrigation of tomato; technical data for PRD and RDI strategies are illustrated (Stikic et al., 2010)

Patané et al., (2011) calculated the marketable yield losses and the water savings (%) for different tomato DI strategies for the time period from 2001 to 2002 in Sicily. The maximum temperatures during the growing period (May-July) ranged from 23.4 to 33.1°C and 22.6-30.1°C in 2001 and 2002 respectively (Patane et al., 2011). In parallel the minimum temperatures ranged from 12.8-19.6°C and 12.8-19.4°C for 2001 and 2002 respectively.

The three scenarios that were developed were: i. normal irrigation – no DI strategy application, ii. application of 50% DI (50% ETc restoration) and iii. no irrigation following plant establishment (Patané et al., 2011).

Table 10.16 illustrates the amount of total water distributed, the number of the applied irrigations, the marketable yield losses as well as the water savings.

Table 10.16. Deficit irrigation strategies for three scenarios for the time period 2001-2002; the number of applied irrigations, the amount of water distributed, the marketable yield losses and the water savings are presented (Patané et al., 2011).

Scenario	Amount of distributed water (mm)		Number of applied irrigations		Marketable yield losses (%)		Water savings (%)	
	2001	2002	2001	2002	2001	2002	2001	2002
i	377.6	380.8	10	11	0	0	0	0
ii	211.1	197.3	10	11	16.6	9.9	44.1	48.2
iii	44.6	47.5	2	2	82.9	70.6	88.2	87.5

Definition: i. no DI strategy, ii. 50% of applied DI strategy, iii. 100% of applied DI strategy

PepsiCo UK

PepsiCo UK reported that 80% of crisps by will be made from new, proprietary potato varieties by 2017, which are more resistant to specific climate conditions. The i-crop tool is used in order to establish and set precise agronomy policies for the farmers. Hence, parameters like right variety and right location grown in the right way are taken into account. For instance, 10% of UK crop under i-crop tool application and monitoring are rolled out to the Netherlands, Belgium, France, Germany, Iberia, Poland and Turkey (PepsiCo, 2012).

The water modelling is also achieved targeting to the optimisation of the potential yield. In particular, Figure 10.9 depicts the daily water use/requirement for a crop combining also the soil moisture and the irrigation needed for a certain time period. Consequently, the actual water used is less from the estimated water needs, proving the optimised efficiency of the described tool. More specifically, this crop reached 95% of its potential yield receiving 402 mm water in total. However, it should be highlighted that the ideal (optimum amount of water for the crops) water amount was only 326 mm.

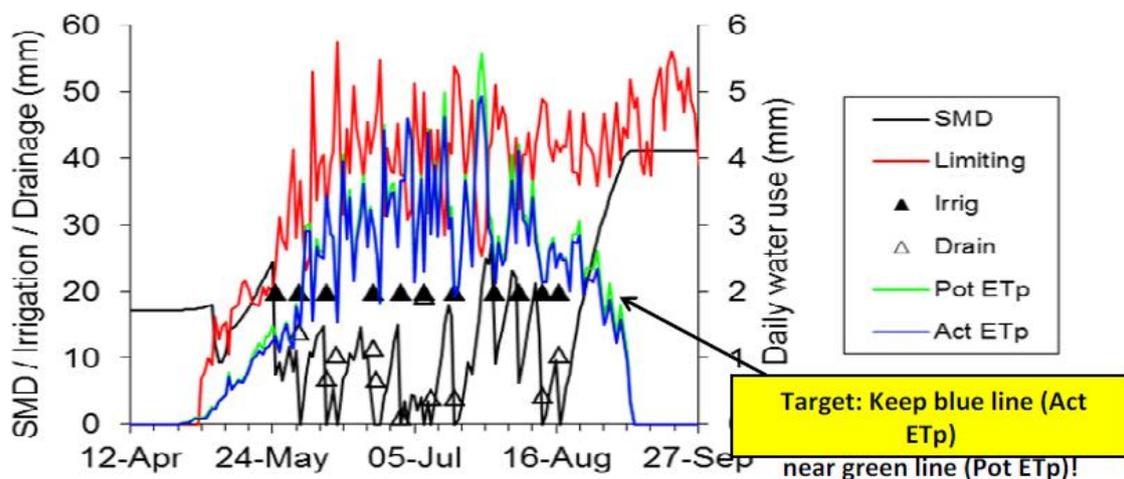


Figure 10.9. Water modelling through the use of i-crop tool (PepsiCo, 2012)

The findings from the implementation of the four pillars sustainability policy are summarised in Table 10.17 where the performance of this tool is illustrated.

Table 10.17. Performance of four pillars sustainability policy for the time period 2009-2012 (PepsiCo, 2012)

New varieties	2009	2010	2011	2012
	1.75%	5.2%	9.7%	18.3%
i-Crop		UK: 24 fields, 55 crops	UK: 46 fields, 83 crops	UK: 46 fields, 84 crops + Poland and Turkey
Irrigation/fertilisers			UK: 100 Ha drip TU: 240 Ha drip	UK: 100 Ha drip TU: 240 Ha drip
Cool farm tool	1 carbon footprint (carbon trust)	2 footprints UK	26 footprints UK, WER, Iberia	> 80 footprints UK, WER, Iberia, Poland, Turkey

Regarding the irrigation media, water guns are the most common method to irrigate potatoes in the UK, which spray water around the field from a fixed position. Water guns use significant amounts of water but many plants are partially irrigated. In 2011, the irrigation method changed and the water guns were replaced by drip irrigation. In particular, drip irrigation technology was applied on three fields. Pipes were laid down on the ground/field to deliver specified scheduled amounts of water to every crop. It should be noted that 36% decrease in water use and 7% yield increase were achieved. The same technique continued in 2012 with similar results (taking into account the wet weather); 46% water use decrease and 5% yield increase (Pepsico, 2012).

Marks & Spencer

Marks & Spencer uses a three-tiered approach according to the water footprint methodology. The three tiers are presented below (Marks and Spencer, 2011; RPA, 2011; EEA, 2012):

1. Tier 1 - *Standards*: Definition of the criteria that their suppliers must have to meet
2. Tier 2 - *Risk*: Use information on water risk in its supply chains to identify which products are from areas at risk of water stress.
3. Tier 3 - *Influence*: Using the information on water risk, Marks & Spencer selects which suppliers to target with its water stewardship approach. Marks and Spencer does not target only to suppliers located in areas at risk of water stress, but provides an award to those that are work sustainably.

Summarising, suppliers have to work sustainably even though they are located in a high risk area (area where the potential of water stress is high), while the sustainable suppliers receive an award for their applied sustainable practices.

Applicability

The controlled irrigation techniques that increase the irrigation efficiency should be farmer-friendly. Therefore, the farmers can model the techniques accordingly to their needs, water sources available, soil type etc.

DI is applicable in Southern Mediterranean climates. However, it should be noted that DI cannot be used as a strategic measure over long time periods (Feres and Soriano, 2007).

Economics

The irrigation requirement should be calculated according to the actual crop water requirements. DI reduces the crop yields but also reduces the nitrate leaching (Quemada et al., 2013).

When water availability is scarce the farmer should target to maximise net income per water used (i.e. m³) and not per land unit (Feres and Soriano, 2007). The Water Productivity (WP) factor is expressed, either as yield or net income per water used (m³). WP is increased under deficit irrigation status as compared with the relative values of full irrigation according to the literature (Feres and Soriano, 2007; Zwart and Bastiaansen, 2004; Fan et al., 2005).

Fertigation, the application of fertilisers through an irrigation system, is economically feasible mostly in arid and semi-arid regions where irrigation occurs. On irrigated fields the estimated additional costs per hectare could be around 2,500-3,000 € when compared with furrow irrigation, and range between 0 and 1,000 € when compared with high efficient sprinkler irrigation (depending on whether PVC or polythelene is used). Subsidies for covering costs of investment could be of interest because potential benefits include not only the reduction of non-point pollution (N, P, pesticides) but also because of soil conservation and water saving, which are important topics in arid and semi-arid regions (Delgado, 2011)

Driving forces for implementation

The installation and implementation of efficient and controlled irrigation system is the main driving force for implementation of this practice.

Reference organisations

The major companies that have already developed appropriate tools/techniques in order to optimise the irrigation management are listed below:

Pepsico UK i-crop tool, optimisation of irrigation practices and selection of the suppliers
Marks & Spencer application of water footprint methodology, 3-tiered methodology

FAO, (2002) presents all the applied DI strategies including various cultivations. Also Patané et al., (2011) and Karrou et al., (2011) summarises the best applied strategies towards minimising irrigation demand.

Reference literature

- Burton M. (2006), Benchmarking: a pathway to efficient and productive irrigation, UK irrigation 34.
- Delgado A. (2011), Fertilizer placement near crops, available online at: http://www.cost869.alterra.nl/Fs/FS_placement_near_crops.pdf, last accessed on 19th August 2014.

- Dworak T., Berlund M., Laaswer C., Strosser P., Roussard J., Grandmougin B., Kossida M., Kyriazopoulou I., Berbel J., Kolberg S., Rodriguez-Diaz J.A. and Montesinos P. (2007), EU Water saving potential, European Commission Report. Ecologic together with ACTeon, National Technical University of Athens and Universidad de Córdoba, (http://ec.europa.eu/environment/water/quantity/pdf/water_saving_1.pdf) accessed on 19 August 2014.
- Eck H.V., Mathers A.C., Musick J.T. (1987), Plant water stress at various growth stages and growth and yield of soybeans. *Field Crops Research* 17, 1–16.
- EEA (2012), Towards efficient use of water resources in Europe, EEA report 1/2012, ISSN 1725-9177.
- EEA (2012), Trends in annual precipitation across Europe, Available online at: <http://www.eea.europa.eu/data-and-maps/figures/observed-changes-in-annual-precipitation-1961-3>, last accessed at 31st March 2014.
- Fan T., Stewart B.A., Payne W.A., Wang Y., Song S., Luo J. and Robinson C.A. (2005), Supplemental irrigation and water: yield relationships for plasticulture crops in the loess plateau of China, *Agronomy Journal* 97, 177–188.
- FAO, (2002), Deficit Irrigation practices, Water reports, ISBN: 92-5-104768-5.
- Fereres E. and Soriano M.A. (2007), Deficit irrigation for reducing agricultural water use, *Journal of Experimental Botany, Integrated Approaches to Sustain and Improve Plant Production under Drought Stress - Special Issue*, 58(2), 147–159.
- Istanbuluoglu A. (2009), Effects of irrigation regimes on yield and water productivity of safflower (*Carthamus tinctorius* L.) under Mediterranean climatic conditions, *Agricultural Water Management*, 96(12), 1792-1798.
- Karrou, M., Oweis, T. and Bahri, A. (2011), Improving water and land productivities in rainfed systems. Community-Based Optimization of the Management of Scarce Water Resources in Agriculture in CWANA. Report no. 8. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. vi + 170, ISBN: 92 - 9127 - 209 - 6.
- Marks & Spencer (2011), 'Water Footprints: Who are they for?', British Hydrological Society Workshop, Royal Institute of Civil Engineers, London, 17 March.
- Patanè C., Tringali S., Sortino O. (2011), Effects of deficit irrigation on biomass, yield, water productivity and fruit quality of processing tomato under semi-arid Mediterranean climate conditions, *Scientia Horticulturae*, 129, 590-596.
- Pepsico (2012), Pepsico's Sustainable future, Pepsico Europe, available online at: <http://www.pepsico.co.uk/purpose/environmental-sustainability/agriculture>, last accessed on 12 March 2014.
- Quemada M., Baranski M., Nobel-de Lange M.N.J., Vallejo A. and Cooper J.M. (2013), Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield, *Agriculture, Ecosystems and Environment*, 174, 1-10.
- RPA (2011), Assessment of the efficiency of the water footprinting approach and of the agricultural products and foodstuff labelling and certification schemes, report prepared for DG Environment.
- SAFIR (2009), Saving precious drops, EU-project SAFIR-Safe and high quality food production using low quality waters and improved systems and management, available online at: http://www.safir4eu.org/Lib/SAFIR/Deliverable/SAFIR_Leaflet_180706.pdf, last accessed on 19 March 2014.
- Stikic R., Stricevic R., Jovanovic Z., Matovic G., Savic S., Rovcanin S., Knezevic N. and Dordevic S. (2010), Deficit irrigation methods, Management practices for horticulture and viticulture, Faculty of Agriculture, University of Belgrade, Serbia, available online at: http://www.cropwat.agrif.bg.ac.rs/content/files/Deficit_irrigation_methods-Management_Practices_for_Horticulture_and_Viticulture.pdf, last accessed on 26 of May 2014.
- Zhang Q., Xia Q., Liu C.K., Shu G. (2013), Technologies for efficient use of irrigation water and energy in China, *Journal of Integrative Agriculture*, 12(8), 1363-1370.
- Zwart S.J. and Bastiaanssen WGM (2004), Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize, *Agricultural Water Management* 69, 115–133.

11 CROP PROTECTION PRODUCTS

Introduction

On the 21st October 2009, the European Parliament and the Council of the European Union decided on establishing a framework for Community action to achieve the sustainable use of pesticides by reducing the risks and impacts of pesticide use on human health and the environment and promoting the use of integrated pest management and of alternative approaches or techniques such as non-chemical alternatives of pesticides. This new Directive 2009/128/EC was published in the Official Journal of the European Union on the 24th November 2009.

This Directive⁴⁸ introduced the concept of Integrated Pest Management (IPM), which is defined as *"the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically and ecologically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms."*

It sets the obligation for member states to adopt National Action Plans (NAPs) to reduce risks and impacts of pesticide use by encouraging the development and introduction of IPM and of alternative approaches/strategies or techniques in order to reduce dependency on the use of pesticides.

The proper use of crop/plant protection products according to the principles of IPM is mandatory in the EU since 1st January 2014 (Regulation (EC) No 1107/2009, Art. 55).

In line with this legislative framework, this chapter describes best practice in how farmers can go beyond the legal requirements and implement a full set of actions to optimise and reduce the use of crop protection products, and, when needed, choose those products which have the least impact and are most compatible with the rest of the strategy (e.g. biological pest control). In particular, two techniques are described:

1. The introduction of a dynamic crop management plan by farmers, which includes a series of measures such as crop rotation, biological pest control, operators/farmers training and precise application of crop protection products (if and when needed).
2. The selection of crop protection products with the lowest environmental impact.

Reference literature

- Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides, Official Journal of the European Union, L 309/71.
- Regulation (EC) No 1107/2009 (art. 55) of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC, L 309/1.

⁴⁸ This Framework Directive addresses only pesticides which are considered as Crop/Plant Protection products, excluding biocide products.

11.1 Optimising and reducing the use of crop protection products

Description

The use of Crop Protection Products (CPP) contributes significantly to the environmental impact of agriculture. To minimise the risks of adverse effects on human health and the environment, the SUD Directive⁴⁹ promotes the use of Integrated Pest Management⁵⁰ (IPM) and, in general, non-chemical pest control methods as alternatives to pesticides. According to the SUD Directive, Member States must compile and implement national action plans for reducing 'risks and impacts' of pesticide use on human health and the environment, including timetables and targets for use reduction, if the reduction of use constitutes an appropriate mean to achieve risk reduction. Additionally, aerial crop spraying is generally banned, especially in fields close to residential areas, and there are obligations for Member States to include and/or set buffer zones around water bodies and safeguard zones for surface and groundwater, and to protect the water supplies from the impact of pesticides.

On the other side, effective crop protection is a key dimension of agriculture, in order to ensure the expected harvest and thus economic feasibility of the agricultural activity.

Beyond the legislative obligations, from a farmers' perspective, the prevention or suppression of pests in the crops can be achieved by the adoption of a dynamic crop protection management plan, which incorporates key aspects of the IPM strategy. The main elements of an effective dynamic crop protection management plan are:

- a) crop rotation;
- b) operators/farmers training;
- c) biological pest control; and
- d) use of crop protection products with precise application (if needed).

In addition to these elements, an important contribution can come from selecting variety of plants that are less susceptible to common pests (PennState, 2008).

Effective monitoring is also needed to guarantee the effectiveness of the dynamic crop protection management plan. Tools like monitoring traps, screens, fences, etc. are some of the options that can be used. For instance, monitoring traps (which can be either mechanical devices or sticky surfaces) either kill the captured pests or trap them (farmer can later remove them). They can allow farmers to know and monitor over time the amount and species of pests affecting the fields.

In the paragraphs below, the above-mentioned four main elements of dynamic crop protection management are presented. Figure 11.1 instead shows the entire IPM principles including, but not limited to, the above points (Boller et al., 2004; Meissle et al., 2011; Bigler, 2013).

After these four main elements, this BEMP also covers guidance on the application of crop protection products, relevant to all farmers needing to use crop protection products.

⁴⁹ The SUD Directive is the acronym used to refer to Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides.

⁵⁰ According to the SUD Directive "‘integrated pest management’ means careful consideration of all available plant protection methods and subsequent integration of appropriate measures that discourage the development of populations of harmful organisms and keep the use of plant protection products and other forms of intervention to levels that are economically and ecologically justified and reduce or minimise risks to human health and the environment. ‘Integrated pest management’ emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms".

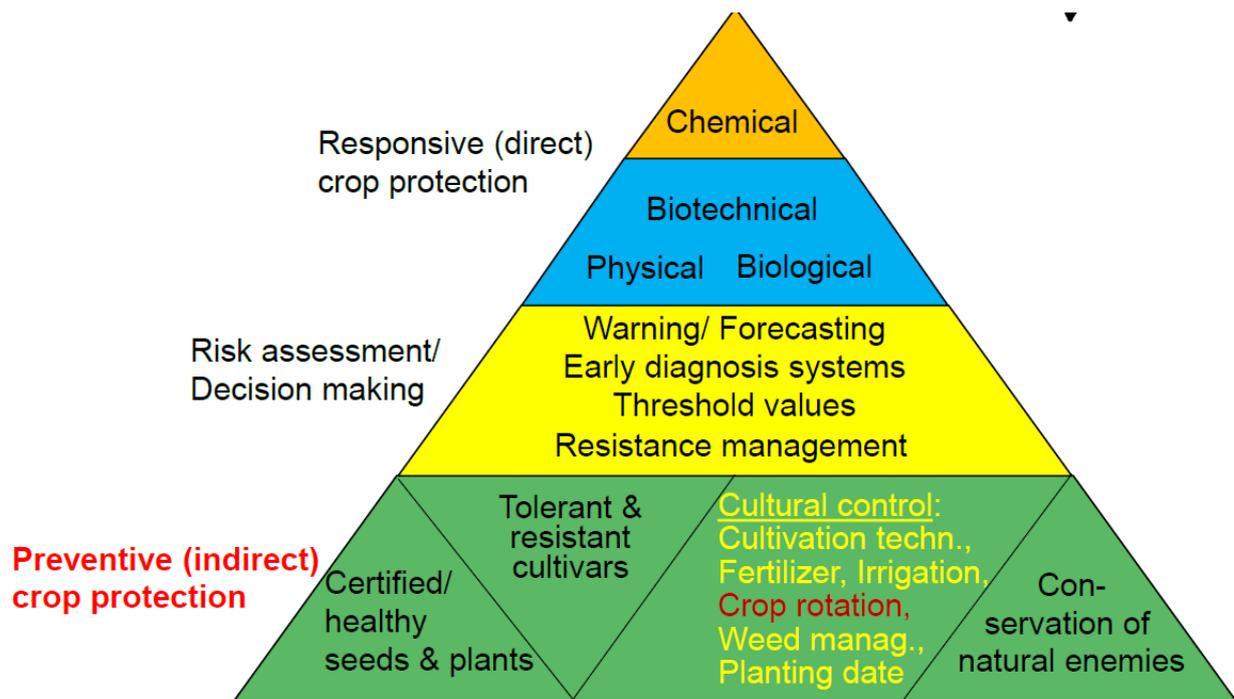


Figure 11.1. The IPM principles (Boller et al., 2004; Meissle et al., 2011; Bigler, 2013)

Crop rotation

Crop rotation is a preventive control method for insects, nematods, diseases and weeds (Bigler, 2013). It is a farming practice in which different crops are grown in the same field at different times over several years in order to ensure conditions which are conducive for the development of crops (BIO, 2010). Crop rotation is important for arable crops, vegetables and mixed farming systems. Especially for mixed farming systems (with both crop production and livestock), crop rotation is implemented to avoid problems with soil-borne pathogens and pests and to maintain fertility (see also Section 5.2 on best practices in crop rotation for efficient nutrient cycles).

In the EU, crop rotations typically last 3 to 5 years in conventional agriculture, and 5 to 10 years in organic agriculture, where they are particularly important due to the very restricted use of pesticides/fertilisers (BIO, 2010).

The specific crop rotation scheme suitable for each specific farm should be identified according to several parameters: i. type of farming system (arable or mixed), ii. local climatic conditions, iii. soil type, iv. water availability, v. irrigation applied, vi. types of crops cultivated and vii. market opportunities.

In general, the most effective crop rotations in terms of pest prevention are those (BIO, 2010):

- including crops of various families and species rotated with one another;
- rotating spring-sown and autumn-sown crops, to break cycles of weeds, pests and pathogens;
- avoiding following a crop with a closely related species, to avoid common weeds, pests and pathogens;
- growing more than one fast-growing crop in close proximity ("intercropping", "cover crops" or "catch crops") which provide habitat to beneficial insects (see below on biological pest control).

A minimum delay between two same cultivations is required in order to break the life cycle of the pests in the soil (depending upon the crop type, weather etc.). In general, at least five years should

pass before the same crop is sown on the same field again, but this varies from place to place and can also be shorter e.g. 2 or 3 years (Table 11.1).

Table 11.1. Suggested return time for crops in Belgium (BIO, 2010; Leteinturier, 2006)

	Cereals	Legumes/grasslands	Root Crops	Oil crops	Fallow	Other
Recommended minimal return time (years)	1	Leguminous Grasses			Native vegetation	
	2	Winter wheat, Spring wheat, Spring barley, Grain maize, Silage maize				
	3	Winter rye, Oat, Triticale, Spelt, Buckwheat	Temporary meadow	Sugar beet, Fodder beet, Chicory		
	4	Winter barley	Clover, Alfalfa		Swede, green and winter turnip rape, Soybean, Sunflower, Winter and Spring rape (not for food)	(Textile and not textile) hemp, Sweet lupin
	5			Potato	Swede rape, summer turnip rape	
	6		(Dry) pea, (Dry) Brown and horse beans, Beans	Fodder carrot		(Textile and not textile) linen, Tobacco

Operators/farmers training

An important element of a dynamic crop protection management plan is the training of the operators/farmers. Farmers should ensure that they have appropriate knowledge about pests, pest control strategies, risks to human health and environment of crop protection products and how to ensure their effective application. The main objective of the training courses is the maximisation of the product benefits as well as the minimisation of their risks. The training schemes must cover all aspects from buying and using the crop protection products to proper handling (storing) and/or their disposal. Some important elements of an effective training on crop protection are listed below⁵¹ (based on Croplife, 2014):

- Identification of pests as well as beneficial insects or natural predators
- Assessing the risk of pest populations and attempting to estimate the potential crop damage
- Management of the pests in accordance with the main principles of IPM (e.g. crop rotation or other agronomic practices)
- Safe and effective application of crop protection products if required
- Avoiding unacceptable risks to human health, animals and environment; special emphasis on the identification of the entry routed of the CPPs into water bodies
- Minimising the crop protection products residues
- Monitoring for pest resistance
- Safe storage of the crop protection products

⁵¹ An exhaustive list of concrete measures and sound best practices can be found on the following link from the TOPPS Life project: www.topps-life.org.

- Proper disposal and cleaning of the empty containers
- Proper cleaning and maintenance of the equipment used

Biological pest control

Several environmental factors like weather, food availability and natural predators keep insect populations under natural control. When the level of natural control in agricultural crop fields is not sufficient, the pest population increases. While some environmental factors, such as weather, cannot be altered to enhance control of pests, others e.g. natural enemies populations can be influenced by farmers. The practice of taking advantage of and manipulating natural enemies in order to suppress pest populations is called biological control (Vegetable crop handbook, 2014). Biological pest control is a method of controlling pests by using other organisms: beneficial organisms or natural enemies. Natural enemies are divided into predators (capture and eat pests) and parasites (grow in or on the bodies of their victim).

Beneficial insects are a key element of the biological control and provide significant services to agriculture such as pollination and the natural regulation of plant pests. Those services are critical to the conservation of the ecological balance and to the economical profitability of the agricultural production, contributing therefore to food security (Gill, 2013). Natural enemies are insect predators and parasitoids that attack and feed on other insects. In agricultural landscapes, natural enemies have the potential to prevent crop pests from reaching economically damaging levels by reducing pest population growth thanks to contributing to pest mortality (Gill, 2013; Klein et al., 2012).

Three methods can be applied: importation, augmentation and conservation. The first method (importation) is based on determining the relevant pests to be controlled, identifying the associated natural enemies and importing them to the field. The second option, called augmentation, consists in the supplemental release of natural enemies already present on-site. Therefore the naturally occurring population is boosted. Conservation of existing natural enemies consists in ensuring that the conditions allow naturally occurring populations of natural enemies to persist. This is the simplest method to implement, given that natural enemies are already adapted to the habitat and to the target pests.

The success or the failure of a biological pest control is influenced by the population levels of pests when and where natural enemies are applied. In particular, it should be mentioned that when a pest population level is high then the efficiency of the natural enemies may be lower and the application of CPP may be needed. On the other hand, when the pest population level is low, it is possible that natural enemies exist already in the field and conserving them or boosting their presence may be the most efficient and effective pest control strategy.

If a farmer purchases natural enemies, it is important that he obtains from the supplier the certificates and the specifications of the natural enemies he is purchasing as well as appropriate instructions for safe and optimal application. The optimal application is also linked to the number of natural enemies to be released in the field by the farmer. Moreover the timing of releases of natural enemies (applications) is a critical factor of success for biological pest control. Some natural enemies are affected by the season and in many instances by the time of the day when they are released. In warm climates, if the release occurs in higher temperatures, there can be problems with high mortality rates of the introduced natural enemies or with the introducing organisms leaving the field, reducing significantly the shield of the crops. As a general rule, farmers should release the natural enemies when the temperature is relatively low e.g. early in the morning or late in the afternoon/evening, under favourable weather conditions and in the best season (which should be precisely described by the supplier). After the release, it is extremely important for the farmers to ensure suitable conditions for the activity of the natural enemies, such as maintaining a proper habitat in the field (providing a suitable 'shelter' in the field for the natural enemies so they do not leave or die) as well as implementing appropriate agricultural practices such as reduced tillage. It is also recommended to monitor the natural enemies populations to ensure that a sufficient number is maintained (Linker et al., 2009).

Precision application of the crop protection products

When the application of CPP is needed, the use of precision application contributes to reducing the use of pesticides as well as increasing the application efficiency.

The precision application of CPP builds on three key elements: information, technology and decision support. The information element includes the collection and mapping of pest populations in fields. To do this, the farmer walks on the fields in order to see the actual situation of the plants (if they look healthy, if they have black dots/spots etc.). Afterwards the pest populations is mapped, either manually (on a field plan) or by using suitable technology (e.g. using GPS and/or appropriate Geographical Information Systems – GIS software in order to map precisely which crops have pest problems). This information element ensures that the farmer has all the necessary data in order to apply precisely the required treatment to the crops (Linker et al., 2009).

On top of the already mentioned use of GPS and/or GIS software for collecting data, the second element on which precision application builds (technology) includes systems to apply pesticides only in the amounts and where required. An example is the use of the so-called 'lightbar' navigation and/or auto-steer. The 'lightbar' navigation consists of a row of LEDs, a GPS receiver and a microprocessor. These guide the farmer during the application and reduce application overlap and over-spraying thus reducing application costs.

Moreover, modern electronics (such as electronic flow meters, pressure gauges, speed sensors and appropriate software) can also be used to improve the application efficiency and accuracy (Linker et al., 2009).

The last element of precision application (decision support) consists in analysing the data, building databases, using and refining analytical tools so that decision are taken based on them. Although this offers the largest potential, it is so far the less developed element (Grisso et al., 2009).

General guidance on application of crop protection products

Whenever a farmer needs to apply CPPs, it is important that he implements all the measures that can guarantee his personal safety and the maximum level of environmental protection. A selection of the most relevant actions is presented below:

- Looking for entry points of CPPs into water

As a first step the farmer should identify all the major entry routes of CPPs into water across all his operations. This is important in order to focus efforts on the most relevant phases, which may or may not be the spraying itself (e.g. important contamination may come from disposal of CPP containers or refilling).

- Using all safety equipment and clothing

Farmers/applicators must use all safety equipment and clothing and ensure that these are maintained in good state of repair. It should be noted that as crops grow, the potential contamination danger increases because of the height of the plants compared to the farmer/applicator (FAO, 2001).

- Respecting weather conditions, buffer zones and wells, minimizing spray drift

Before the CPP application, the farmer/applicator must check the local weather conditions⁵² and the forecast of the specific day in order to avoid as much as possible the spray drift. He must also be

⁵² Depending upon the local weather conditions, certain values in wind velocity should be selected during the application unless there are local requirements in place (Balsari et al., 2015): low and medium wind spray at 0,5-3,0 m/s, at spray dispersion height; for high wind (3.1–

knowledgeable about the local regulations concerning buffer zones. The farmer/applicator must know the distance from a crop to be sprayed to any sensitive or protected area. Also he should keep the existing vegetation and/or establish windbreaks structures between sensitive or protected areas and the crop areas to be sprayed. Particular attention should be given not to overspray ditches/watercourses, buffer strips and field roads (Roetelle, 2014) and to ensuring that wells are correctly covered. Furthermore, in order to minimise spray drift, the farmer can use sprayers with multi-nozzle bodies with low amount of fine droplets (e.g. $< 100 \mu\text{m}$) and use them under low pressure. Also use of air induction nozzles (selecting correctly the operational pressure) in field crop sprayers is preferable (Balsari et al., 2015).

– Operational parameters for CPP application

During the CPP application, important operational parameters like the forward speed and the height at which the spray is released above the target must be set properly by the farmer/applicator. For a tractor sprayer, the forward speed is determined by the stability of the sprayer devices over the surface to be sprayed. It should be noted that excessive speeds reduce the spray deposit efficiency. For a knapsack sprayer, the forward speed must be maintained for long periods and the chosen walking speed must be sustainable. When mist blowers are used in orchards, the forward speed must match the volume of air generated by the fan to the tree volumes as it replaces the still air within the tree canopy (FAO, 2001). In general, it is important for the farmer/applicator to select the lowest effective forward speed and the lowest effective pressure in order to minimise the effective distance of the spray droplets to the targets (Balsari et al., 2015). A complete list of best practices, together with all their technical parameters that can be implemented by the farmers/applicators are described in EU funded TOPPS projects (www.topps-life.org) (Balsari et al., 2015).

– Maintenance/calibration

The filling of the sprayers can be done either in the fields or on the farm yard. When the filling takes place in the field, farmers should select a safe filling place at adequate distance to water bodies. When filling on farm yard, this must be performed only on a dedicated place and implementing all precautionary measures to avoid any drainage to surface water and to collect eventual spills. It is also important that the farmers fill the correct amount of water and spray volume in the sprayer and that the sprayers are maintained properly (e.g. proper calibration according to the manufacturer guidelines and frequency). Sprayers should be calibrated when nozzles are either new or replaced. A recalibration should be performed each few hours of use (according to the instructions) due to the fact that the flow rate of the new nozzles may increase rapidly. The farmer/applicator should check regularly the flow rate of all nozzles on the sprayer to ensure that these flow rates are all similar. It should be noted that the volume of applied CPP depends upon the forward speed, system pressure, size of nozzle and spacing of nozzles on the sprayer. Therefore a change in parameters like system pressure or nozzle effective size may result in changing the application rate (Roetelle, 2014).

– Cleaning, disposal, storage and transport

It is very important that the farmer manages correctly the cleaning of the machinery and equipment used as well as the disposal of any CPP residue and effluent from the cleaning operation to minimise the risk of point source pollution. The residual volumes after application (inside the sprayers) should be diluted with clean water and sprayed out in the last treated field (or part of the field). Also, the sprayers should be cleaned from the outside (using high pressure cleaners) in the field or on farm when washing water is collected and cannot reach water bodies. Sprayers and in general empty packages (e.g. plastic boxes, bags, etc.) should never be left in the rain but stored in a dry and protected place and following the label recommendations.

The CPPs must be stored properly in storage rooms, containers or cupboards, located away from risky areas (flood, fire, etc.) and protected from direct sunlight and high temperatures.

Farmers/operators should also make sure that during the transport from the farm to the field, all the sprayers are sealed and there are no leaks. They must select the easiest route to the application area

5.0 m/s) stop spraying until the wind speed decreases; if timing is a critical factor or if for other reasons the CPP application cannot be postponed, use the most efficient drift spray measures available; never spray at very high wind speed (>5.0 m/s).

(field) in order to reduce the risks of an accident and respect the maximum loads that the vehicle can transport⁵³ (Roetelle, 2014).

Summarising, best practice in optimising crop protection and reducing the use of CPP includes:

1. Prevention and/or reduction of the harmful organisms/pests by (taking into consideration local parameters e.g. soil physical conditions, local weather conditions, etc.):
 - a. crop rotation (BIPRO, 2009);
 - b. appropriate cultivation techniques, such as superficial tillage, use of balanced fertilisation, liming and irrigation/drainage practices;
 - c. use of resistant/tolerant cultivars;
 - d. hygiene measures (e.g. cleansing of machinery);
 - e. protection and enhancement of important beneficial organisms.
2. Monitoring of harmful organisms/pests.
3. Implementation of a plant protection strategy based on monitoring data.
4. Use of biological, physical and other non-chemical methods if they can provide satisfactory pest control (e.g. bio-products).
5. Application of pesticide limited to cases and levels that are necessary and as *'targeted'* as possible
6. Anti-resistance strategies to maintain the effectiveness of the products by minimising the risk of development of resistance in populations of harmful organisms
7. Reviewing the success of plant protection measures and using the data collected and experience to improve the future decision making

Achieved environmental benefits

Reducing the use of crop protection products is of paramount importance to the environment. Minimising and optimising their use helps to reduce drastically the risk of pesticides residues running off into streams and rivers or migrating through soil into groundwater, as well as the risk of pesticide vapours being carried into the nearby environment by air currents during application. Other core environmental benefits include the enhanced conservation of the natural habitat (Norton, 2006), positive contribution to the maintenance of the earthworm populations and other organisms (i.e. beneficial insects, arthropods etc.), better maintenance of the soil structure and of the transformation and mineralisation of the organic matter (Gill and Garg, 2014). Reducing the use of pesticides is also very important for biodiversity, including wild birds and mammals and pollinating insects (such as bees).

A second relevant set of environmental benefits are those linked to the saving of resources from lower need of chemical pesticides and the reductions in the level of greenhouse gas emissions derived from the reduction in fuel use due to less-frequent use of pesticides. It is reported a reduction of 2.7 kg/ha of carbon dioxide emissions per spray application (EcoPest, 2012). Furthermore, the application of minimum tillage system instead of the conventional one and appropriate crop rotation reduces the soil emission of carbon compounds, increases the levels of soil organic matter, contributes to improving the soil structure and reducing soil degradation, contributing, inter alia, to improving drainage as well as reduced risks of water-logging during floods or high water precipitation. Section 5.2 on best practices in crop rotation for efficient nutrient cycles should also be consulted for further (nutrient management related) environmental benefits.

Appropriate environmental performance indicators

The following environmental performance indicators can be used:

- Application of crop rotation scheme that aims at pest prevention (Y/N)
- Implementation of biological pest control (Y/N)
- Precision application of CPP (if their use is needed) (Y/N)
- When CPP are applied: Treatment frequency (number of times/year)

⁵³ More technical details can be found in the following link: http://www.topps-life.org/uploads/8/0/0/3/8003583/topps_course_engl.pdf

- Participation in appropriate training on crop protection (Y/N)

Cross media effects

Most of the measures described in this BEMP have no negative effects on other environmental pressures. One aspect to be considered carefully is the use of biopesticides. Indeed, some agents may persist in the field for several months and an analysis should be compiled in order to ensure the environmental stability (IOBC, 2011).

Operational data

Innovative business models for crop rotation

Bigler (2013) describes an example of implementation of crop rotation in Switzerland by multiple farms joining efforts in a crop rotation association.

The example concerns 4 farms with a total surface of 145 ha of arable crops plus meat production (beef and pork meat). Figure 11.2 illustrates the business model, based on joint use of land, machinery and labour, joint purchase of goods and services and joint harvesting of the market benefits. In this implementation, this model resulted in a significant cost reduction and up to 30% lower investment in machinery and purchase of pesticides, fertilizers, seeds, etc. Moreover more flexibility and better planning of the work was achieved and more time to generate additional income. Bigler (2013) notes that support by advisory/legal service is essential and full agreements on crops and productions systems are needed but different types of cooperation models can be formulated adopting the most suitable legal model. The main shortcomings of this model are the personal relations among the farmers which can cause some difficulties and influence the efficiency of the crop rotation association, and the issue that farmers (members of the crop rotation association) feel that they lose partially their independence in decision making (Bigler, 2013).

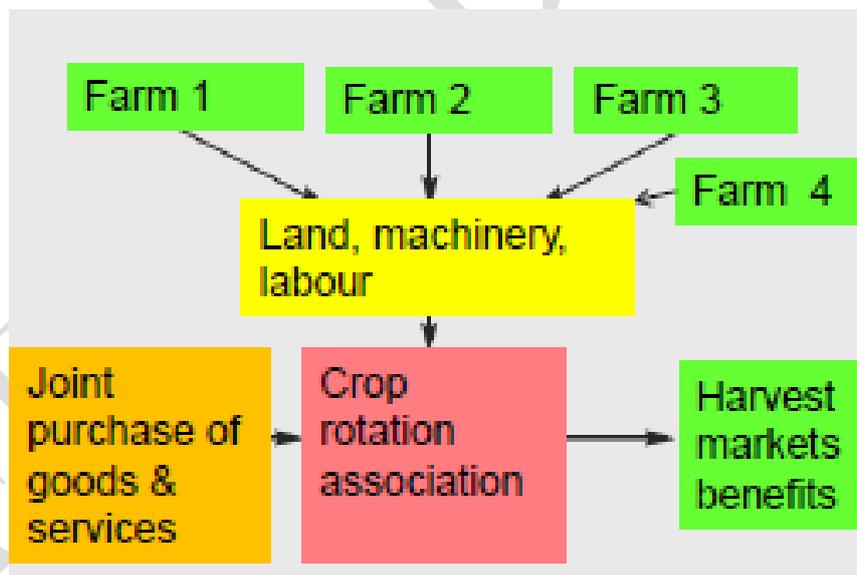


Figure 11.2. The organisational model for a crop rotation association (Bigler, 2013)

Ensuring on the field suitable conditions for the natural enemies to allow effective biological pest control

The development of a natural habitat that will encourage the enemy effectiveness is important for the success of the biological pest control plan. The farmer can implement the following measures (Van Driesche and Bellows, 1996):

- Construction of artificial structures
- Provision of supplementary food

- Provision of alternative hosts
- Improvement of pest-natural enemy synchronization
- Control of honeydew-feeding ants
- Modification of adverse agricultural practices

This last point deserves special care and attention. Mulching damages heavily the fauna and should be avoided on ecological infrastructures. Mowing has also a direct negative impact on the fauna which exists in the field. It should be implemented at a level of 8 cm (or better from 10 to 12 cm) above the ground in order to allow the fauna to escape, and with a direction from the centre to the edge or at least in stripe patterns. In addition, the first cut should be made as late as possible, the mowing frequency should be reduced (e.g. the minimum intervals of 9 weeks at the same spot) and mosaic patterns of wildflower patches should be retained. Additionally, mowing should be done in the early morning or in the evening especially when the bee activity is high (IOBC, 2004).

Cropping patterns are also keys to increase the density of the resident enemy populations or to increase their effectiveness in pest population reduction. For instance practices like crop rotation and intercropping contributes to the separation of the pest populations from continued food supply either over time from one year to the following one or over space. Several researchers concluded that the intercropping systems have a negative impact on the densities of pests; e.g. Andow (1986) and (1988) reported 56% reduction of pest and 28% not affected, while Rusell (1989) reported that the pest population decreased up to 70% because of the enhanced natural enemies. Similarly, the use of cover cropping, e.g. clover, contributes to the reduction of the pest populations by disrupting pest behaviour (Orr, 2009). An important role can also be played by the area surrounding the fields. Natural strips, such as field margins, grass strips, borders or farm trails, should be at least 5 m wide and consist of a spontaneous or sown flora. The spontaneous vegetation is also a possibility on low yielding soils with low nutrient level, which are rich in coarse soil particles and without problem weeds. It is important for the farmer to control the flora in these areas by ensuring it can provide habitat for the natural enemies (e.g. create and maintain hedgerows and field borders). In general ensuring a habitat for natural enemies is simpler for perennial cropping systems e.g. horticultural crops or orchards which are more favourable to natural enemies because of the habitat stability that they provide. In annual crop systems, maximising the overwinter survival of natural enemies might be critical in establishing a sufficient biological control in the following growing season. During the growing season combination of weather conditions like high temperature and low humidity may constrain natural enemy populations (Landis et al., 2000).

IOBC classification of plant protection measures

The International Organisation for Biological and Integrated Control (IOBC) developed a methodology to rank plant protection options for different crops. This methodology divides the plant protection measures into two categories; i. *green* where prevention measures are taken (e.g. cultivar choice, crop rotation etc.) and ii. *yellow* where measures are applicable only if green category measures are not efficient. Table 11.2 illustrates the example of the classification for grapes for the year 2006 showing the logical sequence of the described methodology and describing the steps and measures including the operational actions to be implemented by the farmers (Malavolta, 2011).

Table 11.2. Green and yellow list of plant protection measures for grapes (vinification) for the year 2006 (Malavolta, 2011)

	Green List of preferred options			Yellow List: Options with restrictions	
	1 Preventive measures	2 Monitoring: Justification of direct Measures (Threshold)	3 „Green“ direct control measures	4 “Yellow” direct control measures with restrictions	5 Indications and restrictions
General Aspects	Green cover, alternating mowing, hedges to enhance antagonists; low nitrogen input	Renew subscription of official phytosanitary bulletin (forecasting service)			
Grape moths		operate pheromone traps where not mating disruption (15 moths/trap/week)	Mating disruption	B. thuringiensis + 1% sugar; or IGR 1 or IGR 2	1x one week after start of 2nd flight if > 15 moths/trap/week or 1x 1 week after start 2 nd flight 1x at beginning of 2nd flight
Spider mites	release/protect predatory mites, alternating mowing; low nitrogen	check 50 leaves in stage 11-13. > 70% of leaves occupied	Predatory mites	Acaricides 1,2 or 3	1x if over 70% leaves occupied at stage 13
Acariosis	release/protect predatory mites, alternating mowing	check lateral shoots in August for symptoms and decide on spring treatment	Predatory mites	Wettable Sulfur 2% Acaricide 3	1x at Stage 03-05, only prophylaxis possible 1x Stages 05 - 09, only prophylaxis possible
Green grape leafhopper	green cover in summer, alternating mowing, hedges with roses +bramble	operate yellow sticky traps in June-July. 5 larvae per leaf or 300 – 500* /trap/week (*where parasitoids)	Egg parasitoid <i>Anagrus</i>	IGR 3 Insecticide 1	when more than 500/trap/week when more than 300/week/trap 1st generation in highly sensitive varieties only
Downy mildew	tolerant varieties & clones low nitrogen input	first treatment according to forecast	Fungicides 1 or 2 prebloom Fungicides 3 or 4 postbloom	Fungicide 5 Fungicide 6 postbloom Fungicide 7	maximum 3 treatments max. 2 treatments (max. 3kg Cu/ha/year) maximum 2 treatments
Powdery mildew		first treatment according to forecast	Fungicides 9 or 10 prebloom Fungicides 11 or 12 postbloom	Fungicides 13 or 14	maximum 3 treatments of strobilurines maximum 3 treatments of SSH
Botrytis cinerea	tolerant varieties & clones; defoliation/ventilation of grape zone; low nitrogen, grape moth control	restrict 2 treatments to stage 77 and 81	Utilise effect of downy mildew fungicides 3 or 4	Botryticides 1 or 2 or 3 Botryticide 4	maximum 1 treatment maximum 1 treatment
Phomopsis	remove infested prunings	First treatment at stage 03-05 if infested		Wettable Sulfur 2% Fungicides 15, 16	1x stage 03 - 05 maximum 2 treatments stage 05 - 13

The case of Switzerland: the environmental measures that farmers must implement to receive direct payments include most actions needed for reducing and optimising the use of pesticides

In order to be eligible for direct payments, farmers in Switzerland must fulfil the following agro-ecological pre-conditions (Reinhard, 2012):

- An appropriate share in ecological compensation areas (min. 7% of agricultural land); two examples for arable land:
 - Crop preservation strips: extensively managed strips, no N-fertilizer and no weed control, 3 to 12 m wide;
 - Fallow: perennial strips of land, seeded with native wild flowers; no fertilizer; weeds control only by single plan application; cutting/harvesting in wintertime only.
- Compulsory crop rotation:
 - Maximum acceptable share of the main crops per farm is limited in the annual crop rotation for different crops: cereals 60%, wheat 50%, corn 40% (if no till 50%), sugar beets, potatoes and rapeseed, soya 25%.
- Selected and targeted application of plant protection products:
 - Treatment only if necessary: warning systems for pests and plant diseases and intervention thresholds for pests have to be respected;
 - Restriction of use of insecticides with negative impact on beneficial insects in cereal and potato cultures.
- Measures to protect surface water:
 - Regulation for inspection of sprayer every 4 years;
 - Raising sprayers on the fields;
 - Untreated buffer strips along surface waters (Figure 11.3).
- A well-adjusted fertiliser balance
- Measures for soil protection
- Restricted use of plant protection products
- Animal welfare standards.

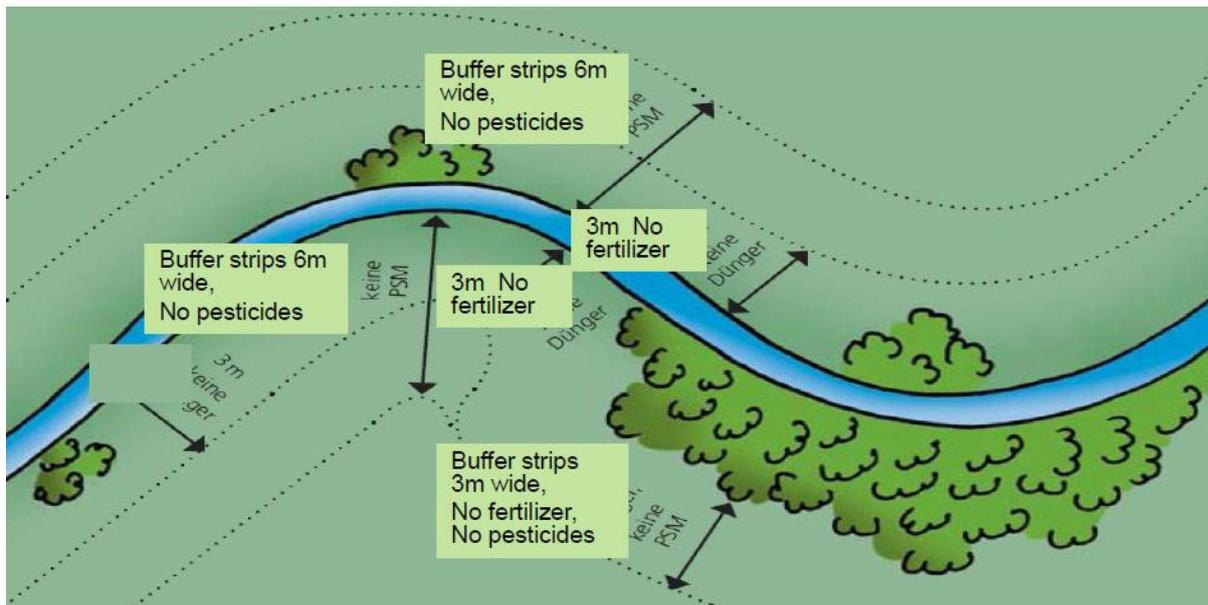


Figure 11.3. Measures to protect surface water (Reinhard, 2012)

Applicability

This BEMP includes a large spectrum of techniques, which can be implemented individually or together and need to be tailored to the specific conditions of each area, farm and field. Implementing a dynamic crop protection management plan is therefore broadly applicable, provided that the measures that it contains are well adapted to the specific case. For instance, biological control is easily implemented in protected horticulture and orchards, where biological control can be more effective than chemical control because resistance to conventional CPP is often an issue. It is instead more difficult in open fields and production systems with short crop cycle (Lefebvre et al., 2015).

More generally, the prevention measures and biological control are more effective when pest population levels are not too high; otherwise they may prove insufficient to protect crops.

Economics

The economics of implementing a dynamic crop protection management plan is mainly determined by two elements: the impact on output quantity (yield), and the cost savings from reduced input (reduced amount of crop protection products bought). If the dynamic crop protection management measures implemented (which reduce input costs) are effective and enable higher, comparable or only limitedly lower yield levels compared to conventional crop protection techniques, then the measures are cost-effective.

However there are other two elements also playing a role: the impact on output quality (which influences the value of the output) and, depending on the specific measure implemented, the additional labour and/or investment costs (e.g. for deployment of reliable cultivars, precision application systems with GPS).

The economic sustainability of a specific set of measures will thus depend heavily on the specific measures implemented (some of which are very labour or investment intensive) and their complementarity and ability to provide effective and efficient pest control, as well as on the specificities of the farm (e.g. type of farm/crops, geographical conditions, labour costs, owner-operated vs labour hired farms).

Lefebvre et al. (2015) carried out an extensive review of the economic sustainability at farm-level of the implementation of integrated pest management strategies relative to non-IPM/conventional pest

control solutions. The study acknowledges the lack, especially in Europe, of quantitative empirical region- and crop-specific evidence from field trials (currently being produced by the European project PURE, Innovative Crop Protection for Sustainable Agriculture, www.pure-ipm.eu). However, the following points highlighted by the study can be interesting to farmers considering the implementation of the measures described in this BEMP:

- There are several studies and examples of successful implementation of IPM measures with high benefit-cost ratios (e.g. McConnachie et al., 2003) and/or relatively short payback time (e.g. Vasileiadis et al. (2011) reports net profits within 3-4 years for measures such as deployment of reliable cultivars, pests and diseases forecasting models, precision application systems with GPS).
- An important source of costs for the implementation of IPM is the additional labour cost due to labour-intensive farming practices (e.g. mechanical control using specific tilling and cultivation techniques) and training.
- There are considerable differences across European regions. For instance Mouron et al. (2012) found that IPM strategies in apple orchards led to better economic performance in some countries (through increased yield and quality and reduced pesticides use in some countries compensating for increased labour and capital cost) and lower economic performance in others, depending on the specific measures that need to be implemented and on labour cost.
- There may be opportunities to market at better conditions products grown according to IPM strategies rather than conventional products.

Driving force for implementation

The main driving force for implementation is the better management of the land by applying the above-mentioned principles of a dynamic crop protection management plan. Furthermore the application of those principles result in less costs for the farmers, products with better quality as well as achieving a balanced approach to managing crop and livestock production systems.

Reference organisations

IOBC - International Organisation for Biological and Integrated Control – produced useful crop specific integrated production guidelines, which are available online at: http://www.iobc-wprs.org/ip_ipm/IP_guidelines_crop_specific.html.

The Voice of British Farming has developed an Integrated Pest Management Plan, available online at: <http://www.nfuonline.com/ipm-plan/>.

The TOPPS Life project focuses on reducing losses of Crop Protection Products to water. Farmers can find several information regarding best practices and measures that can apply on the project website: <http://www.topps-life.org/>

Reference literature

- Andow, D.A. (1986), Plant diversification and insect population control in agroecosystems. In: Pimentel, D. (eds), *Some Aspects of Integrated Pest Management*. Cornell University Press, New York, 277–286.
- Andow, D.A. (1988), Management of weeds for insect manipulation in agroecosystems. In: Altieri, M.A. and Liebman, M. (eds), *Weed Management in Agroecosystems: Ecological Approaches*. CRC Press, Inc. Boca Raton, FL, 265–301.
- Balsari P., Marucco P., Doruchowski G., Roetelle M. (2015), *SPRAYDRIFT – Best Management practices to reduce spray drift*, available online: http://www.topps-life.org/uploads/8/0/0/3/8003583/ansicht_drift_book_englisch.pdf, last accessed June 2015.
- Bauder T., Waskom R. and Pearson R. (2010), *Best Management Practices for Agricultural Pesticide Use to Protect Water Quality*, Colorado State University, Extension, Bulletin #XCM-177, available online: <http://www.ext.colostate.edu/pubs/crops/xcm177.pdf>, accessed 25 September 2014.

- Bigler F. (2013), Innovation in crop rotation for better IPM – the Swiss model, IOBC-WPRS, Agroscope Switzerland, available online: http://www.iobc-wprs.org/20131205_IOBC-IBMA-PAN/20131205_IOBC-IBMA-PAN_symposium_Franz_Bigler.pdf, accessed 1st October 2014.
- BIO (2010), Environmental impacts of different crop rotations in the European Union, Bio Intelligence Service, available online at: http://ec.europa.eu/environment/agriculture/pdf/BIO_crop_rotations%20final%20report_rev%20executive%20summary_.pdf, accessed April 2015.
- BIPRO (2009), Draft guidance document for establishing IPM principles, Supplement to the Final Report, Project Number: 07.0307/2008/504015/ETU/B3.
- Boller E.F., Avilla J., Joerg E., Malavolta C., Wijnands F.G. and Esberg P. (2004), Integrated Production – Principles and Technical Guidelines, 3rd edition, IOBC-WPRS Bulletin, Bulletin OILB srop, 27(2), ISBN: 92-9067-163-5.
- Boller E.F., Avilla J., Joerg E., Malavolta C., Wijnands F.G., Esbjerg P. (2004), Guidelines for integrated production-principles and technical guidelines, 3rd edition, IOBC/WPRS Bulletin 27.
- Christensen H., Becheva S., Meredith S. Ulmer K. (2012), Crop rotation, benefiting farmers, the environment and the economy, available online at: http://aprodev.eu/files/Trade/crop%20rotation%20briefing_pan_ifoam_aprodev_foee_fina.pdf, accessed April 2015.
- Copa-cogeca (2011), Implementing good practices within the Sustainable Use Directive for Plant Protection products: the farmer's perspective, publication reference code: PHY(10)9181.
- Croplife (2014), Integrated Pest Management, online available: <https://croplife.org/wp-content/uploads/2014/05/Integrated-pest-management.pdf>, last accessed 22nd January 2015.
- EcoPest, (2012), Strategic plan for the adoption and application of the principles for the sustainable use of pesticides in a vulnerable ecosystem, Project summary, available online at: http://www.ecopest.gr/index.php?option=com_content&view=article&id=158&Itemid=97&lang=en, last accessed on 15th April 2014.
- EISA (2012), Sustainable agriculture, What is it all about? available online at: http://sustainable-agriculture.org/wp-content/uploads/2012/07/BrochureEISA_ECPA_web.pdf, last accessed on 14 May, 2014.
- FAO (2001), Guidelines on good practice for ground application of pesticides, Food and Agriculture Organization of the United Nations, ISBN: 92-5-104718-9
- Ferguson A and Evans N. (2010), Reducing pesticide inputs in winter cropping systems in the UK, Winter Crops Based Cropping Systems Case Study Guide no. 3, ENDURE network for diversifying crop protection, Food Quality and Safety, 6th Framework Programme, Project number: 031499.
- Gill K.A. (2013), Development of best practices for conserving beneficial insects within Iowa's agricultural landscape, Iowa State University, Graduate theses and Dissertations, Graduate College.
- Harman G.E., Petzoldt R., Comis A., Chen J. (2004), Interactions between *Trichoderma harzianum* strain T22 and maize inbred line Mo17 and effects of these interactions on diseases caused by *Pythium ultimum* and *Colletotrichum graminicola*, *Phytopathology*, 94, 147-153.
- Gill K.H. and Garg H. (2014), Pesticides: Environmental impacts and management strategies, Intech, Chapter 8, available online: <http://dx.doi.org/10.5772/57399>.
- IOBC (2004), Ecological Infrastructures, Ideabook on functional biodiversity at the farm level, Eds. by Boller E.F., Hani F. and Poehling M., IOBC-WPRS, ISBN: 3-906776-07-7.
- Grisso R., Alley M. McClellan P., Brann D., Donohue S. (2009) Precision Farming: A Comprehensive Approach, Virginia Cooperative Extension, Virginia Tech, Virginia State University, available on-line: <http://pubs.ext.vt.edu/442/442-500/442-500.html>, accessed 14 May 2015.
- IOBC (2005), Appendix 5 of basic document on integrated production 2004, IOBC Commission on "IP guidelines and endorsement", available online: http://www.iobc-wprs.org/ip_ipm/03011_IOBC_GreenYellowList_Explinations.pdf, accessed 24 September 2014.

- IOBC (2008), guidelines for integrated production of pome fruits, IOBC technical guideline III, 4th edition, edited by: Malavolta C. and Cross J., IOBC wprs Bulletin, 47.
- IOBC (2011), Classical and augmentive biological control against diseases and pests: critical status analysis and review of factors influencing their success, edited by Nicot P.C., ISBN 978-92-9067-243-2.
- Klein A.M., Brittan C. Hendrix S.D., Thorp R., Williams N., Kremen C. (2012), Wild pollination services to California almond rely on semi-natural habitat, *J. Appl. Ecol.* 49, 723-732.
- Lefebvre M., Langrell S.R.H., Gomez-y-Paloma S. (2015), Incentives and policies for integrated pest management in Europe: a review, *Agronomy for Sustainable Development*, January 2015, Volume 35, Issue 1, pp 27-45, <http://dx.doi.org/10.1007/s13593-014-0237-2>.
- Leteinturier B., Herman J.L., de longueville F., Quintin L., Oger R. (2006), Adaptation of a crop sequence indicator based on a land parcel management system, *Agriculture, Ecosystems and Environment* 112, 324-334.
- Linker H.M., Orr D.B., Barbercheck M.E. (2009), Insect Management on Organic Farms, North Carolina Cooperative Extension Service, available online: <http://www.cefs.ncsu.edu/resources/organicproductionguide/insectmgmtfinaljan09.pdf>, accessed April 2015.
- Malavolta C. (2011), Integrated Pest Management A European perspective, IOBC WPRS, Commission "guidelines for integrated production", available online: <http://liveinc.org/sites/default/files/Carlo%20Malavolta%20Presentation.pdf>, accessed 29 September 2014.
- McConnachie A., de Wit M. et al (2003) Economic evaluation of the successful biological control of *Azolla filiculoides* in South Africa. *Biol. Control* 28:25–32. doi:10.1016/S1049-9644(03)00056-2.
- Meisle M., Romeis J., Bigler F. (2011), Bt maize and integrated pest management - a European perspective, *Pest Management Science*, 67, 1049-1058.
- Mouron P., Heijne B. et al (2012), Sustainability assessment of crop protection systems: sustainOS methodology and its application for apple orchards. *Agric Syst* 113:1–15. doi:10.1016/j.agsy.2012.07.004.
- Norton G.W. (2006), Environmental benefits of IPM: Evidence at home and abroad, available online: <http://www.ipmcenters.org/ipmsymposiumv/sessions/4-5.pdf>, last accessed October 2014.
- Orr D. (2009), Chapter 9: Biological control and integrate pest management, *Integrated Pest Management: Innovation-Development Process* edited by: Peshin R. and Dhawan A.K., DOI 10.1007/978-1-4020-8992-3 9, Springer Science and Business Media B.V.
- PAN (2004), Moving towards Pesticide Reduction – Realising best agricultural practice in Central and Eastern Europe, Pesticide Action Network Germany, ISBN: 3-9809392-4-3.
- PAN (2014), Reducing pesticide use across the EU, Implementation of the EU Directive on sustainable use of pesticides, Pesticide Action Network Europe.
- Reinhard E. (2012), The Swiss agricultural policy – how a policy contributes to the sustainable use of pesticides, in proceedings of: Integrated pest management- the way forward to sustainable agricultural production, 19th June, Brussels, Belgium, available online: <http://www.pan-europe.info/Activities/Conferences/120619/Eva%20Reinhard%20120619%20Brussels%20IPM.pdf>, accessed 2 October 2014.
- Republic of Poland (2013), National action plan to reduce the risk associated with the use of plant protection products, Minister of Agriculture and Rural Development of 6 May 2013, O.J. of Republic of Poland "Monitor Polski" item 536.
- Roettele M. (2014), Information and training presentation, available online: http://www.topps-life.org/uploads/8/0/0/3/8003583/topps_course_engl.pdf, last accessed 11 June 2015.
- Russell E.P. (1989), Enemies hypothesis: a review of the effect of vegetational diversity on predatory insects and parasitoids, *Environmental Entomology*, 18, 590-599.
- Vasileiadis V.P., Sattin M. et al (2011) Crop protection in European maize based cropping systems: current practices and recommendations for innovative integrated pest management. *Agric Syst* 104(7):533–540. doi:10.1016/j.agsy.2011.04.002.

- Vegetable crop handbook (2014), South-eastern US vegetable crop handbook, Senior editor: Kemble J.M., available online: http://www.pubs.ext.vt.edu/AREC/AREC-66/AREC-66_pdf.pdf, accessed April 2015.
- Voluntary Initiative (2007), Pesticide Disposal, After Spraying, Available online: <http://www.voluntaryinitiative.org.uk/media/1046/pesticide-disposal.pdf>, accessed 29 September 2014.

FINAL DRAFT

11.2 Crop protection products selection

Description

When crop protection products (CPPs) are needed (see section 11.1 on best practice in optimising and reducing their use), it is crucial to minimise the environmental impact related to their application, by selecting the products with the least environmental impact and hazard to human health and the environment.

When selecting CPPs farmers can consult the labels of these products as well as referring to publicly available databases that provide indications of the toxicity of the pesticides (including their side effects). The aim is to select products with least toxicity and least persistence, and as selective as possible towards the pest species to be tackled, as well as not interfering with the implemented biological control measures (e.g. natural enemies). The specific characteristics of the field to be treated (in particular the soil texture characteristics) must also be taken into account in order to determine the suitability of a specific CPP.

This section provides guidance on the use of the labels of CPPs as well as three examples of possible databases/methods that can be used by farmers to select CPPs.

Use of labels available on Crop Protection Products

All CPPs available on the market are registered and approved products which bear a specific label. The product label is a key source of information for the user/farmer/applicator. It includes guidance on: the dose rate, volume of spray solution, chemical name and active ingredient, crops for which it is registered, number of permitted treatments during the growing season, number of days (or time period) that the product can be used before harvest, type of equipment required for safe application and all the necessary safety measures to be taken by users/farmers/applicators. Farmers should also consult labels in order to receive information about "non-spray" barriers when CPPs are to be used near waterways or other sensitive environmental areas, given that the width of unsprayed barriers depends on the CPP applied, the sprayer type and its drift potential. Labels also contain information regarding safe disposal and after use treatment as well as emergency services in case of an accident e.g. poisoning (Ajeigbe et al., 2010; FAO, 2001).

The IOBC database

The International Organisation for Biological and Integrated Control (IOBC) developed a database compiling the effects of different CPPs on beneficial arthropods as well as human health. The IOBC database has three search functions: by active ingredient, test species and species group (Jansen, 2013; IOBC, 2014). It classifies CPPs into the 4 categories listed below (IOBC, 2013b). The toxicity (harmful) levels of each category are presented in the Operational Data section (below).



The criteria for selecting the appropriate CPPs are the toxicity to human, key natural enemies, other natural organisms, potential pollution to the environment, persistence, ability to stimulate pests and diseases, potential to develop resistance in target, incomplete or missing information, selectivity and necessity for use (IOBC, 2013b). The same database also takes into consideration the toxicity caused to human according to the World Health Organisation (WHO) classification, in terms of acute toxicity of the active ingredient. When no WHO classification exists for an active ingredient, assumptions based on expert judgement are added in the database.

The Environmental Impact Quotient (EIQ) method

The Environmental Impact Quotient (EIQ) method estimates the toxicity and the environmental impact of CPPs. The results from this method are used in order to compare different pesticides and/or pest management programs and can help to select the products and/or programs with the lowest environmental impact (Kovach et al., 1992). This method has three end points: the risk/hazard to farmworkers, to consumer and to the environment. The concept of this method is illustrated in Figure 11.4. The sum of three EIQ values, each calculated for each of the three components, gives the final overall EIQ (Cross, 2013).

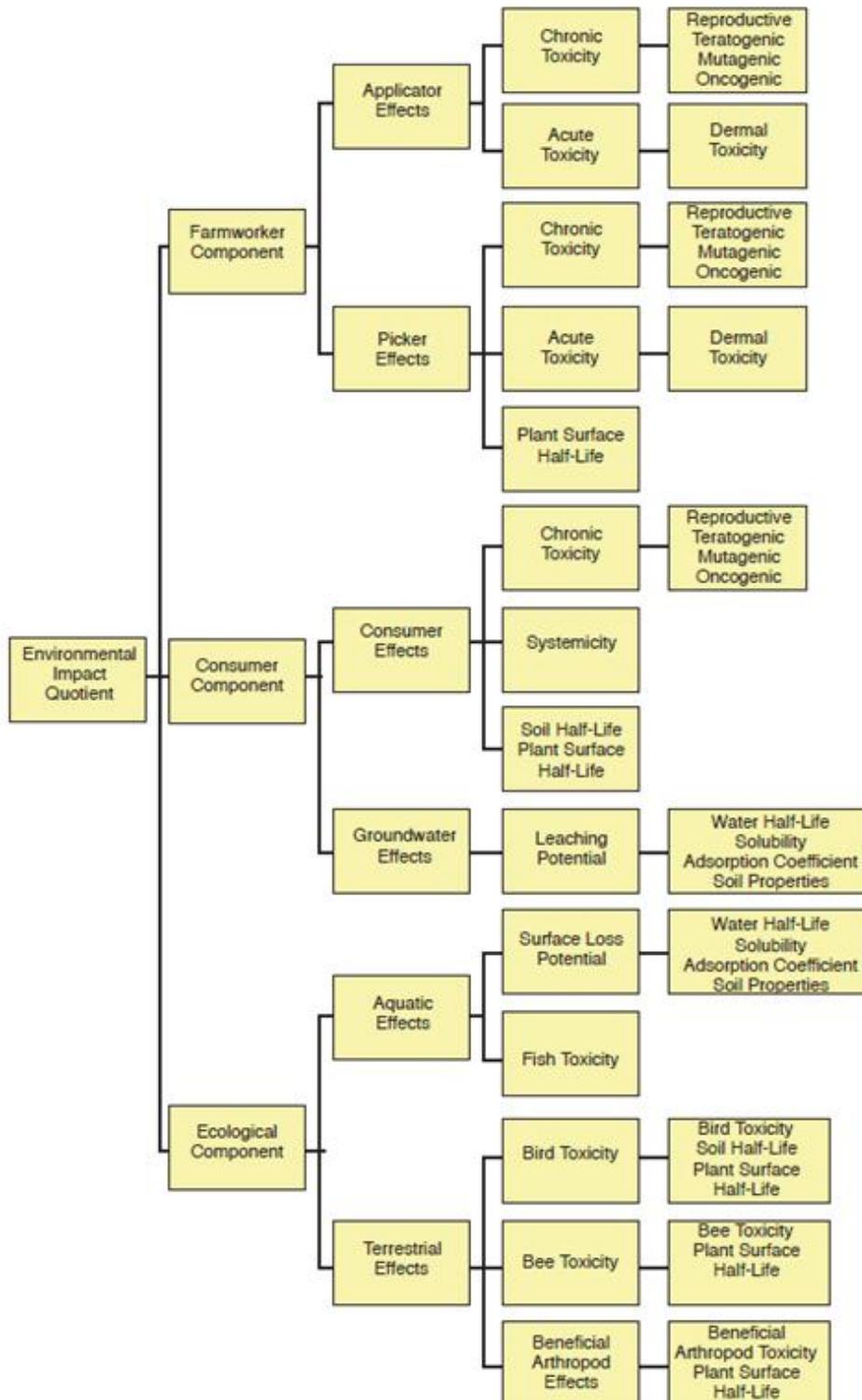


Figure 11.4. Aspects covered by the EIQ method (Kovach et al., 1992)

The CLM software

The Centre for Agriculture and Environment (CLM), in the Netherlands, developed a software for the assessment of the environmental risk and impact of some pesticides that are used in the Netherlands. The software provides to the user (farmer) an indicator that quantifies the environmental impact to surface water organisms and the risks for infiltration to groundwater. The interface of this software is illustrated in Figure 11.5 (SAI, 2010).

Input				Output (environmental effects)						
Ground	6-12 % organic matter			Active matter (kg/ha)	EIP water life	EIP ground life	EIP ground water	Risk biological controllers	Risk pollinators	Risk applicer
Season	Fall (September - February)									
Pesticide	Dose (kg/ha of l/ha)	Drift (%)								
ADMIRAL	1.00	1.00	0.10	€	0	0	0	A	B	S
ADMIRAL	1000.00	10.00	100.00	80000	0	0	0	A	B	S
AGRICHEM FLUROXYPYR	100.00	1.00	20.00	400	1100	0	0	?	?	S
MAGIC TANDEM	20.00	1.00	7.80	80	480	0	0	?	?	
ZETANIL	100.00	10.00	69.50	2000	600	2000	0	A	B	I

Legenda	
Milieubelastingspunten (MBP):	 0-10 MBP 10-100 MBP >100 MBP → voor waterleven >1000 MBP → voor bodemleven en grondwater
Nuttige organismen:	 A Bruikbaar in geïntegr. teelt B Beperkt bruikbaar C Niet bruikbaar ? Risico niet bekend
Risico voor de toepasser:	 I Irriterend S Schadelijk G Giftig ZG Zeer giftig B Bijtend

Figure 11.5. Interface of the CLM software (SAI, 2010)

Achieved environmental benefits

Appropriate selection of CPPs allows reducing the negative effects on the environment due to their application (mainly water and air pollution).

Appropriate environmental performance indicators

When selecting a CPP, the most important aspect is that environmental risks and hazards should be estimated precisely. However, it is very difficult to capture in a quantitative absolute indicator how "good" a certain CPP is. Therefore an appropriate environmental performance indicator can only be about the amount of active ingredient of CPP used:

- Kg active ingredient/ha/year

Cross-media effects

There are no reported cross-media effects for this BEMP.

Operational data

Use of labels available on Crop Protection Products

An example of a label of a CPP according to the current EU legislation⁵⁴ in this field is presented in Figure 11.6. It includes: product name and commercial information, the hazard symbol (pictogram), the Danger, Hazard and Precautionary Statements, and transport information. Examples of the Hazard and Precautionary statements are listed in Table 11.3 (HSA, 2010).

Figure 11.7 illustrates the symbols and the terminology according to Directives 67/548 EEC and EEC 1999/45/EC (old regulations) and from Regulation EC 1272/2008 (currently valid). The first set of symbols is used by CPPs that were in the market when the EU Directives 67/548/EEC and

⁵⁴ According to the new EU CLP Regulation, labels must include hazard statements (H), Precautionary (P) statements and hazard symbols (pictograms) instead of Risk (R) and Safety (S) phrases and danger symbols.

1999/45/EC were valid, whereas the CPP put on the market after the EC Regulation 1272/2008 came into force use the symbols illustrated in the right columns.

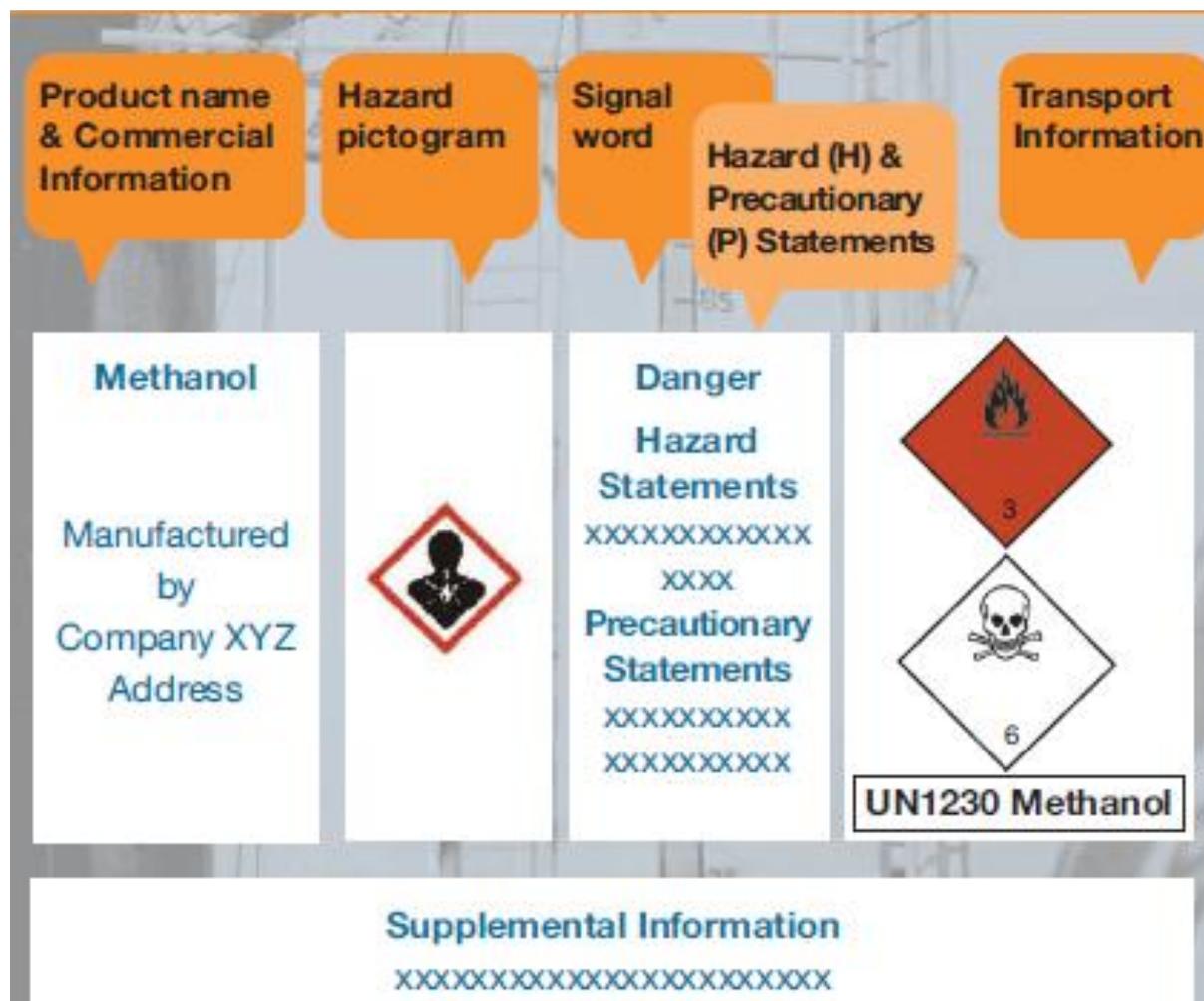


Figure 11.6. Example of supply and transport label for single packaging of CPP (HSA, 2010)

Table 11.3. Hazards and Precautionary statements as a part of the CLP (HSA, 2010)

<i>Hazard (H) statements</i>	
H200-H299	Physical hazard
H300-H399	Health hazard
H400-H499	Environmental hazard
<i>Precautionary (P) statement</i>	
100 general	P102 "keep out of reach of children"
200 prevention	P201 "Obtain special instruction before use"
300 response	P310 "Call a poison centre"
400 storage	P410 "Store in a well-ventilated place"
500 disposal	P501 "Dispose of container to..."

Current Indication of Danger & corresponding symbols (CPL) From Directives 67/548/EEC & 1999/45/EC		New* Signal words & corresponding pictograms (CLP) From Regulation EC 1272/2008		
Indication of Danger	Symbol	Class/Category	Signal Word	Pictogram
Explosive E		Explosives 1.1-1.3 Explosives 1.4	Danger Warning	
Extremely Flammable F+ Highly Flammable F		Flammable Liquids 1,2 Flammable liquids 3	Danger Warning	
Oxidising O		Oxidising Liquids 1,2 Oxidising Liquids 3	Danger Warning	
No Match	No Match	(NEW) Gases under pressure, compressed gases	Warning	
Corrosive C		Skin Corrosion 1A,1B,1C Corrosive to metals 1	Danger Warning	
Very Toxic T+ Toxic T		Acute Toxicity 1,2,3	Danger	
Harmful Xn Irritant Xi		Acute Toxicity 4 Skin Irritation 2	Warning Warning	
Harmful Xn Toxic T	 or 	Aspiration hazard Respiratory sensitization, Germ cell mutagenicity, Carcinogenicity, Reproductive toxicity, Specific target organ toxicity	Warning or Danger	
Dangerous to the environment N		Hazardous to the aquatic environment 1	Warning	

*This is a non exhaustive list and is for illustrative purposes only. The user should refer to the Regulation (EC) 1272/2008 for more detailed information

Figure 11.7. Symbols (pictograms) in the labels of CPP (HSA, 2010)

IOBC database

The pest selective database developed by IOBC (2013b) presents for a large number of active ingredients information about the results of testing that active ingredients on specific species and the toxicity class, including remarks, dose tested and other relevant data (Figure 11.8).

Imidacloprid OR Select Test Species ... OR Select Species Group ...

search | clear search

▶ Legends

Active Ingredient	Product	g/l or kg	Cat.	Test Species	Species Group	Cat. of test	Dose tested (a.i./ha)	IOBC toxicity class	Effects and duration of activity	Field site (crop - country)	Remarks	Ref.
Imidacloprid	Gaucho FS600	600	I	<i>Aleochara bilineata</i>	Soil dwelling predator	Extended lab	52g	1			seed dressing	DAR
Imidacloprid	Gaucho WS 70	700	I	<i>Aleochara bilineata</i>	Soil dwelling predator	Extended lab	945g	1			seed dressing	DAR
Imidacloprid	Confidor 200SL	200	I	<i>Amblyseius californicus</i>	Predatory mite	Field aged	40 g	3-1	3 5DAT, 1 15DAT			Van de veire et al., 2001
Imidacloprid	SL200	200	I	<i>Aphidius rhopalosiphi</i>	Parasitic hymenoptera	Extended lab	1.0g	4				DAR
Imidacloprid	SL200	200	I	<i>Aphidius rhopalosiphi</i>	Parasitic hymenoptera	Extended lab	0.32g	1				DAR
Imidacloprid	SL200	200	I	<i>Aphidius rhopalosiphi</i>	Parasitic hymenoptera	Extended lab	2x100g (14D)	4-1	4 (0-7DAT), 1 (14DAT)			DAR
Imidacloprid	SL200	200	I	<i>Aphidius rhopalosiphi</i>	Parasitic hymenoptera	Extended lab	2x100g (14D)	4-1	4 (0DAT), 3 (7-14DAT), 1			DAR

Figure 11.8. Pest selective database; image of the toolkit; search by product (IOBC, 2013b)

That information is available in a toolbox to assist farmers and organisations in the choice of pesticides. This shows data on the side effects of the CPP to beneficial arthropods and human health (Table 11.4). The side effects to beneficial arthropods are presented according to the following toxicity classes (Boller et al., 2005; Malavolta, 2011):

- **N** = harmless or slightly harmful (reduction field, semi-field 0-50%, laboratory tests 0-30%)
- **M** = moderately harmful (reduction field, semi-field 50-75%, laboratory tests 30-79%)
- **T** = harmful (reduction field, semi-field > 75%, laboratory tests > 80%)

Regarding the impacts on human health, the WHO (human) toxicity classification is used (Boller et al., 2005; WHO, 2010):

- | | |
|--|---|
| I _a = Extremely Hazardous | I _b = Highly hazardous |
| II = Moderately hazardous | III = Slightly hazardous |
| U = unlikely to present acute hazard in normal use | O = Obsolete as pesticide, not classified |

This database also addresses the toxicity to bees, fish and earthworm, which is indicated by the symbols of (-) and (+), indicating respectively absence and presence of toxicity (without showing toxicity level) (Boller et al., 2005).

Table 11.4. Crop production product selectivity (Malavolta, 2011)

IOBCwprs Working Group "Pesticides and Beneficial Organisms & IOBCwprs Commission "IP Guidelines and Endorsement" (05.12.2005 Comm.)	Type	Formulation	Concentration tested	Grams a.i./ ha	Classification of side effects to beneficial organisms															WHO toxicity class				
					N = harmless or slightly harmful (Reduction field, semi-field 0-50%, lab 0-30%) M = moderately harmful (Reduction field, semi-field 50-75%, lab 30-79%) T = harmful (Reduction field, semi-field > 75%, lab >80%) Normal black entries = laboratory data (IOBC) Bold black face = semi-field test data (IOBC) Asterix * marked black entries = Field test data (IOBC) Red = additions by Commission (expert judgments), final classification pending Pink marked data = data added by Commission (expert judgments)																			
Active ingredient	I = Insecticide F = Fungicide A = Acaricide H = Herbicide PGR = Plant Growth Regulator				Predatory mites (Tetranychus pyram)	Predatory mites (Phytoseiulus persimilis)	Spiders (Paedosa spp.)	Spiders (Cheiracanthium mitchell)	Flower bugs (Anthrenorhynchus nemoralis)	Flower bugs (Ortus laevigatus)	Lacewings (Chrysoperla carnea)	Lady bird beetles (Coccinella 7-punctata)	Rove beetles (Aleochara bilineata)	Ground beetles (Poecilus cupreus)	Parasitoids (Aphidius mopalosiphii)	Parasitoids (Trichogramma cacoeciae)	Hoverflies (Syrphus corollae)	Toxicity to bees	Toxicity to earthworms (Eisenia foetida)	Fish Toxicity	Coding key see appendix			
Code number of beneficial organism					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16				
Abamectine	A	18 EC		13.5	N-T	T				T	N	N			T							+	(II)	
Amitraz	A	200 g/L	0.3	360	T*	T			M		M	T	T			T	T	-				+	III	
Azadirachtine	A	1% T/S		30	N	T			T	N	N*	N		N	M	T	M	-				-	(U)	
Azocyclotin	A	25 WP	0.1			N						T				T						+	II	
Benzoximate	A	200 g/L	0.15			N					M					M						-	O	
Bromopropylat	A				M				N		N					N						+	U	
Clofentezine	A	500g/L	0.04		N*	N		N	N*		N	N	N			N	N					-	U	
Cyhexatin	A				N-M				N							T						+	(III)	
Diafenthiuron	A	250 SC		500	N*	T				T	M	N			M	T							+	U
Etoxazol	A				M						M					N						+	(U)	
Fenazaquin	A				M				M													+	(III)	
Fenitrothion	A	550 g/L	0.1	330	T	T			T		T	T	T			T						+	II	
Fenpropathrin	A	10 WP		300	T	T		T	T		M	N	T			T						-	+	II
Fenpyroximate	A	50 EC		50	N-M	T			N-M	N	N	T	N	N	T	M						-	+	(III)

Applicability

The selection of the CPPs according to their potential hazards to human health and environment, with due consideration of the overall crop protection strategy implemented (e.g. including biocontrol), and as specific as possible to the pests to be tackled, is broadly applicable by all the farmers.

Economics

It is difficult to calculate/estimate the economics of this BEMP in isolation from the overall crop protection strategy implemented. Given that CPPs selected as explained here are not necessarily more expensive and given that lower quantities are needed if more selective CPPs are used within a broader dynamic crop protection management plan, the implementation of this BEMP does not often lead to additional costs for the farmers.

Driving force for implementation

The main driving forces for implementation are avoiding pest resistance to CPPs and limiting the impacts of CPP application on the environment and to human health.

Reference organisations

Regularly updated data regarding the eco-toxicological profiles of the CPP are assessed and published by International Organisation for Biological and Integrated Control (IOBC). Those values can be found online at: www.iobc-wprs.org. Moreover the same institution has compiled the pest select database (IOBC, 2013b), which is a new tool to use selective pesticide for an Integrated Pest

Management (more information is available at: http://www.iobc-wprs.org/ip_ipm/IPM_Future_Jansen_20130320.pdf).

Likewise, ANR (2005) summarises the toxicity levels of the active ingredients of the most frequently used protection products. The related information is available at the link below: <http://anrcatalog.ucdavis.edu/pdf/8161.pdf>.

Another source of information are the databases on registered plant protection products which have been formulated for each member state. They can be found at (EMPPPO, 2014): http://www.eppo.int/PPP/PRODUCTS/information/information_ppp.htm

IOBC has also developed specific integrated production guidelines for several crops, which summarise best practices for the CPP application. They are available at: http://www.iobc-wprs.org/ip_ipm/IP_guidelines_crop_specific.html.

The Centre for Agriculture and Environment (CLM) developed a software for the assessment of the environmental risk and impact of some pesticides that are used in the Netherlands: <http://www.milieumeetlat.nl/>.

Reference literature

- Ajeigbe H.A., Mohammed S.G., Adeosun J.O. and Ihedioha D. (2010), Farmers' Guide to Increased Productivity of Improved Legume–Cereal Cropping Systems in the Savannas of Nigeria, IITA, Ibadan, Nigeria, 104, ISBN: 978-978-49796-1-0.
- ANR (2005), Pesticide choice: Best Management Practice (BMP) for protecting surface water quality in agriculture, University of California, Division of Agriculture and Natural Resources, publication number 8161, ISBN: 978-1-60107-330-3.
- Bauder T., Waskom R. and Pearson R. (2010), Best Management Practices for Agricultural Pesticide Use to Protect Water Quality, Colorado State University, Extension, Bulletin #XCM-177, available online: <http://www.ext.colostate.edu/pubs/crops/xcm177.pdf>, accessed 25 September 2014.
- Boller E.F., Vogt H., Ternes P. and Malavolta C. (2005), Working document on selectivity of pesticides, Explanations to IOBC database, available online: http://www.iobc-wprs.org/ip_ipm/03021_IOBC_WorkingDocumentPesticides_Explanations.pdf, accessed 30 September 2014.
- Centre for Agriculture and Environment (CLM) (2015), Software for the assessment of the environmental risk and impact of pesticides that are used in the Netherlands: available online: <http://www.milieumeetlat.nl/>.
- Cross P. (2013), Pesticide hazard trends in orchard fruit production in Great Britain from 1992 to 2008: a time-series analysis, Pest Management Science, 69, 758-774.
- EMPPPO (2014), Information on plant Protection Products, Databases on registered plant protection products in Europe, European & Mediterranean Plant Protection Organisation, available online: http://www.eppo.int/PPP/PRODUCTS/information/information_ppp.htm, accessed 25 September 2014.
- HSA (2010), Classification, Labelling and Packaging (CLP) of substances and mixtures under EU CLP regulation, Health and Safety Authority, available online at: <http://www.google.fr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&cad=rja&uact=8&ved=0CE8QFjAE&url=http%3A%2F%2Fwww.ul.ie%2Fhr%2Fsites%2Fdefault%2Ffiles%2Fdocs%2FHealth%2520And%2520Safety%2FClassification%2C%2520Labelling%2520and%2520Packaging%2520of%2520Substances%2520and%2520Mixtures.pdf&ei=zUxVJLVPIvwaIH1gugG&usg=AFQjCNEYJUc-OCFJSWEfzH9YGGC2KXDdMg>, last accessed 7 October 2014.
- IOBC (2005), Appendix 5 of basic document on integrated production 2004, IOBC Commission on "IP guidelines and endorsement", available online: http://www.iobc-wprs.org/ip_ipm/03011_IOBC_GreenYellowList_Explanations.pdf, accessed 24 September 2014.
- IOBC (2013a), Guidelines for integrated production of stone fruits, IOBC technical details III, 3rd edition, edited by Malavolta C. and Molinari F., Darmstadt, Germany, ISBN: 978-92-9067-265-4.

- IOBC (2013b), Pest select database: a new tool to use selective pesticide use for IPM, by Jansen J.P., produced by IOBC, available online: http://www.iobc-wprs.org/ip_ipm/IPM_Future_Jansen_20130320.pdf, accessed 24 September 2014.
- IOBC (2014), IOBC pesticide side effect database, available online: http://www.iobc-wprs.org/ip_ipm/IOBC_Pesticide_Side_Effect_Database.html, accessed 30 September 2014.
- Jansen J.P. (2013), Pest select database: a new tool to use selective pesticide for IPM, available online: http://www.iobc-wprs.org/ip_ipm/IPM_Future_Jansen_20130320.pdf, accessed 30 September 2014.
- Malavolta C. (2011), Integrated Pest Management A European perspective, IOBC WPRS, Commission "guidelines for integrated production", available online: <http://liveinc.org/sites/default/files/Carlo%20Malavolta%20Presentation.pdf>, accessed 29 September 2014.
- SAI (2010), Water conservation, technical briefs, TB4- Integrated pest management: A guide to protecting water quality, available online: <http://www.saiplatform.org/uploads/Library/Technical%20Brief%204.%20Integrated%20Pest%20Management%20A%20guide%20to%20protecting%20water%20quality-2.pdf>, accessed December 2014.
- Voluntary Initiative (2011), Metaldehyde slug pellets, available online at: http://www.voluntaryinitiative.org.uk/importedmedia/library/1151_s4.pdf, last accessed on 14 may 2014.
- WHO (2010), the WHO Recommended classification of pesticides by hazard and guidelines to classification 2009, NLM classification: WA 240, International Programme on Chemical Safety, World Health Organization, ISBN: 978-92-4-154796-3.
- Williamson (2010), French farmers and integrated production of wheat, Pesticides News, 90, 16-17.

12 PROTECTED HORTICULTURE

Introduction

Protected horticulture refers to the cultivation of fruits and vegetables, as well as other products such as nuts, herbs, mushrooms and flowers, with a cropping technique wherein the micro-climate surrounding the plant body is controlled partially/fully as per the requirements of the plant species (Akbar et al., 2013). This is achieved thanks to the use of greenhouses, with or without active heating and/or cooling.

Although greenhouses have been used in Europe for over two centuries, protected horticulture has grown significantly in the recent past and become more and more intensive. It is now very widespread in the EU, both in northern Europe and around the Mediterranean Basin, where some of the largest concentrations of greenhouse in the world are located.

The total surface area in the EU Mediterranean region occupied by greenhouses is estimated to be 140,000 hectares (Pardossi et al., 2004), if only the most common large walk-in tunnels are considered. Most of these greenhouses are dedicated to vegetable production (Cantliffe and Vanslicke, 2012). Additionally, there are an estimated 62,000 ha of small tunnels in the Mediterranean zones of the EU (Pardossi et al., 2004), taking the total area of protected horticulture in this region to 202,000 ha. Among EU member states, Italy and Spain have the largest greenhouse producing areas of approximately 35,000 and 56,000 ha, respectively (Pardossi et al., 2004), with France and Greece following with surface areas of 11,300 and 5,000 ha, respectively (Pardossi et al., 2004).

The large increase in protected horticulture in the EU is due to several factors. Changes in diet have contributed to an increase in vegetable consumption in Europe, opening windows of opportunities for vegetable growers. Improvements in transportation also have increased production by improving quality and lowering costs in transporting vegetables. The European Union is considered to be self-sufficient in vegetable production for most fresh vegetable crops (Cantliffe and Vanslicke, 2012).

Most of protected horticulture is in soil, although soilless cultivation is developing. It is estimated that soilless cultivation in protected horticulture occupies approximately 5,000 ha, using mostly inert substances such as perlite, rockwool, sand, and volcanic gravels. Most soilless cropping is located in Spain where there are an estimated 4,000 ha (Pardossi et al., 2004).

Best practices in improving the environmental performance of protected horticulture are:

- Dynamic control of the climatic parameters
- Reducing and optimising the use of energy inputs
- Use of renewable energy sources
- Use of innovative covering (and not only for covering purposes (e.g. mulches, pots etc.)) materials that have suitable physical properties and low generation of after-use waste
- Optimised water and nutrient delivery to the plants
- Reducing the use of crop protection products.

Most of these aspects are dealt with in detail in this chapter in the three following BEMPs:

- Energy efficiency in protected horticulture (section 12.1)
- Water management in protected horticulture (section 12.2)
- Waste management in horticulture (section 12.3)

The aspect of reducing the use of crop protection products is not addressed here as the best practices in chapter 11 are also applicable to protected horticulture.

The aspects of water management in protected horticulture is particularly important for the large share of greenhouses located in water stressed regions in the Mediterranean zones of the EU (see also chapter 10 on irrigation practices in general).

Other than the scarce use of reclaimed municipal water and other alternative sources of recycled water, in the sector of protected cultivations and nursery productions, not much has been done with regard to the reuse of the water supplied with irrigation and drained out from the cultivation systems after irrigation in open (free-drain) systems.

For nursery productions also the collection and reuse of rain water, which is only partially intercepted by the crops, is very relevant.

Although looking at alternative sources of water will be compulsory in the agriculture of the next future, the first task remains the optimisation of water use. The demand of water in protected cultivations and nursery productions is high due to the exigencies of the specific species (ornamentals and vegetables) and to the fact that a leaching fraction (LF, i.e. the percentage of water drained out from the cultivation system per quantity of supplied water) up to 20-30% is often necessary to avoid salt accumulation and ensuring high yield and quality. This brings about a waste of water and, sometimes, nutrients that, in turn, may be possible pollutants for the environment in open systems. To solve, at least partially, this problem, water drained out from the cultivation system can be collected and reused for successive irrigations by putting in place a closed-loop system (section 12.2).

Reference literature

- Akbar P.I., Kanwar M.S., Mir M.S., Hussain A. (2013), Protected Vegetable Cultivation Technology for Cold Arid Agro-ecosystem of Ladakh, *International Journal of Horticulture*, 2013, Vol.3, No.19 109-113.
- Cantliffe D.J. and Vansickle J.J. (2012), Competitiveness of the Spanish and Dutch Greenhouse Industries with the Florida Fresh Vegetable Industry, Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, publication code: #HS918.
- Pardossi, A., Tognoni, F., Incrocci, L., (2004), Mediterranean Greenhouse Technology, *Chronica Horticulturae*, 44, 28–34.

12.1 Energy efficiency measures in protected horticulture

Description

The energy consumption is a key environmental pressure for greenhouse horticulture in both cold and warm climates. This can be minimised by using renewable energy sources and better insulation of greenhouses (Vox et al., 2010).

This is relevant for all regions of Europe. Indeed, although the Mediterranean Basin and the northern European areas have significant climatic differences, they share the same objectives in greenhouse management. During autumn and winter, the radiation entering should be maximized and energy loss should be minimised. During summer and spring, high temperatures must be avoided.

Indicative figures for annual energy use in horticulture greenhouses are in the order of 1,900 MJ/m² (measured for Scandinavia) for northern European climatic conditions, and 500-1,600 MJ/m² in the Mediterranean Basin. However, this energy use is increasing due to more use of heating to achieve earlier production, and to the use of cooling systems. Average energy use accounts for 10-30% of the total production costs depending on the region (FAO, 2013).

Having said so, the different climate conditions between Northern and Southern Europe determine to a large extent the most appropriate climate control technology. In northern Europe, heating is a primary issue and the geothermal potential for heating the greenhouse should be investigated. In southern Europe, instead, it is the cooling systems that are usually more important.

This BEMP describes a full set of techniques to reduce the energy demand of greenhouses and meet it with on-site renewable energy generation:

- Dynamic control of climatic parameters
- Geothermal heating system for greenhouses in Northern Europe
- Cooling system in Southern Europe
- Insulation-Maintenance
- Lighting

Even before considering them, the initial step in the design of an energy efficient greenhouse is the characterisation of the climate of the area. Parameters like temperature, humidity, sun, wind and snow must be determined in order to select structural materials, orientation, window-positioning and eventually the proper heating system technology (Panagiotou, 1996).

Dynamic control of climatic parameters

The management of climatic conditions within the greenhouse is strongly linked to the growth of the crop and eventually to production (Vox et al., 2010). Each crop species requires different climatic conditions, while for a given species optimal temperatures for different phenological stages can differ. The usual temperature range for crop species is from 10 to 24°C. Under sunny conditions, crops are usually grown with day-time temperatures that are 8-10°C higher than night-time temperature (Nelson, 2002; Vox et al., 2010).

Atmospheric humidity within the greenhouse must be also controlled. High levels of humidity increase the possibility of condensation on leaves which favours the development of fungal diseases. High humidity is reduced by applying effective passive ventilation through window, forced ventilation within the greenhouse or by heating (according to the current weather conditions) without opening windows. Forced ventilation can be combined with heating. The main advantage of using forced ventilation is that it provides more uniform distribution of temperature and atmospheric humidity. In particular, the use of forced ventilation means that outside dry air gets into the greenhouse where it is heated and thus reduces the internal relative humidity (de Gelder et al., 2012).

Dynamic climate control systems allow setting a control strategy that is based on adapting the conditions in the greenhouse within certain limits to the external weather conditions in order to reduce energy use. A commonly-used approach is to increase the temperature set point to initiate ventilation during the day to enable relatively high average day-time temperature and to lower the set point during night in order to reduce heat needs. The system can also take into account other external weather parameters like wind speed (Vox et al., 2010).

Geothermal heating system for greenhouses in Northern Europe

The thermal storage capacity of water in soil is large thus large amounts of heat can be stored there. The use of the warm water from geothermal sources has high potential for greenhouse heating. Geothermal water at relatively low temperature is compatible with a wide range of heating systems including heat exchangers and heat pumps, piping systems and tubes (Figure 12.1). Geothermal wells can supply water, at a temperature appreciably higher than ambient air temperature, directly to the heat delivery equipment in the greenhouse. In this Figure a CHP is also illustrated as an additional element, which eventually can reduce the amount of the required fossil fuel.

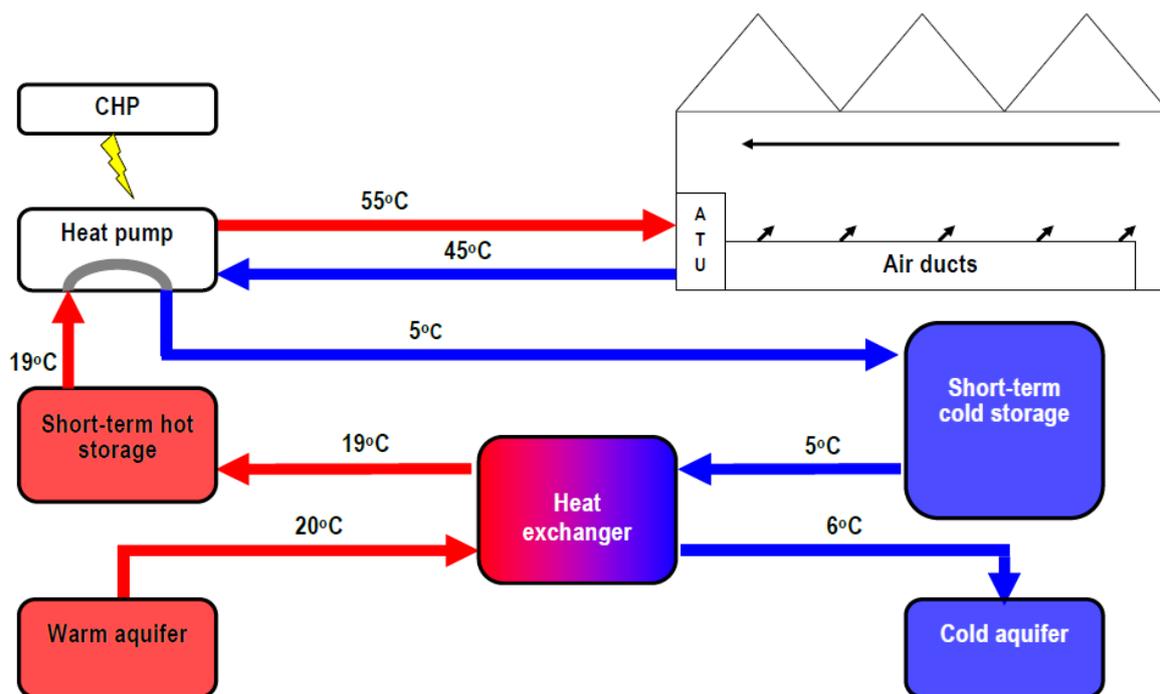


Figure 12.1. Heating option (Pratt et al., 2007)

Geothermal systems are classified into shallow and deep. The shallow systems are divided into heat extraction systems (with heat pump) and energy storage systems (for both cooling and heating). Deep geothermal systems extract heat from the underground layers of the earth and are installed to depths of up to 5,000 m below the surface. If the extracted heat has a temperature above 120°C, electricity can also be generated (Willemsen and Godschalk, 2010). In particular, the choice of the most appropriate solution is also based on the conditions beneath the greenhouse (aquifer depth etc.) which must be appropriately investigated.

Heat extraction systems

Shallow systems

The concept is that during summer the surplus of heat is stored and cooling is provided with stored winter cold and during winter the stored summer heat is used for heating (Figure 12.2).

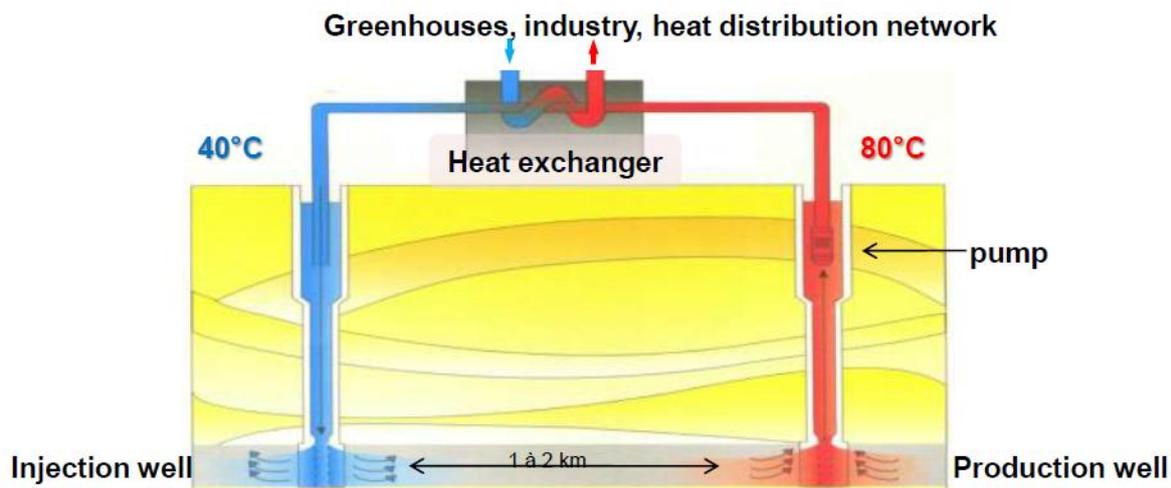


Figure 12.2. Geothermal energy – aquifer, main description of the operation of the geothermal systems (Martijn van Aarssen, 2012).

The energy is stored underground in sandy aquifers or 'water' layers, usually 20-500 m below the ground. If this water is pumped up, cooled down and then infiltrated back into the soil, the temperature of soil and groundwater near infiltration well decreases. After a certain time, a zone of cold groundwater will develop around the filtration well (Willemsen and Godschalk, 2010). In summer, groundwater is extracted from the cold water zone – with a temperature 5-10°C, which is then used for cooling purposes.

Groundwater is used to absorb energy from the greenhouse and in doing so is heated. When this water, which has a higher temperature than natural groundwater temperature, is infiltrated into an aquifer, it creates a zone with a temperature of 15-30°C. This amount of water is subsequently used for heating during winter (Willemsen and Godschalk, 2010).

Energy storage can be implemented taking into consideration the following factors: (i) characteristics of the subsoil, and (ii) groundwater quality and flow. In general, energy storage is most effective in sandy subsoil and at a depth range of 20-250 m (Willemsen and Godschalk, 2010).

Deep systems

Temperature increases from the surface of the earth by 30°C for each km of depth. Therefore heat extracted from a depth less than 1 km can be used directly for heating purposes in greenhouses. This heat is extracted by pumping up groundwater from the selected depth and by subsequently extracting heat from the groundwater. The water is then returned underground.

Energy storage systems

Short-term storage

The initial point for energy storage is to recover heat from a greenhouse during a summer day and use it for providing a heat source for the heat pump when heating is needed during the following night. In the case of the energy efficient greenhouse the temperature range within the greenhouse (in the crop growing area) is 5-20°C, while in the conventional one the temperature ranges from 40 to 50°C or even higher (Pratt et al., 2007).

Regarding storage requirement for cooling, an existing greenhouse (called Themato) uses 1,600 m³/ha of cool storage room. Special care should be given in the equipment used (pipes, valves, pumps etc.) in order to avoid both condensation and corrosion (Pratt et al., 2007).

Long-term storage

Long-term cool storage can be implemented by Aquifer Thermal Energy Storage (ATES) where the aquifer provides the required amount of water. One pair of vertical wells is required (one warm and

one cold). The water extracted from the aquifer passes through a heat exchanger to transfer heat to the greenhouse loop. Special care must be taken to avoid corrosion irrespective of whether the water extracted is salty or not and other problems in the equipment used (Pratt et al., 2007).

The Netherlands have compiled guidelines for commercial scale ATEs installations, which are listed below:

- Each well must ensure an extraction/absorption rate of at least 160 m³/h
- The pair of warm and cold wells must have a minimum of 300 m apart in order to ensure that the water does not mix.
- Dutch government has set the maximum water temperature that can be put into the aquifer to 25°C.

Where geothermal sources are not sufficient, (or when the aforementioned geothermal options are combined with a CHP), the total environmental performance of the greenhouse increases. In particular, in the case of an installed CHP, an amount of the generated electricity from the CHP can be further used internally, within the greenhouse, whereas the rest is distributed to the electricity network; also the produced heat can be used for heating the greenhouse. In addition, with CHP, CO₂ produced by the internal combustion engine can be captured and eventually distributed to the crops affecting positively their growth.. It should be noted that the use of CHP involves the use of fossil fuel, while the geothermal energy can result in an almost carbon-free greenhouse. Moreover, the use of CHP depends on the price of electricity and gas.

Ground Source Heat Pump

An alternative method always involving exploitation of aquifers is the use of a Ground Source Heat Pump (GSHP). The main difference with the geothermal exploitation of the aquifer is that the heat is not stored in the ground or in the aquifer but it is dissipated. This technology can be installed everywhere without any technical limitations. It is reported that the combination of GSHP and CHP can result in reduction of fossil use (used for heating) of 50% (Pratt et al., 2007; Benli and Durmus, 2009).

GSHP are installed at a depth of more than 2 m from the ground surface where the temperature, in north-western Europe, is generally close to 10°C throughout the year. Water is delivered at the 10°C all the year. With this technology heat is not stored but it is dissipated in the surrounding earth layers (Pratt et al., 2007; Belni and Durmus, 2009).

The heat and cool energy storage is implemented either long term (months -1 year) or short term (1 day).

The general concept of such greenhouses is depicted in Figure 12.3 (Turgut et al., 2006).

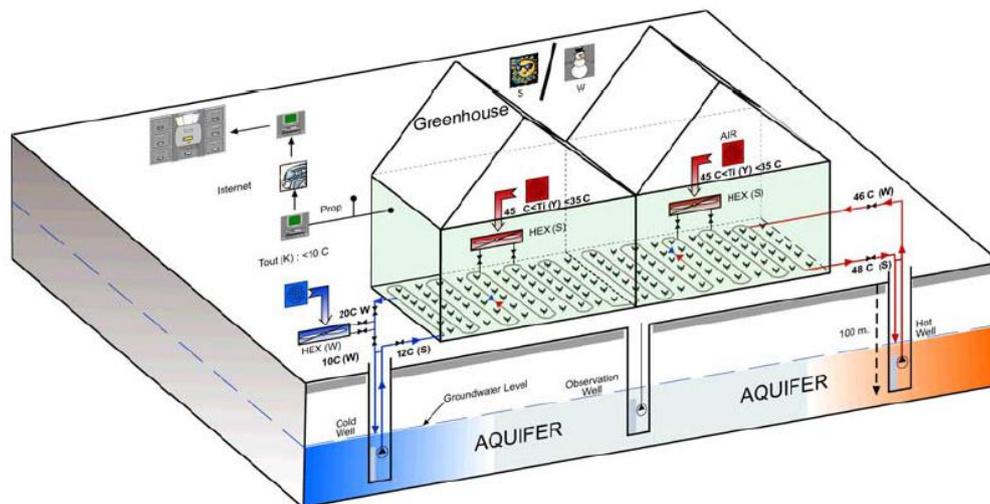


Figure 12.3. Detailed concept of a greenhouse with an exploitation of geothermal energy – aquifer (Turgut et al., 2006).

Cooling system in Southern Europe

In warmer climates e.g. southern Europe, crops require cooling during the spring and summer period. Apart from the mechanical systems (mechanical ventilation), which are mainly used in northern climates (where cooling is not always necessary), some passive methods exist like shading and white washing. Mobile shading screens can be installed which reduce solar radiation reaching the crop; generally these screens are mounted inside the greenhouse. They can also be mounted above the greenhouse roof, but these systems are very uncommon. Whitewashing reduces solar radiation entering the greenhouse thereby cooling the greenhouse interior. In south-eastern Spain where there is the largest concentration of greenhouses in Europe, whitewashing is the most commonly-used method of cooling. Evaporative cooling techniques are the popular in Italy below (Vox et al., 2010; Campiotti et al., 2012). The main evaporative techniques are:

- Cooling pads: this approach is based on placing fans in one wall and a wet pad in the opposite wall. Outside air is sucked into the greenhouse through the wet pad decreasing the inside temperature. The efficiency of that systems ranges from 80 to 90%. This system creates a positive pressure in the greenhouse, impeding the entry of dust and harmful insects into the greenhouse (FAO, 2013). This technique requires fresh water; however, Davies et al. (2006) showed that even seawater can be used for cooling purposes.
- Fogging: this technique is based on the supplying water in the smallest possible drops, with diameter of 6-20 μm aiming to enhance the exchange of heat and humidity between the applied water and the air. Therefore, the surface area of the water in contact with the air increases in a direct relationship to the decrease in drop diameter. The technique has high efficiency due to the fact that it is possible to evaporate water in sufficient quantities to match the heat entering in the greenhouse. Most of the fogging systems are equipped with high-pressure nozzles (e.g. 1,000 psi) that can uniformly distribute the applied water droplets above the crop and with fans in throughout the greenhouse. Air entering the greenhouse is cooled and is then distributed absorbing excess heat.

In areas where underground aquifers exist, heat storage can be implemented based on the use of a fine wire heat exchanger (Figure 12.4). A sprinkling system is used to collect heat from the greenhouse cover during summer months. The cooling concept using the aquifer is the same as it was explained above in the heating systems for northern Europe (Pratt et al., 2007).

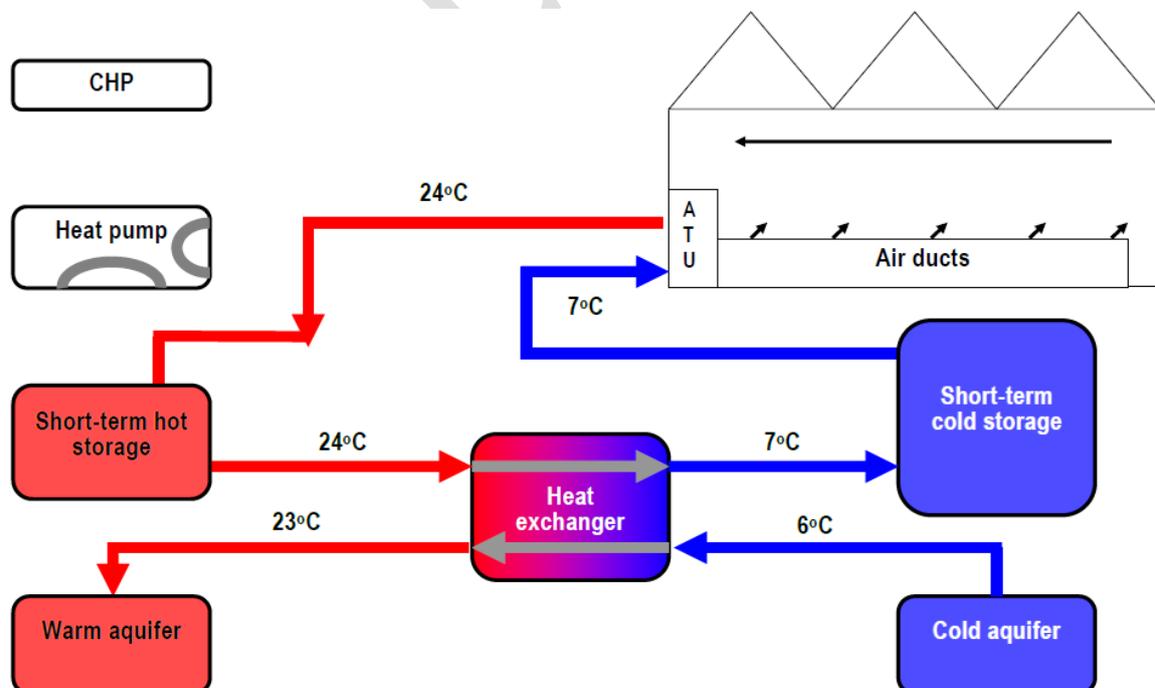


Figure 12.4. Geothermal cooling option (Pratt et al., 2007)

Insulation – Maintenance

One important aspect for reducing energy use is the selection of the appropriate covering materials. Practices like double glass with a layer between of air between the sheets of glass or a double plastic cover that is inflated in the air by a blower seem best to improve the 'building (greenhouse)' envelope or to decrease the heat load (Vox et al, 2010; Campiotti et al., 2012). All the heating/cooling equipment must be well insulated in order to reduce losses. Moreover simple maintenance is an essential part of the minimising losses, including actions like glass cleaning, replacing broken glazing and repairing damaged insulation. Carbon Trust (2004) reported that a 1 m length of uninsulated 100 mm diameter pipe carrying water at 80°C can waste 200 kWh of heating fuel a week.

Lighting

Where light is required e.g. in northern Europe, appropriate lighting equipment should be installed in the greenhouse. Each greenhouse should consider local climatic conditions taking into consideration the ratio between the temperature and light. In particular, in tomato production in northern Europe, light is an important factor where in the low-light period of the year the light sum is often less than 400 J/cm² per day, while a high production requires at least 1,700 J/cm² per day. In particular, the type of lighting equipment that must be installed is a LED system, which produces photosynthetic wavelengths of light that target the plants' needs.

It should be also mentioned that some energy efficient greenhouses are located near industrial sites. In such cases, waste heat from the sites and waste CO₂ can be transferred to the greenhouses by an appropriate pipe network. This pipe network must be insulated properly and well maintained to avoid leakages and energy losses (Carbon Trust, 2012).

Achieved environmental benefits

Geothermal energy is a useful energy source for saving or replacing fossil fuels due to the fact that this kind of energy is renewable, and is always available. Moreover, by saving fossil fuel use, CO₂ emissions are also significantly prevented.

Lighting

Regarding the lighting energy savings, by installing LED systems, significant energy savings can be achieved, of 50-80% compared to traditional lighting systems. In particular, Fionia Lighting developed a highly efficient LED system, which achieved during one year a 53% electricity savings compared to the conventional high pressure sodium (HPS) bulbs and a 43% electricity savings compared to the new 1,000 Watt HPS system (Fionia lighting, 2012). Additional benefits are summarised below:

- 20% increase in yield production
- Improved efficiency in water use, estimated 20% savings in total water use
- Reduced pesticide use (approximately 80%) due to the maintenance of stable conditions inside greenhouse

Heating/cooling

The energy savings with the implementation of aquifer thermal energy storage systems are summarised below (van Aarsen, 2012).

Cooling

- 60-80% saving on electricity consumption for cold production: only electricity consumption is for the pump
- 80-90% reduction of peak electricity use for cold production: no or limited chiller capacity needed

Heating

- 20-30% saving on primary energy consumption for heat production: in comparison with gas-fired boiler because of highly efficient heat pump
- No or smaller gas grid connection needed: no or limited gas-fired boilers needed

De Gelder et al., (2012) calculated the energy savings for a closed greenhouse in the Netherlands using geothermal energy sources for cooling and heating. The energy savings are presented in Table 12.1 where the contribution of each element of the greenhouse is also listed. Therefore, for a greenhouse with a reference value in energy demand of 1,300 MJ/m²/y it was calculated that almost 500 MJ/m²/y could be saved by applying appropriate techniques.

Table 12.1. Energy savings in an energy efficient greenhouse; contribution of each element (FAO, 2013)

	Energy demand (MJ/m²/y)
Reference/initial value -	1,300
Forced ventilation	-75
Temperature integration	-130
Cooling, heat pump and aquifer	-375
Screens/windows	-145
<i>Final energy demand</i>	<i>645</i>

Appropriate environmental performance indicators

The appropriate environmental indicators for an energy efficient greenhouse are listed below (Carbon Trust, 2012):

- Lighting: kWh/m²/year
- (Total energy input)/m²
- (Total energy input)/yield

In 2000, the Handbook of environmental measures in glasshouse market gardening (2000) published Dutch data regarding best practice and typical benchmarks (heat and electricity) for protected horticultural and ornamental crops, which are illustrated in Table 12.2 (Carbon Trust, 2012).

Table 12.2. Typical and good practice benchmarks for protected horticulture (Carbon Trust, 2012).

Energy consumption (kWh/m ²)	Edible crops				Ornamental crops			
	Intensive		Extensive		Intensive		Extensive	
	Heat	Electricity	Heat	Electricity	Heat	Electricity	Heat	Electricity
Best practice	375	8.5	125	6	280	6*	110	5
Typical	495	10	165	8	375	10.5*	165	8

* energy use for supplementary and night-break lighting are also included in these figures

Cross media effects

Appropriate measures should be adopted with the equipment used (pipes, valves, pumps etc.) in order to avoid any leakage of chemicals and to prevent contamination of aquifers. The evaporative cooling technique such as pad and fan requires significant amount of fresh water (Vox et al., 2010).

Operational data

Dynamic climate control

Inside air temperature is an important parameter that should be monitored in energy efficient greenhouses. Each crop species has different ranges of optimal temperatures, whilst several researchers have reported that some crop species have wide boundaries in accepting high day-time temperatures. For tomato, day-time temperatures are allowed to reach 27°C, while during the night lower temperatures must be used in order to obtain the required diurnal temperature (de Gelder et al., 2012). The energy savings that can be achieved by reducing the temperature during night time inside

greenhouse by 1°C, increasing ventilation by 2.5°C and temperature modification/adaptation, are up to 130 MJ/m²/y (de Gelder et al., 2012).

Heating system in northern Europe

Several sources report that simple horizontal ground-source heat pump configurations can supply 20-35 W/m² of ground surface occupied by the loop. Applying this technique in a greenhouse with total surface of 1,000 m², 45 kW of power can be extracted from the ground (Campiotti et al., 2012).

For the heating of the greenhouses with the implementation of geothermal technology, the following data have been obtained from the literature and from leading companies. The water temperature should be about 60°C with a flow rate of approximately 160 m³/h. The capacity of such system is 4-5 MWth where 7 ha of tomato in the greenhouse can be heated, avoiding 3 million m³ of gas annually (van Zaaij, 2009).

A Dutch horticultural company in the greenhouse area in Bleiswijk near The Hague, heats a 7.2 ha tomato greenhouse with warm water coming from a borehole. The aquifer was at 1,700 m depth and two wells were implemented. The re-injection of water occurs at flow rates of about 130-160 m³/hour with a pressure of 9 bar, demanding 200 kW of pumping power. The water temperature is approximately 60°C at 1,700 m depth.

The operational data of an orchid greenhouse in The Netherlands, named Maurice van der Hoorn, are presented below. The crops cultivated in this greenhouse are orchids, the surface is approximately 15,000 m² of which half requires cooling (+20°C) and the other half requires heating (+28°C). The greenhouse is equipped with an ammonia heat pump. The heat pump operates only during the winter time in order to produce warm water. The amount of cold water is stored in underground earth layers with a total capacity of 180 m³/h. During summer the greenhouse is cooled by the use of the cold water stored in the aquifers. In other words, the heat pumps in the summer months are switched off. The heat pumps are operated with electricity by using a large water buffer tank (400 m³), which provides the opportunity for working during off-peak hours (GEA group, 2014).

As was mentioned in the description section, the choice of the heat pump is crucial. For selection of the most appropriate heat pump, various selection criteria are summarised below (Rene, 2010):

- Reliability of the selected equipment
- Proper dimensioning of the project including the selected heat pump (power, operating temperature, etc.)
- High Coefficient of Performance (COP), in order for the greenhouse to be operated efficiently

Cooling system in southern Europe

The existing cooling systems in the greenhouses are mostly based on passive ventilation, whitewashing, and on evaporation. The use of ventilation and evaporation has a direct impact on atmospheric humidity inside the greenhouse. It should be noted that the humidity inside the greenhouse ideally should be 60-75%. The characteristics of the main evaporative technique are summarised below (Agritex, 2014):

- Fog system: this technique can decrease the temperature inside the greenhouse from 3-5°C, but on the other hand can increase the humidity inside the greenhouse up to excessive levels.
- Pad and fan: This technique does not have an impact on the humidity but it is efficient only when the width of the greenhouse is not more than 50 m.

Insulation

The use of double-wall glass decreases convective energy losses but at the same time decreases the transmissivity of solar radiation by up to 8-10%. However, this decrease can be further reduced by applying anti-reflection coatings/layers, which eventually increase solar transmissivity by 6.8-7.4%. For warm periods in the southern European countries, glasses filtering out NIR solar radiation can be used, especially when a large amount of energy is used for cooling purposes (Vox et al., 2010).

Plastic films can also be used. The polyethylene-co-vinyl acetate (EVA) films allow reductions of the thermal infrared losses and significant energy savings in greenhouse heating (Vox et al., 2010).

The typical thickness of a double-glazed glass is 4 mm, in particular has 2 panels with thickness of 3 mm with anti-reflexive coating in three sides and one low energy coating in one inside. Given the extra weight, the frame is reinforced and contains more materials (e.g. 6.7% steel and 3.3% aluminium) (Vox et al., 2010).

Moreover, insulation has to be at least 200 mm deep in roof spaces and 75 mm elsewhere. As far as the pipes insulation is concerned, hot internal pipes and external pipes should have an insulation of 25 mm and 50 mm respectively using weatherproof insulation. All the supplementary equipment like valves and flanges should be insulated as well (Carbon Trust, 2012).

Case study –aquifer exploitation

The Themato greenhouse is located in The Netherlands and was constructed in 2003. This plant is called a closed greenhouse and a combination of geothermal energy and CHP is used (Figure 12.5). This plant works with a sealed and an open greenhouse system in combination with heat recovery and storage in underground reservoirs for later use. The application of the described practices resulted in a yield increase of 20%, a reduction in crop protection agents and recycling of evaporated water. In total the energy consumption and the release of CO₂ emissions (compared to conventional tomato growers) were both reduced by 50%.

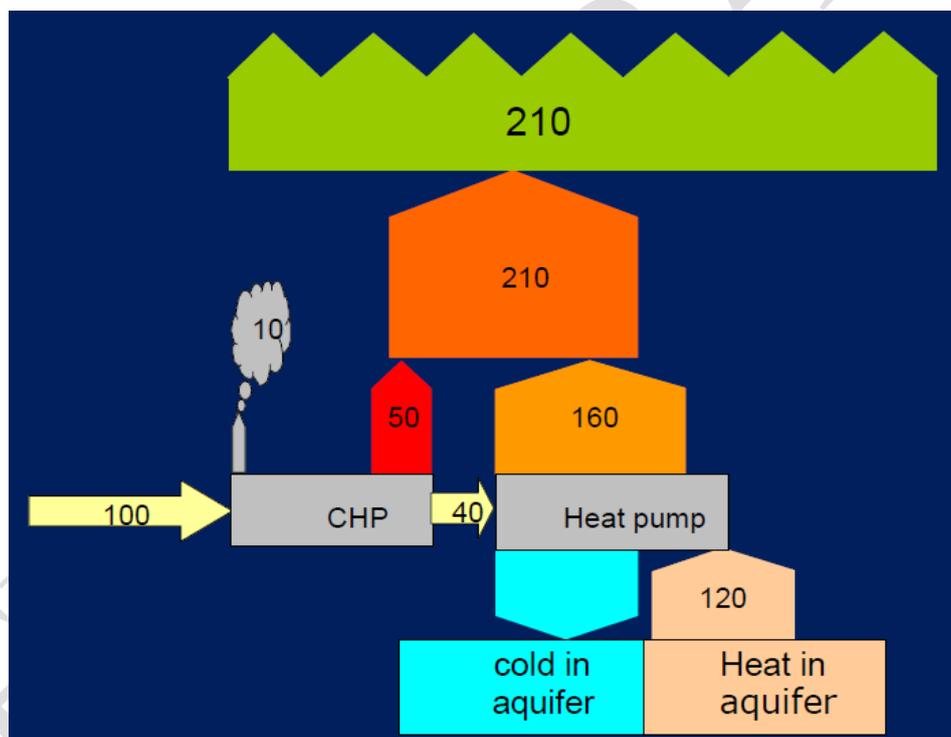


Figure 12.5. Sustainable energy generation at Themato greenhouse (Heller, 2010)

During summer the greenhouse is cooled using chilled water. This water which warms during circulation in the greenhouse is then stored in the aquifer and is used later for heating (during the winter months). Moreover, without the need for ventilation in the summer period, levels of CO₂ are maintained at much higher levels compared with conventional greenhouses. Cooling gives better control of summer temperatures resulting in an improved crop management (meaning reduced pests, reduced disease incidence due to the improved air circulation) which contributes to significantly increased yields.

During the operation to provide cooling, cold water at a temperature of approximately 60°C is drawn from a well which is then supplied to the air treatment units (ATU). ATU are located inside the

greenhouse and comprise water-to-air heat exchangers and a fan. The fan takes the air through the heat exchangers and blows it into the greenhouse. However, in order for adequate air circulation to be maintained, plastic ducts are connected to the ATU outlet. The circulated (cooling) water returns from the greenhouse to another well at a temperature range of 20-24 °C. In this well the water is stored in the aquifer in order to be used for heating purposes in the winter.

When the system is used to provide heat in the winter, water is pumped up from the aquifer and is guided to a heat pump, which increases the temperature from 20-24 °C to a range of 45-55 °C. In parallel, the heat pump produces cold water (~5 °C) which is then stored and used afterwards for cooling.

A CHP works also together with the geothermal energy systems. The principal aim of the CHP is to generate electricity for the heat pump and also to generate heat, which is distributed to a nearby open (i.e. not closed) greenhouse.

The total surface of this greenhouse is 1.4 ha and requires an open surface of 4 ha for the installation of 6 wells (3 for cold and 3 for warm water). These wells are located 315 m under the ground and at a distance of 175 m. In total there are 100 air treatment units and 100 air socks resulting 35% energy saving and 20% higher production (Pratt et al., 2007).

Regarding the temperature profiles of the warm and cold water, the heat pumps generate electricity at a range of 3-5 kWh of heat for every 1 kWh used for powering. The air distribution ducts are 85m long, while the aquifer provides three cold (60 °C) and three warm (20 °C) volumes. The surplus heat, which is generated because of the fully closed greenhouse area, is delivered to a remaining 'open' area of 40,000 m². The reduction in the total used energy is calculated approximately 30-40% for the entire greenhouse area of 54,000 m².

Applicability

The application of geothermal energy is limited compared with the other available technologies. In particular, the temperature profile differs in each aquifer providing difficulties in the implementation of similar projects.

The evaporative cooling techniques involve the use of high quality water and thus the actual use of water must be determined in order to understand better how the evaporative cooling affects plant transpiration for different crops. Moreover, it should be also taken into account that water availability is limited in many horticultural areas (Vox et al., 2010).

Moreover, as far as the applicability of the cooling techniques is concerned, the pad and fan systems must not be installed in greenhouses with a width more than 50 m, while fogging systems must not be installed in areas with high level of atmospheric humidity (Agritex, 2014).

Economics

The investment cost of a geothermal technology greenhouse is estimated about 6M€. The maintenance and depreciation of a geothermal greenhouse is estimated about 80,000 € annually.

Regarding the operation and maintenance costs, 10-50% savings can be achieved at gas prices (reference year 2013) (Radobank, 2013).

Moreover, it should be mentioned that few countries provide subsidies for generation of electricity, which is an important factor regarding the viability and feasibility of each project. Therefore, the factor of electricity generation strongly influences the choice of technology, which influences the overall costs and economics of the project.

The LED lighting systems offer longer life. It is estimated that LED offers ten years of lifespan compared with the ordinary bulbs, which offer almost one year of lifespan. Therefore, the installation costs are significant lower. Finally due to the fact that their spectral composition is fine-tuned, it is easy to consider the seasonal changes in light levels, such as the cloud cover.

For the evaporative cooling techniques, the investment costs are listed below (Agritex, 2014):

- Fogging system: estimated costs 300 – 400 €/ha
- Pad and fan system: 700-1,000 €/ha

Driving forces for implementation

The reduced use of fossil fuel for heating the greenhouse is one of the main driving forces for implementation. The operational costs are thus becoming less compared with the conventional greenhouses.

Reference organisations

Table 12.3 presents the features of various heat pumps that have been already installed in several greenhouses and Table 12.4 lists geothermal plants installed in The Netherlands.

Table 12.3. Various heat pumps in different greenhouses

	Power HP	Refr.	COP (H/E)	Temp. out	installation
	kWe			C	
Themato	525	R134a	4.0	54	heat HP in HT buffer
Tas	90	R134a	4.2	45	Condenser in series met CHP 40->90C to buffer
Prominent	626	R134a	5.0	47	heat HP in HT buffer via diffusers
Delta	375	R134a	3.9	53	no aquifer but day buffer
BiJo	460	R134a	6	35	100% sustainable

Table 12.4. Details of geothermal project of energy efficient greenhouses in the Netherlands

Project name	Location	Area supplied (ha)	Heat demand covered	Produce/ end demand	Status	Geothermal capacity (MWth)
A. en G. van den Bosch	Bleiswijk	15	60-80%	Tomatoes	Running	6
A. en G. van den Bosch	Bleiswijk	na			Planning	
A. en G. van den Bosch	Berkel & Rodenrijs	6			Running	
Ammerlaan Grond- en Hydrocultuur	Pijnacker	4	100% + power	Potted plants, school, swimming pool, housing	Running	na
Gebroeders Duijvestijn	Pijnacker	14	100%	Tomatoes	Running	6.6
Aardwarmtecluster Koekoekspolder I	Ijsselmuiden	18	70-80%	Tomatoes, cucumbers, peppers	Running	5.4
Greenwell Westland	Honselersdijk	30	65%	Plants & flowers, peppers	Running	10
Maatschap Geobalanz/ Wijnen Geothermie	Grubbenvorst	33	na	Peppers	Running	6
Aardwarmte VOF Den Haag/ Eneco Solar Bio & Hydro B.V.	Den Haag	-	-	Housing	Delayed	na
Ce-Ren beheer/ Floricultura	Heemskerk	13	100%	Orchids	Drilling	na
Aardwarmtecluster Koekoekspolder II	Ijsselmuiden	20	na	Tomatoes, cucumbers	Planning	na
Agriport Warmte VOF/ ECW	Middenmeer	300	15%	Tomatoes, peppers	Drilling	na
A.C. Hartman B.V.	Sexbierum		na	Cucumbers, tomatoes, peppers, aubergines	Planning	na
Aardwarmte Erica B.V.	Erica	73	na	Potted plants, vegetables, flowers	na	15.1

Source: Agentschap NL, 2013

Carbon Trust (2004) presents the Dutch energy use values (kWh/m²) for different crops for a time series 2000-2010 as well as the Dutch technology allowances (kWh/m²) for different technologies. Carbon Trust (2012) presents all the technological options for a greenhouse including quantified energy savings applying different technologies for heating/cooling, lighting etc. either for intensive or extensive cultivations.

Reference literature

- Agritex (2014), Personal communication, www.agritex.gr.
- Benli H. and Durmus A. (2009), Evaluation of ground-source heat pump combined latent heat storage system performance in greenhouse heating, *Energy and Buildings* 41, 220-228.
- Campiotti C. Viola C., Alonzo G., Giagnacovo G., Scoccianti M., Tumminelli G. (2012), Sustainable greenhouse horticulture in Europe, *Journal of Sustainable Energy*, 3(3), 1.
- Carbon trust (2004), Energy Benchmarks and Saving measures for protected greenhouse horticulture in the UK, Queen's Printer and Controller of HMSO, September 2004, Reference ECG091.
- Carbon Trust (2012), Agriculture and horticulture, Introducing energy saving opportunities for farmers and grower, Report reference code: CTV055, available online at: http://www.carbontrust.com/media/39180/ctv009_agriculture_and_horticulture.pdf, last accessed on 14 July 2014.

- Davies P.A., Harris I., Knowles P.R. (2006), Cooling of greenhouses using seawater: a solar driven liquid-desiccant cycle for greenhouse cooling in hot climates, *Acta Horticulturae* 719, 139-146.
- de Gelder A., Poot E.H., Dieleman J.A. and de Zwart H.F. (2012), A concept for reduced energy demand of greenhouses: the next generation greenhouse cultivation in the Netherlands, *Proceedings on GreenSys*, Eds Kittas C. et al., *Acta Horticulturae* 952.
- DEFRA (2008), Comparative life cycle assessment of food commodities procured for UK consumption through a diversity of supply chains, available online at: <http://s360241366.onlinehome.fr/master/Tomatoes>, last accessed on 29th April 2014.
- European Commission. Green Paper, 2006. A European Strategy for Sustainable, Competitive and Secure Energy (COM(2006) 105 final).
- FAO, (2013), Good Agricultural Practices for greenhouse vegetable crops - Principles for Mediterranean climate areas, Kittas et al., *Greenhouse climate control and energy use* (p.63), E-ISBN 978-92-5-107650-7 (PDF).
- Fionia lighting (2012), The LED fixture for the horticultural industry, available online at: <http://www.fionalighting.dk/modules/Filarkiv/upl/FL300%20Fixture%20-%20Technical%20specification.pdf> last accessed on 30 April 2014.
- Fthenakis, V., Alsema, E. - Progress in photovoltaics: research and applications. *Progress in Photovoltaics: Research and Applications*, vol.14, pp.275-280, 2006.
- GEA group (2014), The first greenhouse in the Netherlands without using natural gas, available online at: <http://www.gea.com/en/produktnews/20080514-00191.html>, last accessed on 30 of April 2014.
- Heating demand and transport from warmer climate could be reduced through season extension techniques.
- Nelson P.V. (2002), *Greenhouse operation and management*, Sixth Edition, Prentice Hall, upper Saddle River, new Jersey, USA, 692.
- Panagiotou C. (1996), *Geothermal greenhouse design*, Geothermal Training Programme, The United Nations University, Orkustofnun, Grensasvegur 9, IS-108, Reykjavik, Iceland.
- Pratt C.T., Adams S., Hargreaves D., Jacobson R., (2007), An initial investigation into the potential for using sealed greenhouse technologies in the UK, project number PC256, FEC Services Ltd. & Warwick HRI, available online at: http://www.hdc.org.uk/sites/default/files/research_papers/PC%20256%20final%20report%202007.pdf, last accessed on 8th of May 2014.
- Simmelink E. and Geel K. (2008), Sustainable tomatoes are growing on geothermal heat, TNO Knowledge for business, Available online at: <https://www.tno.nl/downloads/Information20-article%20Geothermal%20energy%20Bleiswijk.pdf>, last accessed on 29 of April 2014.
- Sinke, W. - PV priorities and the Strategic Research Agenda (SRA). PVTP General Assembly, Brussels, 2006.
- Tal A., Segal I., Regev R., Steinfel A., Cohen S., Zer I. (1987), Design procedure for a greenhouse space heating system utilising geothermal warm water, *Energy in Agriculture*, 6, 27-34.
- Turgut B., Paksoy H., Bozdogan S., Evliya H., Abak K., Dasgan H.Y., (2006), Aquifer Thermal Energy Storage Application in Greenhouse Climatization, available online at: http://intraweb.stockton.edu/eyos/energy_studies/content/docs/FINAL_PAPERS/4A-2.pdf, last accessed on 5th May 2014.
- van Aarssen M. (2012), *Geothermal energy in the built environment*, IF Technology, Engineering the earth, available online at: http://www.tue.nl/fileadmin/content/onderzoek/Eindhoven_Energy_Institute_EEI/EnergyDays/Serie_2_2011_2013/2012_11_29/Aarssen.pdf, last accessed on 7th May 2014.
- Vor Zaaken (2009), *Geothermal greenhouses – the Dutch case, low temperatures, high performance*, TNO, available online at: http://www.google.es/url?sa=t&rct=j&q=&esrc=s&source=web&cd=8&ved=0CHeQFjAH&url=http%3A%2F%2Fpromise.klimaatvoorziening.nl%2Fpro1%2Fpublications%2Fshow_publication.asp%3Fdocumentid%3D3017%26GUID%3D2ea55ae2-1686-4b9e-8edb-

[00dbe3b51593&ei=l8hnU5PnD8aS0QX694DwAg&usg=AFQjCNGZ2iFCgfNwjqlUDO84Y1dqOtHSbg&sig2=iC5V1-UY7w4D-hXRAwZGQ](https://doi.org/10.1007/978-1-60876-269-9), last accessed on 28th April 2014.

- Vox G., Teitel M., Pardossi A., minute A., Tinivella F. and Schettini E. (2010), Sustainable greenhouse systems, Sustainable Agriculture, 1-79, ISBN: 978-1-60876-269-9.
- Willemsen A., Godschalk M.S. (2010), Geothermal energy - 20 years of Dutch experience with management of hot and cold groundwater, available online at: <http://www.pai-international.org/documents/MicrosoftWord-managementofhotandcoldwater-GuusWillemsen.pdfmailto:gronia2@yahoo.de>, last accessed on 5th May 2014.

FINAL DRAFT

12.2 Water management in protected horticulture

Description

In order to evaluate the efficiency of irrigation of vegetable crops in Mediterranean greenhouses four aspects should be considered (Gallardo et al., 2013): i. crop water requirements, ii. applied irrigation practices, iii. irrigation scheduling of soil-grown and/or substrate-grown crops and iv. water-use efficiency.

The *crop water requirements* are presented in detail in BEMP 10.1. In particular, for protected horticulture activities the net crop water requirements are considered equal to crop evapotranspiration (ET_c) because rainfall does not enter the greenhouse and thus little moisture depletion occurs (Gallardo et al., 2013). Especially for crops grown in substrates, the crop water requirements of free-draining substrate-grown crops are equivalent to ET_c plus an additional amount of water that prevents salt accumulation. The additional volume of water to prevent salt accumulation is expressed as a percentage of the ET_c and is referred to as the drainage volume.

Irrigation scheduling

Irrigation scheduling (IS) determines the volume of water to be applied and the frequency of irrigation according to the crop water demand and the availability of water in the root zone in the soil or substrate. IS is implemented by soil moisture sensors (especially for crops grown in substrates precise irrigation control systems are required due to the small volume that roots have) in order to implement frequent irrigation with small volumes of water ensuring adequate supplies of water and nutrients. For crops grown in substrate, in order to prevent the root zone from accumulating harmful amounts of salinity, drainage fractions of 20-40% are applied to leach salts from the substrate. The drainage fraction increases with the salinity of applied nutrient solutions (Gallardo et al., 2013; Medrano et al., 2003).

Water-use efficiency

Two commonly-used indicators to assess irrigation efficiency on the farm are water use efficiency (WUE) and application efficiency (AE). WUE is ratio between marketable crop production and amount of applied irrigation water. AE is the ratio between the volume of water that is retained in the soil layer and is used by the crops/plant and the water delivered to the irrigated area. In fact the WE factor quantifies the water losses during irrigation. The watering efficiency of the micro-irrigation systems according to this definition ranges between 90 and 95%.

Applied irrigation practices

Micro-irrigation

Compared to other irrigation application techniques, micro-irrigation is the most efficient irrigation system⁵⁵. The principal components of a micro-irrigation system (Figure 12.6) are a pump, a filtration system, control valves and the delivery system (Barbieri and Maggio, 2013). The most frequent problem is the clogging of the nozzles (emission devices), and thus a filtration system is required. The water delivery systems are: mainlines made in plastic, which convey water from source to the crop, driplines placed along the rows of the crop on which the emitters are connected and the appropriate devices through which water is delivered directly to the root zone of each crop/plant. Regarding the devices, water can be delivered via dripping, bubbling or micro-sprinkling (Barbieri and Maggio, 2013). Fertigation is also possible in micro-irrigation system, by adding nutrients close to the root zones of the plants/crops. However, it should be noted that in drip lines where fertigation is applied, flash (sufficient) clear water could be used (taking care properly the nutrient content) at regular intervals (Barbieri and Maggio, 2013). The most widely used systems are drip lines, systems with drippers, intermittent emitters or capillary tubes. However, it should be noted that the use of automated sprinklers is necessary in climates where, during spring, dangerous frosts can occur, but not in greenhouses (BEMP 10.2).

⁵⁵ However, this technique is limited to substrate grown-crops

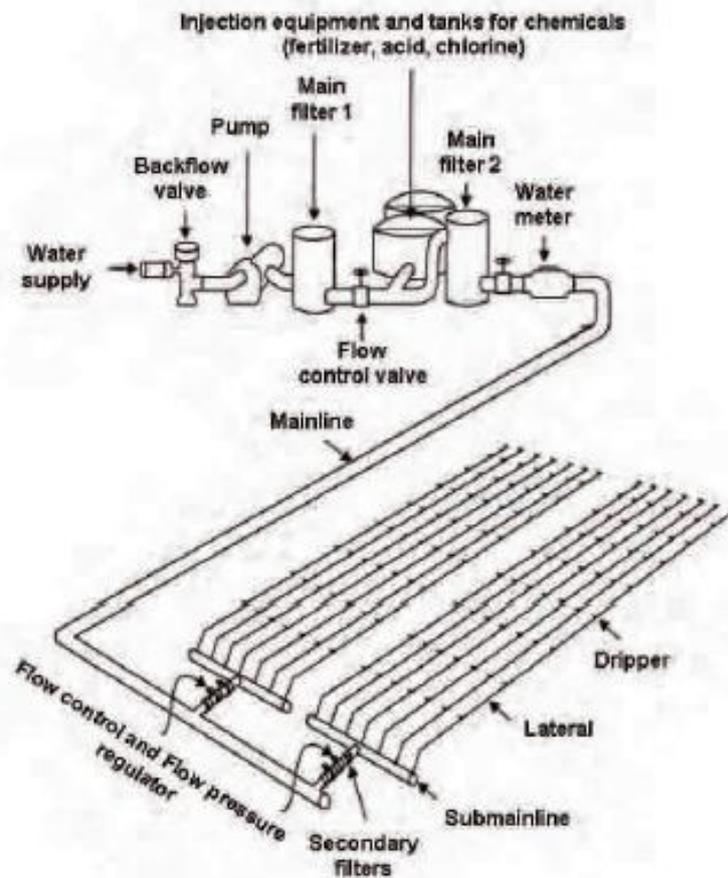


Figure 12.6. A schematic micro-irrigation system (Barbieri and Maggio, 2013).

Closed systems

The closed systems implemented in greenhouses provide the highest economic water use efficiency and thus can afford relatively expensive irrigation water, whilst reduction of fertilizer loss in the environment is achieved. Moreover water use efficiency is maximised by using capillary mats, which are composed by an absorbent fabric lined on the bottom with an impermeable polyethylene film and covered on top with a perforated layer, which minimises the water loss by evaporation (Piatti et al., 2011).

In the closed-loop system the drainage water is captured and recirculated after nutrient replenishment and disinfection in order to reduce the risks of root borne diseases. At specific interval, the recycling water is discharged e.g. to sewage treatment plants etc. and eventually it is replaced by water with a proper nutrient solution. For that reason, these systems are better called 'semi-closed loop systems'.

However, it should be clearly stated that the frequency of the nutrient solution discharge is implemented according to the salinity levels of the irrigation water and the crop tolerance to salt stress (Carmassi et al., 2007; EFSA, 2010). Moreover, in cases where poor quality of irrigation water takes place, the proper system that should be applied is the semi-closed-loop. Figure 12.7 illustrates the concept of an open and semi-closed loop irrigation system for protected cultivations (Massa et al., 2014).

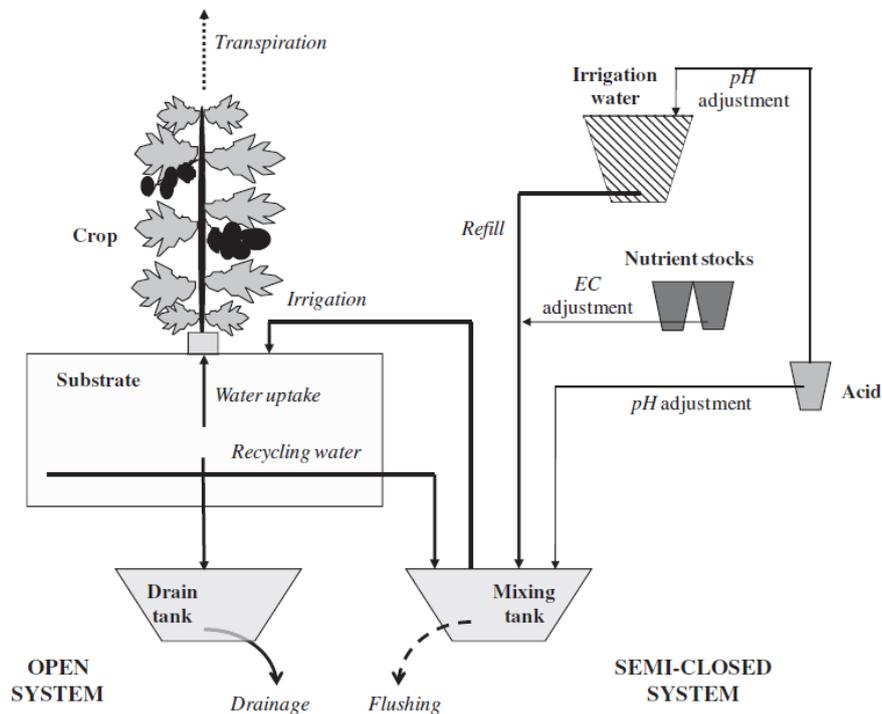


Figure 12.7. Description of the open and semi closed loop system; in open system the drainage water from the substrate is not recirculated, whilst in the semi closed loop systems the recirculating nutrient solution is periodically discharged (Massa et al., 2014).

Protected horticulture depends on water quality of the irrigation applied because crops are sensitive to the water salinity. In addition, the growers have to deal with the increasing pollution because of the use of agrochemical crop protection products. Therefore greenhouse growers are urged to reduce the use of the aforementioned products and to minimise crop emissions, including run-off. Figure 12.8 illustrates the concept of the crop growing in a greenhouse (Hortimed, 2003).

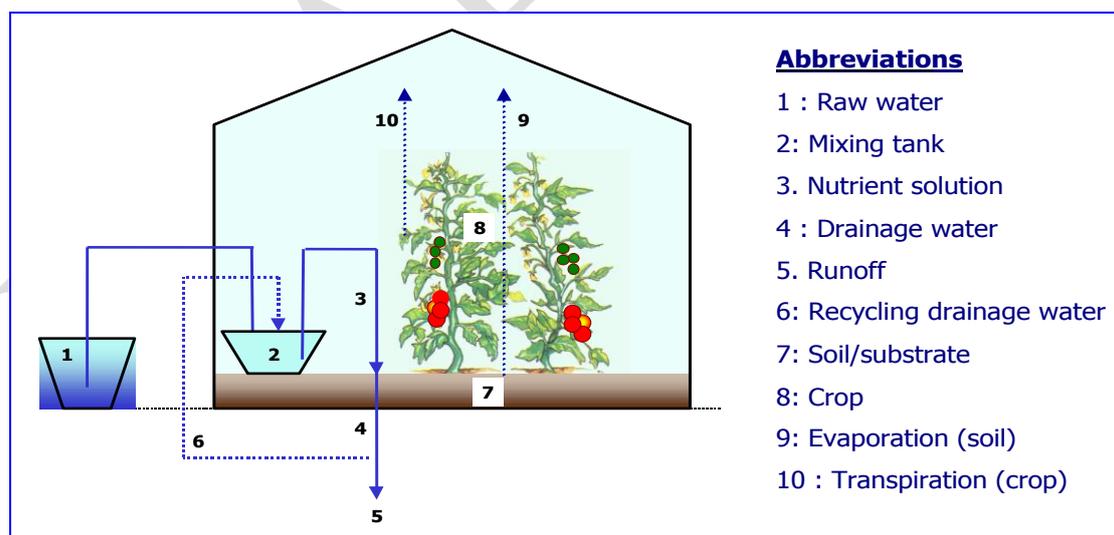


Figure 12.8. Water reaction of greenhouse crops (Hortimed, 2003)

In existing commercial greenhouses, the improvement of WUE depends potentially on yield increase through a better climatic control, crop selection and technical management such as irrigation, fertilisation and pest management as well as by a decrease of water use by applying suitable agronomic methods (see BEMP 10.1) (Hortimed, 2003).

Cross media effects

Where closed-loop irrigation systems are in practice mandatory (e.g. the Netherlands), discharge of water to surface water or sewage treatment plant is allowed when a crop-specific concentration of sodium is reached in the closed loop. According to EFSA (2010), a survey of 561 growers pointed out that approximately 40% acknowledge discharging with some regularity or incidentally; on the other hand the rest growers admitted discharging for reasons other than sodium concentration, which is the only legal reason at present.

If the ground is permeable, then excess irrigation can transport PPPs, leading to potential emissions of PPP to groundwater. If the ground is impermeable (e.g. concrete) or if there is a drainage system in place, then excess irrigation will be routed to surface water rather than vertically downwards

Achieved environmental benefits

As was previously mentioned, micro-irrigation provides high application efficiency compared to other irrigation systems. Therefore, assuming that for every 100 m³ of net irrigation requirements the efficiency is 70% (non micro-irrigation system) and 90% (micro-irrigation) the actual water volume is calculated for both cases ((100m³/0.7=142.9m³) and (100m³)/0.9=111.1m³). Consequently, the water savings can be estimated (31.7m³), which are equal to 28.6% of additional surface for irrigation.

In southern Europe, excessive applications of irrigation are associated with environmental issues such as aquifer depletion, salt water intrusion into coastal aquifers and salinization of aquifers. Appreciably reducing water use by improving application efficiency can reduce the incidence of these negative environmental impacts.

Applicability

Closed systems are technically effective but are financially viable only in the two listed cases: i. in areas with good water quality or ii. where high-value crops are cultivated and offset the costs of ensuring good water quality e.g. rain collection and/or desalination (Stanghellini et al., 2005).

The closed or semi-closed loop systems are applicable in soilless and soil cultivations in greenhouses (EFSA, 2010).

In addition, the legislative framework in many countries (e.g. in southern Europe) does not encourage closed loop systems implementation. Nevertheless in most cases there is a lack of specific legislative framework. Therefore relevant services must be developed in order to spread information about the described cultivation techniques and support growers in adopting those.

Micro-irrigation systems contribute to a rational water use, high uniformity of distribution and high efficiency of application. Regarding the installation of these systems; they must be designed and dimensioned correctly, and water must be applied near the plants to ensure high irrigation efficiency.

Appropriate environmental performance indicators

The main indicators for the soilless cultures are listed below (Pardossi et al., 2011):

- Water use (W):
 - Closed systems: crop water uptake (Wu), which is defined by evapotranspiration (ET) and growth
 - Open and/or semi-closed loop: crop water uptake (Wu), which is defined by evapotranspiration (ET) and growth and drainage (D); especially for this system, D is systematically recirculated but the nutrient solution is discharged in a certain frequency
- Volume of water applied to an individual crop
- Volumes of water used for other purposes e.g. salt leaching, cleaning of irrigation systems

Operational data

Closed loop systems

The annual water uptake for tomato crops in unheated greenhouse grown (open system) in southern climate conditions is approximately 500-600 mm. On the other hand the water and nitrogen losses for open systems are up to 100-250 mm and 150-350 kg/ha respectively. Especially for the nitrogen, the mean nitrogen concentration is considered of 10 mM in the nutrient solution for fertigated cultivation. In areas where the water for irrigation has high levels of salinity, the application of semi-closed loop systems reduces up to 60-80% the loss of water and 75-95% the leaching of nutrients depending on different followed strategies when comparing with open systems (Massa et al., 2010). However, in areas where the salinity level of the irrigation water is low, the reduction in water and nutrient losses are 100% and approximately 90-95% respectively.

The discharge frequency rate of the nutrient solution is usually from 5 to 10 days and the drainage fraction might be the same with a well-managed open system (Carmassi et al., 2007).

More operational data regarding the application of closed loop systems in soilless cultivations in greenhouses are presented in table 1 from a commercial greenhouse in Tuscany, Italy (Pardossi et al., 2011).

The tomato cultivations were cultivated before 2010 in an open system. Since then the crops were fertigated according to the growers' protocol. After the application of the closed loop system, the suitable amount of a different nutrient solution was distributed to the plants respecting the previous used substances in the open culture aiming at maintaining constant the nutrient concentration in the root zone (Pardossi et al., 2011). The used water for irrigation had in the target area low NaCl concentration like less than 2.5 mol m⁻³ meaning that the nutrient solution was never discharged. Eventually, the application of this closed loop system resulted to water savings by 21% and nutrients in a range of 17-35%. In addition, comparing to the previous open system, it was possible to minimise/eliminate the nutrient leaching. The operational data of this greenhouse are illustrated in Table 12.5 (Pardossi et al., 2011).

Table 12.5. Operational data for the greenhouse in Tuscany; benefits from the application of closed loop system (Pardossi et al., 2011)

Parameter	Unit	Open system	Closed system	Savings
<i>Fruit yield</i>				
Commercial yield	kg/m ²	19.9	19.6	
Total soluble solids	°Brix	4.4	4.5	
<i>Water</i>				
Use	m ³ /ha	8,632	6,831	21%
Drainage	m ³ /ha	1,682	0	100%
Crop uptake	m ³ /ha	6,950	6,831	2%
<i>Nitrogen</i>				
Use	Kg/ha	1,591	1,032	35%
Leaching	Kg/ha	266	0	100%
Crop uptake	Kg/ha	1,325	1,032	22%

Data regarding crop water requirements (kc and ETc values for various vegetable crops can be retrieved from BEMP 10.1). The operational data of the micro-irrigation (drip) system are presented in BEMP 10.2 (under the description and the operational data section).

Water use and irrigation management

The irrigation water use efficiency (WUE) is expressed as the ratio between marketable crop production and total irrigation supply. In greenhouses, the WUE is higher than in open fields because of the lower evaporation inside the greenhouse and the higher productivity of the crops. In particular,

for tomatoes growing in the Netherlands in a closed greenhouse (with recirculation of nutrient solution), reported WUE values range from 45 to 66 kg/m³, while in Almeria WUE values range from 15 kg/m³ (for autumn winter grown green beans) to 36 kg/m³ for species like spring grown watermelon (Fernandez et al., 2007; Pardossi et al., 2004; Gallardo et al, 2007; Stanghellini et al., 2003; Gallardo et al., 2013). Values for WUE are presented in Table 12.6.

Table 12.6. WUE of tomato crops grown in different countries and ways (Stanghellini et al., 2003; Pardossi et al., 2004; Fernandez et al., 2007; Gallardo et al, 2007; Gallardo et al., 2013)

Cropping conditions	Country	WUE (kg/m ³)
<i>Open field</i>		
Soil	Israel	17
Soil	France	14
Soil processing tomato	Spain (Extremadura, Rioja)	7.4-8.5
<i>Unheated plastic greenhouse</i>		
Soil	Israel	33
Soil	France	24
Open substrate	Italy	23
Closed substrate	Italy	47
Sandy soil – traditional greenhouse		25
Sandy soil – improved greenhouse		35
Substrate short season	Spain (Almeria)	27
Substrate long season		35
<i>Glasshouse-climate controlled</i>		
Substrate open system	Netherlands	45
Substrate closed system		66

Additionally, the efficiency is improved by optimising the distribution uniformity (DU) of the water flow between the emission devices and avoiding the accumulation of excessive water as well as over pressures in the piping system. Typical values for the DU are listed below (Barbieri and Maggio, 2013):

> 87%	excellent	75-87%	good uniformity
62-75%	acceptable	< 62%	unacceptable

Economics

Given the fact that closed systems require high quality water for irrigation, a price structure strategy of it should be compiled. In particular, when the optimisation of the costs pushes towards poorer irrigation water quality, then the closed systems cannot be achieved (Stanghellini et al., 2007).

In view of the environmental impact, it would be advisable for irrigation and local authorities in horticultural areas either to provide good water at a high price or to consider subsidizing investment costs of on-site desalinization plants, rather than stimulating use of poor quality water, or attempting to prevent pollution through regulation that may be both un-economical and un-enforceable, since there is no way that low-value crops using poor irrigation water may still be profitable under stricter environmental rules. This means that local authorities, seriously planning to enforce such rules, should either provide incentives for growers to switch to less sensitive or more valuable combinations of crops, or contemplate developing other economic activities than agriculture (Stanghellini et al., 2007). Moreover to tackle the main environmental problems caused by over-irrigation a proper pricing of the irrigation water must be established. In particular, in the selected water strategy it should be reflected that savings water through the application of the closed loop systems and use of water for irrigation of lower quality is the best environmental management practice for growers (Stanghellini et al., 2005). The operational costs for both semi-closed and closed loop systems cannot be reported because of the different prices in the water supply. Through the application of semi-closed

and/or closed loop systems a significant part of the drain water will not be washed away resulting in fertilizers reuse. Hence, a reduction of the amount of used fertilizers is achieved. Therefore according to Montero et al., (2012) a cost reduction of 0.20 €/m² or 2,000 €/ha/year is achieved when 30% of fertilizers are saved. The extra investment costs and other relevant economic data for installing a fertigation system in an existing greenhouse in Pisa, Italy are reported in Table 12.7.

Table 12.7. Economic data for the installation of closed fertigation systems (CFS) in an existing greenhouse in Pisa, Italy (Montero et al., 2012).

Cost	Extra investment	Depreciation	Maintenance interest	Other costs	Fertilizer savings	Balance of benefit-cost	Depreciation period
<i>Unit</i>	<i>€/ha</i>						<i>Year</i>
CFS	7,500	750	565	1,200	4,650	2,135	3

From the economic point of view, closed systems are also profitable.

Driving forces for implementation

Water savings contribute to the reduction of operation costs. Therefore by establishing an efficient water management system there are various benefits. Moreover, especially for cases where the amount of underground water is scarce, an appropriate water management system is required.

Reference organisations

The application of closed substrate culture to greenhouse tomato cultivation was tested in a commercial greenhouse in Tuscany, Italy (Pardosi et al., 2011).

The operating costs regarding the water use/consumption vary among the member states. The potential economic benefits from the installation of an efficient irrigation system are multiple and they are the main driving forces for establishing an efficient irrigation system in a greenhouse. In addition the limited water resources in Southern Mediterranean areas require efficient water management to maintain high production and to prevent depletion of limited water resources.

Reference literature

- Barbieri G. and Maggio A. (2013), Micro-irrigation, in FAO 2013, Good Agricultural Practices for greenhouse vegetable crops - Principles for Mediterranean climate areas, ISBN 978-92-5-107649-1.
- Carmassi G., Incrocci L., Maggini R., Malorgio F., Tognoni F. and Pardossi A. (2007), An aggregated model for water requirements of greenhouse tomato grown in closed rockwool culture with saline water, *Agricultural Water Management* 88, 73-82.
- EFSA (2010), Scientific opinion on emissions of plant protection products from greenhouses and crops grown under cover: outline for a new guidance, EFSA panel on plant protection products and their residues, *Scientific opinion*, EFSA journal 8(4), 1567.
- Fernandez M.D., Gonzalez A.M., Carreno J., Perez C. and Bonachela S. (2007), Analysis of on-farm irrigation performance in Mediterranean greenhouses, *Agricultural Water Management*, 89, 251-260.
- Gallardo M., Fernandez M.D., Thompson R.B. and Magan J.J. (2007), Productividad del agua en cultivos bajo invernadero en la costa mediterránea, *Vida Rural*, 259, 48-51, in Spanish.
- Gallardo M., Thompson R.B. and Fernandez M.D. (2013), Water requirements and irrigation management in Mediterranean greenhouses: the case of Southeast coast of Spain, in FAO 2013, Good Agricultural Practices for greenhouse vegetable crops - Principles for Mediterranean climate areas, ISBN 978-92-5-107649-1.

- Hortimed (2003), Water management in greenhouse crops how to improve water use efficiency and reduce environmental pollution, INCO-MED Project HORTIMED “Sustainable water use in protected Mediterranean horticulture” (2000-2003), contract number project: ICA3-1999-00009.
- Massa D., Incrocci L., Maggini R., Bibbiani C., Carmassi G., Malrogio F. and Pardossi A. (2014), Simulation of crop water and mineral relation in greenhouse soilless culture, *Environmental Modelling and Software* 26, 711-722.
- Medrano E., Lorenzo P. and Sanchez-Guerrero M.C. (2003), Irrigation scheduling in soilless culture, in M. Fernández, P. Lorenzo and I.M. Cuadrado, eds. *Improvement of water use efficiency in protected crops*, p. 301–320, advanced specialization course, Dirección General de Investigación y Formación Agraria de la Junta de Andalucía, HortiMed, FIAPA, Cajamar, Spain.
- Montero J.I., Antón A., Torrellas M., Ruijs M. (2012), Report on economic & environmental profile of new technology greenhouses at the three scenarios, EUPHOROS project, project code: KBBE- 2007-1-2-04.
- Pardossi A., Carmasi G., Diara C., Incrocci L., Maggini R. and Massa D. (2011), Fertigation and substrate management in closed soilless culture, EUPHOROS project, project code KBBE-2007—2-04.
- Piatti R., Frangi P. and Amoroso G. (2011), Alternative nursery management systems: closed-loop and high retention mat, in proceedings of 6th IS on Irrigation of Hort. Crops, Eds.: S. Ortega-Farías and G. Selles, *Acta Hort.* 889, 581-586, ISHS.
- Stanghellini C., Kempkes F., Pardossi A. and Incrocci L. (2005), Closed water loop in greenhouses: effect of water quality and value of produce, in proceedings IC on Greensys, eds: van Straten et al., *Acta Hort.* 691.
- Stanghellini C., Kempkes F.L.K. and Knies P. (2003), Enhancing quality in agricultural systems, *Acta Hort.*, 609, 277-283.
- Stanghellini C., Pardossi A. and Sigrimis N. (2007), What limits the application of wastewater and/or closed cycle in horticulture? In proceedings VIIIth IS on protected cultivation in mild winter climates, EDS: A. Hnafi and W. H. Schnitzler, *Acta Hort.* 747, ISHS.
- UNESCO (2006), Non-renewable groundwater resources: A guidebook on socially sustainable management for water-policymakers. IHP-VI, Series on Groundwater 10, 103.

12.3 Waste management in horticulture

Description

Different fractions of waste like plastic (packaging materials and plastic coverings), steel (construction materials used for the supported cultivations) and biomass are generated in greenhouse production (Antón et al., 2005). In southern Europe, plastic cladding which is often changed every 2-4 years creates a large amount of waste material. Segregation at source is definitely a best practice for managing the waste generated in a greenhouse.

Several and various kind of plastic materials are used for the greenhouse activities where after the harvest period those plastics become waste requiring appropriate treatment. Moreover in some particular cases, the collection and the recycling is a difficult task (Chelma, 2013). Several researchers have reported the amounts of different waste streams generated in a greenhouse.

Antón (2004) reported the amount of waste generated by tomato grown in a greenhouse (Table 12.8). Gomez (2008) reported that the residual biomass generation from horticultural crops in four towns in southeastern (SE) Spain is significantly higher compared to the Municipal Solid Waste (MSW) generation rate (Figure 12.9). In particular, in town of El Ejido in SE Spain, biomass generation from horticultural crops was 10.87 kg/person/day, while the MSW rate in Spain was approximately 1.38 kg/person/day (reference year 2007).

Table 12.8. Waste generated by tomato cultivation in a greenhouse (Antón, 2004)

Waste streams	Unit (g/kg per tomato crop)
Biomass (dry fraction)	43.5
Low density polyethylene (i.e. greenhouse cover)	6.79
Polyethylene (i.e. watering equipment)	5.9
Polystyrene (i.e. benches)	2.9
Steel (greenhouse structure)	13.3

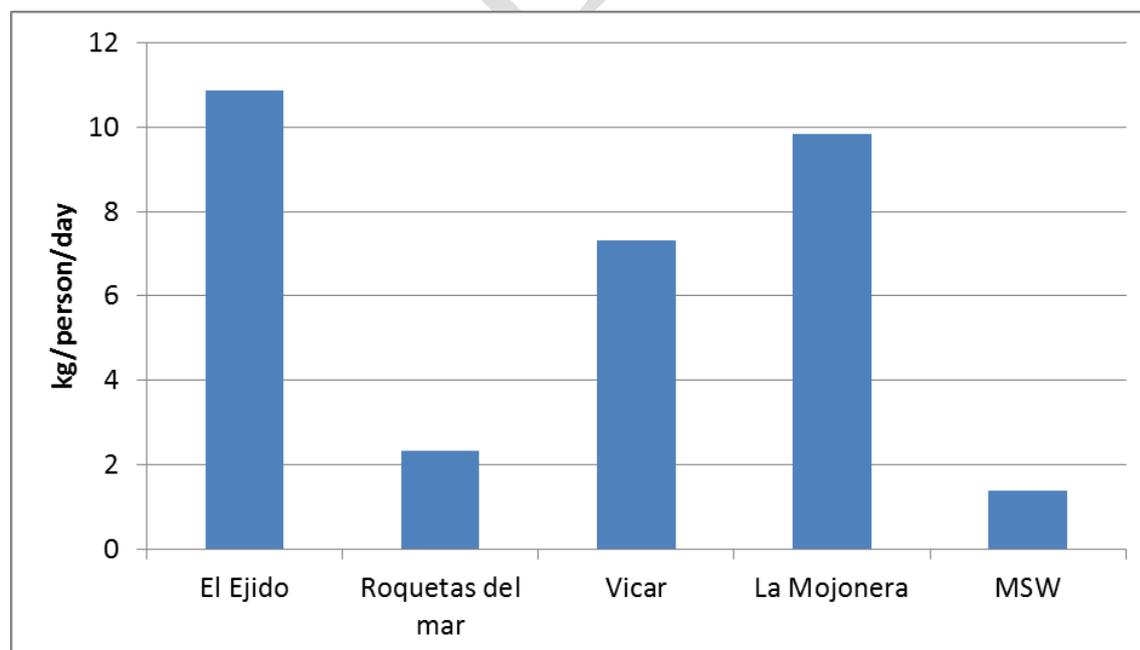


Figure 12.9. Residual biomass generation from horticultural crops in the main towns; comparison with the MSW generation rate (Gomez, 2008)

Residual biomass

The best practice for managing the residual biomass from horticultural crops is composting⁵⁶. The quality of the produced compost plays a critical role. For instance, low quality compost can increase the eutrophication impacts due to the potential leaching of nutrients (Antón et al., 2005). A high quality compost (which is produced by the residual horticultural biomass) can be further used as soil amendment or mulch taking into account that it does not compromise the future sustainable use of the soil to which it is applied (WRAP, 2012). Moreover, biomass residuals can also be used for the manufacture of peat-free substrates, which improve the soil composition (Campden Bri, 2013; Mazuela et al., 2012). A consideration regarding composting of biomass residues is the presence of nylon cords used to vertically support crops, as are used in SE Spain. As much of this nylon cord should be removed as possible prior to composting.

Plastic waste

The current intensive and semi-intensive agricultural practices throughout Europe require large quantities of plastics. Chelma, (2013) reported that agriculture and horticulture are responsible for a consumption of some 1,500,000 t/year of all kind of polymers in Europe. In addition, more than 130,000 t/year mulching films are consumed per year in Europe and 2,600,000 t/year worldwide for the time period 2003–2005⁵⁷.

The management of plastic waste among member states varies significantly. In France 28% of agricultural plastic waste films and 45% of chemicals packaging are mechanically treated. However, in Denmark 100% of agricultural plastic waste films and 100% of chemical packaging are incinerated with energy recovery and treated by pyrolysis respectively (Briassoulis et al., 2013).

Appropriate waste collection schemes exist for farms/greenhouses. As far as waste, plastics like rinsed pesticide containers, fertiliser bags etc. are concerned, must be managed in a registered waste disposal/treatment site. Farmers must separate them and store them properly avoiding leaching incidents and avoiding direct and/or indirect contact with soil/plants/water. Afterwards, the separated materials are collected by special companies that are licensed to manage these special waste streams. The first treatment is the decontamination, removing/cleaning all the hazardous substances and then plastics are further treated (Briassoulis et al., 2014). After the decontamination process, these materials are used for the production of other plastic materials e.g. plastic furniture outside from Europe in Africa and/or Asia.

Garthe and Kowal (1994) categorised the recycling process of agricultural plastics into four stages. The collection stage is the first stage. As was previously mentioned, farmers should segregate their waste at source. The collection of materials can be implemented by various ways, e.g. curbside pick-up, buyback locations, or drop-off locations. The next stage is handling and storage sorting the contaminated materials from the non-contaminated. Afterwards the collected non-contaminated (or recyclable) plastics are conditioned for re-use. The final stage in the recycling process is the production and sale of a usable product made from the recycled plastic (Hurley, 2008). Briassoulis et al., (2013) classified agricultural plastics in two categories: (i) those were plastic waste can become high quality pellets and (ii) materials with good mechanical properties for supporting solid profiles. As it is shown in table 12.9, plastic films are used for several purposes in greenhouses. Plastic coverings for the protection of the cultivated crops, and pots for cultivating new plants/crops are used. Additionally, plastic films are often used in the greenhouses for mulching of the soil in order to improve the cultivation conditions and to control the water content and temperature of soil layer under the covering. The mulching film reduces water evaporation and weed growth.

Plastic parts like greenhouse films, packaging materials from products (i.e. from fertilisers) may be recycled, but another part of the agricultural plastic waste is difficult to recycle for technical and/or financial reasons. In particular, mulching films and covering materials have a low-recyclability

⁵⁶ The residual biomass can also be sent to an adjacent Anaerobic Digestion plant for further treatment.

⁵⁷ The use of plastic coverings in Europe for non-energy efficient greenhouses is approximately 72,000 t/year.

because they are contaminated with soil duct and possibly with agro-chemicals (Chelma, 2013; Biodeg, 2014).

Given the afore-mentioned situation, use of bio-based plastics is definitely a best practice. Two different kind of bio-based plastics exist: (i) biodegradable and (ii) bio-based polymers. Regarding biodegradable plastics, these are fabricated by a process in which the degradation process is implemented using micro-organisms such as bacteria, fungi, and algae. On the other hand, from 2008 onwards, bio-based polymers are moving into main-stream use for many applications (packaging being the dominant one), and the polymers based on renewable “feedstock” (like agricultural biodegradable resources) may soon be competing with commodity plastics, as a result of the sales growth of more than 20–30% per year (Chelma, 2013).

Therefore plastic mulching films that cannot be collected from the soil may be replaced with biodegradable ones, which will decompose in the soil after being used toxic or polluting residues (Chmela, 2013; Corbin, 2013).

In 2006 the reported amount of bio-based plastics used in the agricultural sector in Europe was approximately 2,000 t/year. However, their use is increasing for specific applications in the agricultural sector (Chmela, 2013).

In 2011, 4,000 ha of agricultural land were covered by biodegradable mulching plastic materials where their life span ranged from 60 days to 6 months (Mugnozza et al., 2011).

Pots

A significant amount of plastic materials used in greenhouses is in containers or nursery pots. Several studies report that growers have the willingness to pay a higher price for biodegradable plastic materials in containers, pots etc. (Hall et al. 2010; Yue et al. 2010; Knox and Chapell, 2011). It is reported that every year, 3 billion flowerpots are used in the Netherlands. The flowerpots are constructed from Poly Propylene (known as PP) and consist mainly of recycled materials. For the construction of the flowerpots every year in the Netherlands 30 kt of PP are required. It should be highlighted that these materials have to be disposed of after use.

In particular, the use of bio-plastics and biodegradable plastics is applied in products like films for banana bushes, and plant pots for cultivation like herbs (European bio-plastics, 2014).

Achieved environmental benefits

The use of biodegradable plastics for mulching provides environmental benefits. Soil contamination with pieces of plastic is reduced and the generation of litter is reduced as well.

The waste segregation at source significantly reduces environmental impacts and particularly GHG emissions.

Appropriate environmental performance indicators

The appropriate environmental indicators are listed below:

- Reuse or recycle of the used packaging materials (%)
- Waste generated (kg/m²/year)
- Waste diversion from final treatment/disposal (%)
- Use of any kind of bio-plastic materials like coverings, pots etc. (%)
- Compost production (kg/ha or as a proportion % out of the total biomass production)

Operational data

Bio-based plastics

The characteristics of the biodegradable materials are used in greenhouses are listed below (Chmela, 2013):

- Foils thickness 12 – 80 µm (for mulching the thinner one is the appropriate and for covering the thicker)
- Width up to 3 m
- Lifetime 2-4 months
- Colorless or pigmented (carbon black)

Summarising the technical characteristics of the bio-based plastics, and especially for mulching materials; at the end of their lifetime the biodegradable materials remain in the soil and no further treatment (even treatment in a composting plant) is required. The biodegradable materials are decomposed in the soil by micro-organisms (bacteria etc.) and they are converted into GHG emissions, water and biomass, without hazardous fractions (Scarascia-Mugnozza et al., 2011).

Various experimental tests have been performed to investigate the efficiency of the biodegradability of bio-based plastic materials. The average lifespan of these materials is reported from 1 to 4 months but can last up to 6 months depending on the climatic conditions and the application of soil additives or nutrients. Regarding efficiency of biodegradation, it was found that after one year less than 4% of the initial weight of the material remained in the underground soil without any indication of ecotoxicity (Scarascia 2004; Scarascia 2006; Scarascia-Mugnozza et al., 2011).

Mulching

Mulching is an efficient technique when drip irrigation is applied and is used in order to protect the young plants. When the mulching technique is applied, the soil temperature is increased due to the reduction of water evaporation and heat losses by radiation and convection. Mulching is applied using light films of thin biodegradable plastic films, which are mechanically laid on the soil (Schettini, 2008; Scarascia-Mugnozza et al., 2011). A drip tube is applied on the soil surface under the mulch or buried 5-8 cm under the soil surface. This tube should be installed prior to the mulch film with the emitter holes oriented upward and without excessive stretching. The edges of the mulch film must be secured by adding a reasonable amount of soil so as to make it difficult to move (McCraw and Motes, 2013).

Containers and pots

A representative example of a greenhouse that produces young vegetable and strawberry plants herbs for cooking and using biodegradable containers and pots is the Austrian company called Gartenbau Auer. The total surface consists of 2.5 ha of greenhouses, 0.5 ha of polythene tunnels and 6 ha of open ground cultivations. The cultivation is organic and the final products are sold to retailers in Germany, Austria and Slovakia. Its retail chain requires 100% biodegradable packaging, so the greenhouse company uses only biodegradable materials for pots and containers (Desch plantpak, 2014).

Non-packaging plastics-storage

Farmers should store their non-packaging plastic waste properly before their final destination/treatment. Below, some advice for the storage of these materials is listed (WRAP, 2009):

- Remove silage wraps before transporting bales to feeding areas and store on concrete
- Protect the non-packaging plastic waste materials from UV radiation and wind to avoid creating litters and increasing the possibility of contamination
- Smoking must be prohibited in storage areas to minimize the possibility of fire risk as well as appropriate fire security system is necessary to be installed
- Compaction of the plastic waste decreases the speed of a potential fire would spread
- Keep storage times to a minimum

Due to the fact that collectors can do little to improve the quality of the collected plastics, farmers must segregate their waste as much as they can by applying the previously-mentioned rules/instructions (WRAP, 2009).

Applicability

The use of bio-plastics is applicable to all the greenhouse cultivations taking into account the listed criteria (Chelma, 2013):

- Complete biodegradation (not simply disintegration): biodegradable efficiency >90%
- Duration: depending on the application and the cultivation
- No remains of heavy metals or other harmful chemical elements: no ecotoxic effects

Cross media effects

There is still an open discussion regarding mulching, and in particular of biodegradation in soil and on-farm composting (Scarascia-Mugnozza et al., 2011).

Economics

The current cost of the bio-based and biodegradable plastics compared to the conventional ones in certain applications is still high.

Driving force for implementation

The composting of the residual horticultural biomass contributes to improvement of soil properties, by increasing the organic fraction and improving water retention. In addition, the rational management of plastic waste, which are generated within the greenhouse can prevent environmental contamination and minimize impacts on human health from hazardous substances

Reference organisations

Commercially available biodegradable mulches are listed below:

- AGROERG S (ERG Bieruń-Folie Sp. z o.o., Poland), based on PE
- Plastic Suppliers Inc., EarthFirst® PLA
- Rootplast International Inc., Ohio, USA
- Waste not, Marchant Manufacturing Co. Ltd., UK
- BAYER AG „BAK“ (polyester amide family of biodegradable resins for agriculture applications, Germany)
- Baoding Fengba Modern Agricultural Facility Co., Ltd.,
- MATER Bi ® (Novamont, Italy)

Reference literature

- AIAB (2011), Mater-Bi® products recommended by AIAB, available online at: <http://www.novamont.com/detail.asp?c=16&p=1&id=10910>, last accessed on 15th May 2014.
- Antón A. (2004), Utilización del Análisis del Ciclo de Vida en la Evaluación del Impacto ambiental del cultivo bajo invernadero Mediterráneo, Programa d'Enginyeria Ambiental, Universitat Politècnica de Catalunya, Barcelona (in Spanish), available online at: <http://www.tdx.cat/bitstream/handle/10803/6827/01PREVIS.pdf?sequence=1>, last accessed on 14 of May 2014.
- Anton M.A., Muñoz P., Castells F., Montero J.I. and Soliva M. (2005), Improving waste management in protected horticulture, *Agron. Sustain. Dev.* 25, 447–453
- Biodeg (2014), Agriculture and horticulture, Protecting the Environment through Oxo-Biodegradable Plastic, Position papers, available online at: <http://www.biodeg.org/position-papers/agriculture-and-horticulture>, last accessed on 14 May 2014.
- Briassoulis D., Hiskakis M. and Babou E. (2013), Technical specifications for mechanical recycling of agricultural plastic waste, *Waste Management*, 33, 1516-1530.

- Briassoulis D., Hiskakis M., Karasali H., Briassoulis C. (2014), Design of a European agrochemical plastic packaging waste management scheme - Pilot implementation in Greece, *Resource, Conservation and Recycling*, 87, 72-88.
- Campden Bri, (2013), Factsheet: Low carbon horticulture, low Carbon Farming, available online at: <http://www.soilassociation.org/LinkClick.aspx?fileticket=Gy10DxgTF1M%3D&tabid=1482>, last accessed on 14 July 2014.
- Chmela S. (2013), Mulching foils – photochemical, hydrolytical and biodegradation, Polyfriend, Advanced bio-friendly polymers, September 5, Bratislava, Slovakia.
- Corbin A., Cowan J., Miles C., Hayes D., Dorgan J. and Iglis D. (2013), Using biodegradable plastics as agricultural mulches, Washington state university extension fact sheet, publication reference: FS103E, available online at: <http://cru.cahe.wsu.edu/CEPublications/FS103E/FS103E.pdf>, last accessed on 20 May 2014.
- Desch Plantpak, (2014), Growing together, available online at: <http://www.desch-plantpak.com/pdf/Desch-2013-2014-en.pdf>, last accessed on 18 May 2014.
- European bio-plastics, (2014), Agriculture and horticulture, available online at: <http://en.european-bioplastics.org/market/applications/agriculturehorticulture>, last accessed on 18 May 2014.
- Garthe J. and Kowal P. (1994), Recycling Plastics: The Process and Terms. Agricultural and Biological Engineering Solid Waste Management Bulletin C-10, Penn State University Cooperative Extension, University Park, PA.
- Gomez S.P.(2008), protected horticulture and environment, an integral decision model for greenhouse waste management in southeastern Spain, in proceedings from: 107th EAAE Seminar "Modeling of Agricultural and Rural Development Policies", Sevilla, Spain.
- Hall C., Campbell B., Behe B., Yue C., Dennis J. and Lopez R. (2010), The Appeal of Biodegradable Packaging to Floral Consumers, *HortScience* 45(4), 583–591.
- Hurley (2008), Postconsumer agricultural plastic report, California Integrated Waste management Board, California Environmental Protection Agency, Publication number: #IWMB-2008-019.
- Kasirajan S. and Ngouajio M. (2012), Polyethylene and biodegradable mulches for agricultural applications: a review, *Agronomy for Sustainable Development*, 32(2), 501-529.
- Knox G.W. and Chappell M. (2011), Alternatives to Petroleum-Based Containers for the Nursery Industry, University of Florida, IFAS Extension, reference number: ENH1193, available online at: <https://edis.ifas.ufl.edu/ep454>, last accessed on 15th May 2014.
- Mazuela P., Urrestarazu M. and Bastias E. (2012), Vegetable Waste Compost Used as Substrate in Soilless Culture, *Crop Production Technologies*, Dr. Peeyush Sharma (Ed.), ISBN: 978-953-307-787-1, InTech, Available from: <http://www.intechopen.com/books/crop-production-technologies/vegetable-wastecompost-used-as-substrate-in-soilless-culture>
- McCraw D. and Motes J.E. (2013), use of plastic mulch and row covers in vegetable production, Oklahoma Cooperative extension service, publication code: HLA 6034, available online at: <http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-1099/F-6034%20web.pdf>, last accessed on 15th of May 2014.
- Mugnozsa G.S., Sica C., Russo G. (2011), Plastic materials in European agriculture: actual use and perspectives, *J of Ag. Eng. - Riv. di Ing. Agr.* 3, 15-28.
- Schettini E., Vox G., Candura A., Malinconico M., Immirzi B., Santagata G. Starch-based films and spray coatings as biodegradable alternatives to LDPE mulching films, *Acta Horticulturae*, 2008, 801(1), 171-179.
- WRAP (2009), Non-packaging materials plastics, Environmental good practice guide for the collection of non-packaging plastics, Waste and Resources Action Programme, Environment Agency, available online at: http://www.wrapni.org.uk/sites/files/wrap/Good_Practice_Guide_for_non-packaging_plastics.cc7_6943.pdf, last accessed on 14 July 2014.
- WRAP (2012), Compost, end of waste criteria for the production and use of quality compost from source-segregated biodegradable waste, Environmental Agency, reference report code: GEH00812BWPL-E-E.

- Yue C., Hall C.R., Behe B.K., Campbell B.L., Dennis J.H. and Lopez R.G. (2010), Are Consumers Willing to Pay More for Biodegradable Containers than for Plastic Ones? *Journal of Agriculture and Applied Economics* 42(4), 757–772.

FINAL DRAFT

13 CONCLUSIONS

13.1 Specific conclusions

The conclusions, gathered on this SRD, have been derived by expert judgement, performed by the European Commission through the JRC (Institute for Prospective and Technological Studies), and by the TWG. This group was composed of researchers, farm advisors, umbrella associations, verification bodies, accreditation bodies, and the European Commission, who organised and chaired the meetings of the TWG.

The conclusions on the environmental performance indicators and benchmarks of excellence were drawn at the second meeting of the TWG in June 2014. There was consensus and no split views were recorded.

13.2 Best environmental management practices: Environmental performance indicators and benchmarks of excellence

In this SRD, best practices are described in detail from Chapter 3 to Chapter 12. Table 13.1 summarises the environmental performance indicators and the benchmarks of excellence for each BEMP. Their environmental performance has been evaluated in technical detail along with economic considerations. The described practices address the most important environmental aspects of the Agriculture sector – Crop and animal production, both direct and indirect. Following the preamble of the EMAS regulation, the aim of this SRD is to help farms (organisations or companies) to better focus on the most important environmental aspects of the sector.

Moreover, the applicability of each BEMP is further explained in Table 13.2.

Both tables 13.1 and 13.2 can be used as a stand-alone material.

Table 13.1: Overview of the key environmental performance indicators and benchmarks of excellence

BEMPs	Benchmarks of excellence	Key environmental performance indicators ⁵⁸
3.1. Strategic farm management plan	<p>The farm is managed according to a strategic management plan that:</p> <ul style="list-style-type: none"> i. considers a time period of at least five years; ii. improves the sustainability performance of the farm in three dimensions: a. economic, b. social and c. environment iii. considers ecosystem services delivery in a local, regional and global context using appropriate, simple indicators described throughout this report 	<p>Accreditation schemes such as LEAF Marque, Global G.A.P., Swedish Climate Label for Food, etc. Ecosystem services indicators e.g biomass production, water quality, soil infiltration capacity etc.</p>
3.2. Embed benchmarking in environmental management	<p>Relevant indicators are applied to benchmark the performance of individual processes, and the entire farm system, against all relevant best practice benchmarks described in this report</p> <p>Permanent staff participates in mandatory training environmental management programs at a regular intervals; in temporary staff information on environmental management objectives is provided as well as training on relevant actions</p>	<p>Key indicators in areas: Water e.g. irrigation m³/ha/year Energy e.g. field energy (L diesel/ha/year) GHG emissions e.g. farm and/or product carbon footprint kg CO_{2e}/kg product or per year Animal feed e.g. feed conversion ratio % Manure management e.g. anaerobic digestion % slurry Waste e.g. kg/ha/year waste generated Biodiversity e.g. native species – number</p>
3.3. Landscape water quality management	<p>Catchment sensitive farming is implemented via all applicable BEMP techniques described in this report (Table 3.6)</p> <p>Buffer zones comprising of at least 10 m in width are established adjacent to all water courses, where tillage and grazing are excluded</p> <p>Farmers work collaboratively with neighbouring farmers and river basin managers from relevant authorities to minimise risk of water pollution, for example through the establishment of strategically located integrated constructed wetlands</p>	<p>Soil nutrient concentrations (mg/kg) Visible signs of erosion or runoff Width of buffer strips (m)</p>
3.4. Landscape scale biodiversity management	<p>A biodiversity action plan is implemented on the farm, to maintain and enhance the number and abundance of locally important species</p>	<p>N application rate (kg/ha/year) Key species abundance metrics (no./m²)</p>
3.5. Energy and water efficiency	<p>An energy management plan must be implemented and revised every five years, to include: (i) Mapping of direct energy consumption across major energy-consuming processes; (ii) Mapping of indirect energy consumption via fertiliser and animal feed consumption; (iii)</p>	<p>Total primary energy use (e.g. kWh or L diesel per tonne product) water footprint m³ (blue, green, grey – depending on the water footprint)/tonne product</p>

⁵⁸ The full list of environmental performance indicators is placed in the text of each BEMP.

BEMPs	Benchmarks of excellence	Key environmental performance indicators ⁵⁸
	<p>Benchmarking energy consumption per hectare or animal unit; (iv) Energy efficiency measures; (v) Renewable energy measures.</p> <p>A water management plan must be implemented and revised every five years, to include: (i) Mapping of direct water consumption by source across major processes; (ii) Benchmarking water consumption per hectare or animal unit; (iii) Water efficiency measures; (iv) rainwater harvesting.</p>	
3.6. Waste management	Reduce, re-use, recycle and recover waste arising so that no waste is sent to landfill	<p>Waste arising by type (t/ha/year)</p> <p>Percentage of waste sent to landfill (%)</p> <p>Percentage of waste separated into recyclable categories (%)</p> <p>Percentage of organic waste that is sent for digestion or composting (%)</p>
3.7. Engage consumers with responsible production and consumption	N/A	Percentage of products sold on a defined market
4.1. Assess soil physical condition	<p>A soil management plan should be implemented for the farm that incorporates:</p> <p>(i) annual report for signs of erosion and compaction based on field inspections;</p> <p>(ii) soil bulk density and organic matter analysis at least every 5 years;</p> <p>(iii) implementation of concrete actions for soil quality and organic matter</p>	<p>Soil water holding capacity (% of dry weight)</p> <p>Infiltration capacity (mm/hour)</p> <p>Visual evaluation of soil structure</p> <p>Maintain environmentally appropriate levels of soil P, K, Mg, (index or kg/ha), pH, SNS (kg/ha), trace elements</p> <p>Soil organic matter balance (+/-)</p>
4.2. Maintain/improve soil organic matter on cropland	<p>Ensure all arable soils on the farm receive organic matter inputs from e.g. manures, catch/cover crops, composts, or digestates at least once every three years, and account for all organic nutrient inputs in nutrient management plans</p> <p>Establish grass leys for 1-3 years (BEMP 6.4)</p>	Organic matter application rate t/ha/year (dry matter)
4.3. Maintain soil structure (avoid erosion and compaction)	<p>Maximise natural drainage through careful management of soil structure; maintain the effectiveness of existing drains; install new drains where appropriate on mineral soils</p> <p>Maximize the area and time period of bare soil, ie increase plant cover</p> <p>Minimise drainage of peat soils and soils where there is a high risk of increased nutrient transfer to water via drainage</p>	<p>Soil bulk density (g/cm³)</p> <p>Soil structure definition determined by profile analysis</p> <p>Erosion degree (visual inspection)</p> <p>Arable land with cover crops (%)</p> <p>Practice timely and appropriate tillage operations to avoid erosion</p>
4.4. Soil drainage management	<p>Maximise natural drainage through careful management of soil structure; maintain the effectiveness of existing drains; install new drains where appropriate on mineral soils</p>	<p>Soil moisture status (% water holding capacity, g water/100 g dry soil per season of the measurement)</p> <p>Rooting depth – pasture >15 cm deep</p>

BEMPs	Benchmarks of excellence	Key environmental performance indicators⁵⁸
	Minimise drainage of peat soils, and soils where there is a high risk of increased nutrient transfer to water via drainage	Install drains on grassland and arable land and produce field drain maps
5.1. Field nutrient budgeting	The maximum fertiliser nutrients applied do not exceed those required to achieve the agronomic optimum crop yield, after fully accounting for crop-available nutrients supplied by: a. organic amendments, b. soil nutrient supply and c. crop residues Nutrient surplus or nutrient use efficiency is estimated for nitrogen, phosphorus and potassium for individual crop- or grassland- management parcels	Field nutrient surplus (kg/ha/yr) Nitrogen use efficiency (%) N balance (kg N/ha) Regular soil fertility testing
5.2. Crop rotation for efficient nutrient cycling	All grassland and crop rotations include at least one legume crop and one break crop over a five year period	Integrate legumes and break crops into rotation for N and C cycling Number of break crops (ley, legume, oilseed in a rotation) Length of rotation/years
5.3. Precision nutrient application	Nutrient surplus or nutrient use efficiency is estimated for nitrogen, phosphorus and potassium for individual crop- or grassland- management parcels	NUE from synthetic inputs Apply the 4Rs: right fertiliser, right time, right rate, right method. Use GPS technology to optimise nutrient delivery Apply nutrients to coincide with plant demand
5.4. Select lower impact synthetic fertilisers	Mineral fertiliser used in the enterprise must not have given rise to manufacturing emissions exceeding 3 kg CO ₂ e per kg N, which must be demonstrated in an openly reported calculation provided by the supplier Employ low ammonia emission application of fertilisers	Certified fertiliser carbon footprint (kg CO ₂ e/kg N) Source synthetic fertilisers with lower embodied (upstream) GHG emissions and energy and with lower post application ammonia and GHG emissions Percentage of (%) fertilisers produced in factories implementing best available technology (BAT) as defined in the European Industrial Emissions Directive
6.1. Matching tillage operations to soil conditions	Fields with peat soils must be kept covered with long-term grass ley. Soil tillage on peat soils to reseed the ley may only be carried out after a period of at least 5 years.	Visible signs of erosion e.g. gullies Avoid tillage of peat soils and/or percentage of peat soils cultivated
6.2. Minimise soil preparation operations	Inversion tillage is avoided through use of e.g. direct seed drilling, strip tillage and reduced tillage (chisel plough)	Erosion losses (t/ha/year) Percentage (%) of seeding area where direct drilling applied Check also Section 4.1 the listed soil quality indicators
6.3. Mitigate tillage impacts	N/A	See indicators of sections 6.2 and 4.1
6.4. Crop rotation for soil protection	On farms with a cereal-dominated crop rotation, break crops must be included in the crop rotation. In a seven-year crop rotation, at least two years must be used for break crops. In a six-year crop rotation or shorter,	Percentage of soil coverage during winter (%) Length of rotation (y) No. of break crops (ley, legume, oilseed) in a rotation

BEMPs	Benchmarks of excellence	Key environmental performance indicators ⁵⁸
	at least one year must be used for a break crop. ii. Farms alternate crops cultivated in neighbouring fields to introduce and increase spatial diversity in fields iii. Select early maturing varieties of crops (e.g. maize) to harvest before the wet season and to facilitate cover crops establishment	
6.5. Establish cover and catch crops	Provide evidence of a full assessment of the potential to integrate cover/catch crops into cropping plans, providing justification for any land left bare over winter	DM t/ha cover crop biomass Percentage of land under bare soil over winter (%) Percentage of land with cover crops planted (%)
7.1. Grass management	80% grass dry matter uptake by grazing animals during the grazing period	Grazing days per year Percentage of compaction of grass (%) Visible signs of soil degradation e.g. poaching
7.2. Managing high nature value grassland	A biodiversity action plan established with local biodiversity experts is implemented on the farm, to maintain and enhance the number and abundance of locally important species	Species frequency and diversity (no. and no./m ²) Average stocking rate (Livestock Units-LU/UAA-Utilized Agricultural Area) Measuring cutting frequency as well as the date of the first cut Match stocking rate to biodiversity needs Optimise timing of mowing for biodiversity Replace silage with haylage Postpone mowing until fledglings have left the nests of ground-nesting birds
7.3. Pasture renovation and legume inclusion in permanent pasture and leys	Pasture renovation (e.g. over-seeding) is employed to maximise forage production, maintain high legume coverage and introduce other flowering species	NUE (%) and phosphorus surplus (kg/ha/year) Percentage of (%) seed by weight in ley mix as legume Percentage of (%) non-preferred species in sward
7.4. Efficient silage production	N/A	Percentage of (%) DM loss post-ensiling
8.1. Locally adapted breeds (hybrids)	≥ 50% of the animal population consist of locally adapted breeds (hybrids) ≥ 5-10% of the animal population consist of rare breeds	Percentage of (%) animals that are of local or rare genetic origin
8.2. Nutrient Budgeting on livestock farms	Farm level nitrogen surplus is maximum 10% of farm nitrogen requirements Farm level phosphorus is maximum 10% of farm phosphorus requirements	N and P surplus (kg/kg or L product, kg/ha/year); this indicator is calculated as an average over several years e.g. 3-5 years Farm NUE (%) (nutrient input in exported products)
8.3. Dietary reduction of N excretion	Farms obtain nutritional advice on optimised phase feeding	Dairy urea N (mg/100g). N surplus (kg/kg meat or 1000 L milk, kg/ha)
8.4. Dietary reduction of enteric methane	N/A	Percentage of (%) calving rate kg CH ₄ per kg meat/milk

BEMPs	Benchmarks of excellence	Key environmental performance indicators ⁵⁸
8.5. Green procurement of feed	Imports of soy- and palm-based feeds are minimised, and where used, 100% of such feeds are certified (with e.g. RTRS) not to originate from areas of recent land use change	Feed related kg CO ₂ e per kg feed or per kg meat or milk output Percentage of (%) of procured feed that is certified as sustainable animal feed Select feeds with low upstream (cultivation and transport) impacts. Avoid soya based feeds
8.6. Maintain animal health	The farm systematically monitors animal health and implements a preventative healthcare programme that includes at least one preventative visit per year by a veterinary surgeon	kg meat (milk)/head/ life time Use of antibiotics; frequency (no./year) Occurrences of treatment per head over year
8.7. Herd/flock profile management	N/A	kg CH ₄ per kg meat/milk Daily weight gain (kg/day/animal) Age at first calving (months) Slaughter age (months)
9.1. Efficient housing	Minimise the duration of (cattle) housing and install a grooved floor, roof insulation and controlled natural ventilation systems to animal housing	Grazing days/year kg NH ₃ emitted per cow place or per livestock unit per year
9.2. Anaerobic digestion	100% of slurry generated on farm is treated in an anaerobic digestion system with gas-tight digestate storage, from which digestate is returned to agricultural land	Percentage of (%) slurry and manure generated on farm treated in an anaerobic digestion system from which digestate is returned to agricultural land Percentage of (%) of the co-digestion material (e.g. crops, food, feed) that eventually derives digestate
9.3. Slurry/digestate separation	Slurry or digestate arising on dairy, pig and poultry farms is separated as needed into liquid and solid fractions that are applied to soils in accordance with crop nutrient requirements and soil organic matter requirements	Percentage of (%) dry matter in solid fraction Percentage of (%) slurry or digestate generated on dairy, pig and poultry farms that is separated prior to storage Nutrient surplus (N and P), kg/ha/year Nutrient use efficiency (N and P, %)
9.4. Appropriate slurry storage systems	New build slurry stores, and anaerobic digestate stores, are built as tall tanks (> 3m in height) with tight lid or tent cover Existing tanks stores are fitted with a tight lid or tent cover where possible, or plastic-sheeting-type/clay ball/LECA (Lightweight expanded clay aggregate)/Hexacover (floating systems) cover otherwise, and existing lagoon slurry stores are fitted with plastic-sheeting-type cover Total liquid slurry storage capacity is at least equal to that required by relevant national NVZ regulations, whether or not the farm is in an NVZ, and is sufficient to ensure that the timing of slurry application can	Capacity of liquid slurry stores (m ³), also expressed as the number of overwinter months of storage Slurry processing applying suitable methods (consult the text of this BEMP) Type of liquid slurry stores Manure storage CH ₄ emissions, kg CH ₄ per kg meat/milk

BEMPs	Benchmarks of excellence	Key environmental performance indicators ⁵⁸
	always be optimised with respect to farm nutrient management planning	
9.5. Appropriate solid manure storage	Solid manure fractions are composted or stored for at least three months in batches with no fresh manure additions. Solid manure stores are covered and located away from water courses, with leachate collected and recycled through the farm manure management system	Percentage of (%) solid manure fractions stored according to the described principles in this technique
9.6. Injection slurry application and manure incorporation	In accordance with nutrient requirement of the crop, 100% of slurries applied to land are applied via shallow injection, trailing shoe or banded application, and 100% of high ammonium manures applied to bare arable land are incorporated into the soil as soon as possible and in any case within two hours	Avoided fertiliser requirement (kg/ha/year) Timing of slurry applications in relation to soil conditions (moisture content) and crop nutrient requirements
9.7. Injection slurry application to grassland	In accordance with nutrient requirement of the crop, 100% of slurries applied to land are applied via shallow injection, or trailing shoe or banded application where injection not possible	Percentage of (%) volume slurry applied using efficient methods Nutrient surplus (N and P, kg/ha/year) Nutrient use efficiency (N and P, %)
10.1 Agronomic methods in the design of irrigation methods	An irrigation plan should incorporate the following principles: precise calculation of the water needs, application of irrigation scheduling and measures to improve the water quality	Match crops to available water or vice versa (Y/N) Percentage (%) of change in irrigation demand (m ³ /yr, m ³ /ha/yr) Water footprint (blue water component) (L/tonne crop)
10.2 Optimisation of irrigation delivery	Selection of the best irrigation delivery according to the practices described depending on the crop, local climate and water availability	Water use efficiency (WUE)
10.3 Management of irrigation systems	N/A	Application efficiency (on farm) Irrigation efficiency (on farm) Conveyance efficiency (to farm)
10.4 Efficient and controlled strategies	N/A	Water consumption (m ³ /ha) or (m ³ /t) produced for different crop types related to annual water balance Type of water used (green or fresh) according to the applied water footprint methodology Volume of water abstracted (m ³ /ha), in case of drillings Drip irrigation installed (Y/N) Yield or marketable value of products per unit water abstracted (kg/m ³ or €/m ³)
11.1 Optimising and reducing the use of crop protection	N/A	Application of crop rotation scheme that aims at pest prevention (Y/N)

BEMPs	Benchmarks of excellence	Key environmental performance indicators ⁵⁸
products		Implementation of biological pest control (Y/N) Precision application of CPP (if their use is needed) (Y/N) When CPP are applied: Treatment frequency (number of times/year) Participation in appropriate training on crop protection (Y/N)
11.2 Crop protection products selection	N/A	Kg _{active ingredient} /ha/year (When choosing a CPP assess the environmental and human risks and hazards)
12.1 Energy efficiency in protected horticulture	Combined energy consumption for heating, cooling, lighting and manufacture of carbon dioxide (if applicable) must consist of at least 80% of renewable energy sources, on an annual basis.	Lighting: kWh/m ² /year (Total energy input)/m ² (Total energy input)/yield
12.2 Water management in horticulture	Use of closed-loop water system	Water use (W): - <u>Closed systems</u> : crop water uptake (Wu), which is defined by evapotranspiration (ET) and growth - <u>Open and/or semi-closed loop</u> : crop water uptake (Wu), which is defined by evapotranspiration (ET) and growth and drainage (D); especially for this system, D is systematically recirculated but the nutrient solution is discharged in a certain frequency Volume of water applied to an individual crop (l) Volumes of water used for other purposes e.g. salt leaching, cleaning of irrigation systems (l)
12.3 Waste management in horticulture	Any mulching material should be 100% biodegradable, unless it is a plastic film that can be physically removed 100% waste segregation at source 100% composting of the agricultural biomass generated	Reuse or recycle of the used packaging materials (%) Waste generated (kg/year) Waste diversion from final treatment/disposal (%) Percentage use of any kind of bio-plastic materials like coverings, pots etc. (%) Compost production (kg/ha or as a proportion % out of the total biomass production)

Based on environmental hotspots Table 13.2 maps across the most relevant BEMPs contained in this SRD to 12 major farm types. Simplification is inevitably involved, and farms may include features typical of multiple farm types (mix of intensive and extensive areas, mixed animal and crop production, etc).

Table 13.2: Priority best practices (BEMPs) described in this report for 12 major farm types (dark shading=high priority; medium shading=medium priority; white=not applicable or low priority)⁵⁹

BEMP	Intensive dairy*	Extensive dairy	Intensive eef*	Extensive beef	Sheep	Intensive pigs*	Intensive poultry*	Extensive pig & poultry	Cereals and oils	Root crops	Field fruit & vegetables	Covered fruit & vegetables
3.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
3.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
3.3	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
3.4	Light	Dark	White	Dark	Dark	White	White	Dark	Dark	Dark	Dark	Dark
3.5	Dark	Dark	Dark	Dark	Light	Dark	Dark	Light	Dark	Dark	Dark	Dark
3.6	Dark	Light	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Light	Dark	Dark
3.7	Dark	Light	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
4.1	Dark	Dark	Dark	Dark	Dark	White	Dark	Dark	Dark	Dark	Dark	Dark
4.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
4.3	Light	Light	Dark	Light	Light	Dark	Dark	Light	Dark	Dark	Dark	Dark
4.4	Dark	Dark	Dark	Dark	Dark	White	Dark	Dark	Dark	Dark	Dark	Dark
5.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
5.2	Light	Light	Dark	Light	Light	Dark	Dark	Light	Dark	Dark	Dark	Dark
5.3	Dark	Light	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
5.4	Dark	Light	Dark	Dark	Light	Dark	Dark	Light	Dark	Dark	Dark	Dark
6.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
6.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
6.3	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
6.4	Light	Light	Dark	Light	Light	Dark	Dark	Light	Dark	Dark	Dark	Dark
6.5	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
7.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
7.2	White	Dark	Light	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
7.3	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
7.4	Dark	Dark	Dark	Dark	Light	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.1	White	Dark	Light	Dark	Dark	Dark	Dark	Light	Dark	Dark	Dark	Dark
8.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.3	Dark	Light	Dark	Light	Light	Dark	Dark	Light	Dark	Dark	Dark	Dark
8.4	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.5	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.6	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
8.7	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.1	Dark	Light	Dark	Light	Light	Dark	Dark	Light	Dark	Dark	Dark	Dark
9.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Light	Light	Light	Light
9.3	Dark	Light	Dark	Light	Light	Dark	Dark	Light	Dark	Dark	Dark	Dark
9.4	Dark	Dark	Light	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.5	Dark	Dark	Dark	Light	Light	Dark	Dark	Light	Dark	Dark	Dark	Dark
9.6	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
9.7	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
10.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
10.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
10.3	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
10.4	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
11.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
11.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
11.3	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
12.1	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
12.2	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark
12.3	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark	Dark

*Arable best practice may apply to areas of the farm for feed production, or to farms receiving pig and poultry manure in terms of slurry application

⁵⁹ Particular systems within the broad categories above may have particular environmental hotspots that should be addressed, such as soil erosion for olive production, copper accumulation in soils for vineyards, etc. This SRD cannot be exhaustive, but attempts to address the major areas of environmental improvement potential within European agriculture.

14 APPENDIX

14.1 List of Abbreviations - Glossary

AD	Anaerobic Digestion
ATES	Aquifer Thermal Energy Storage
AWC	Available Water Capacity
BAT	Best Available Technique
BEM	Best Environmental Management Practice
BREF	Best Available Techniques Reference Documents
CAP	Common Agricultural Policy
CHP	Combined Heat and Power
CLP	Classification Labelling Packaging
COP	Coefficient of Performance
CPP	Crop Protection Products
CTF	Controlled Traffic Farming
DI	Deficit Irrigation
DM	Dry Matter
DU	Distribution Uniformity
EC	European Commission
EFA	Ecological Focus Area
EIQ	Environmental Impact Quotient
EMAS	Eco Management Audit Scheme
ET	Evapotranspiration
EU27	Member states of the European Union from 1 st January 2007
FYM	Farmyard Manure
GHG	Greenhouse Gases
GPS	Global Positioning System
GSHP	Ground Source Heat Pump
HNV	High Nature Value
IPM	Integrated Pest Management
IPPC	Integrated Pollution and Prevention Control
IPTS	Institute for Prospective and Technological Studies
IS	Irrigation Scheduling
JRC	Joint Research Centre
LCA	Life Cycle Assessment
ME	Metabolisable Energy
MSW	Municipal Solid Waste
NMP	Nutrient Management Plan
NRV	Nitrogen Replacement Value
NUE	Nitrogen Use Efficiency
OM	Organic Matter
PRD	Partial Root Drying
RDI	Regulated Deficit irrigation
SMB	Soil Microbial Biomass
SMD	Soil Moisture Deficit
SMN	Soil Mineral Nitrogen
SNS	Soil Nitrogen Supply
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SRD	Sectoral Reference Document
TWG	Technical Working Group
WUE	Water Use Efficiency