Bio Intelligence Service

European Commission (DG ENV)

ENVIRONMENTAL IMPACTS OF DIFFERENT CROP ROTATIONS IN THE EUROPEAN UNION

Contract N° 07.0307/2009/SI2.541589/ETU/B1

Final Report

6 September 2010

In association with

INRA Institut National de la Recherche Agronomique

Warsaw University of Life Sciences

ITAB Institut Technique de l'Agriculture Biologique

UNIVERSITÀ DEGLI STUDI DI MILANO *University of Milan*

Bio Intelligence Service - Scaling sustainable development
Industrial Ecology - Nutritional Health

Bio Intelligence Service S.A.S - bio@biois.com
20-22 Villa Deshayes - 75014 Paris - France
Tél. +33 (0)1 53 90 11 80 - Fax. +33 (0)1 56 53 99 90

Contact BIO Intelligence Service
Shailendra Mudgal – Perrine Lavelle
☏ + 33 (0) 1 53 90 11 80
shailendra.mudgal@biois.com
perrine.lavelle@biois.com

Project Team

- **BIO Intelligence Service**

  Shailendra Mudgal

  Perrine Lavelle

  Franck Cachia

  Dalma Somogyi

- **Warsaw University of Life Sciences**

  Edward Majewski

- **ITAB – French Technical Institute for Organic Farming**

  Laurence Fontaine

- **University of Milan**

  Luca Bechini

- **INRA – French Agricultural Research Institute**

  Philippe Debaeke

Contents

EXECUTIVE SUMMARY

Crop rotation is a farming practice in which different crops are grown in the same field at different times over several years, and which can have positive or negative impacts on the environment and the economy. Crop rotation aims to ensure conditions which are conducive for the development of crops, by promoting soil fertility and minimising the development of pests and weeds, and also by ensuring better nutrient management. To achieve this, a balance between the combination of crops and the sequence in which they are cultivated is sought. Often, the first sequence in a rotation is used to prepare and regenerate the soil — using crops such as legumes and grasslands — while the second sequence takes advantage of the increased fertility of the regenerated soil, ideally leading to a farming practice which is economically more sustainable.

In the EU, crop rotations typically last 3 to 5 years in conventional agriculture, and 5 to 10 years in organic agriculture and can include a number of different species and strategies to achieve the desired outcome. Examples of crop rotations, presented in order of decreasing environmental impact, include:

- Crops of various families and species rotated with one another
- Arable crops rotated with grass leys (periods when the land is sown with grass and left fallow)
- Arable crops rotated without grass leys
- Monocultures[1]

The main pros and cons of implementing crop rotations at the farm level are summarised in the boxes below.

PROS

- Improving or maintain soil fertility
- Limiting erosion
- Reducing the build-up of pests
- Spreading the workload on time
- Mitigating risk of weather changes
- Limiting dependence on agricultural chemicals

CONS

- Requiring knowledge on building a crop rotation
- Requiring performing farming practices and knowledge on a range of crops
- Impacts variable according to farming practices, crops and local conditions
- Risks related to crop change and management of a new crop
- Decreasing profitability during the implementation

[1] Technically speaking, a monoculture, where only one crop is repeatedly grown in the same field, is a type of crop rotation, albeit where only one crop is used. In practical terms, however, a monoculture is generally discussed in opposition to crop rotation.

GENERAL GUIDELINES

An ideal crop rotation should base on the following pattern:

- Rotate deep-rooted crops with shallow-rooted ones, to optimise the exploration of nutrients in soil. Moreover the insertion of deep-rooted crops helps to maintain the structure of the soil.
- Rotate spring-sown and autumn-sown crops, to break cycles of weeds, pests and pathogens.
- Avoid following a crop with a closely related species, to avoid common weeds, pests and pathogens.
- Rotate crops with a high level of ground cover, which maintain weeds at low level, and crops where weeds are well controlled mechanically (hoeing);
- Include crops that leave significant amount of residue, in particular if most arable crops are exported, i.e. harvested and used for other purposes out of the field.
- Include legumes in order to help fix atmospheric nitrogen in the system.
- Grow more than one fast-growing crop in close proximity (known as "intercropping", "cover crops" or "catch crops"), which help to manage nutrient cycles between two crops, cover the ground and protect soil structure and which provide habitat to fauna, including beneficial insects.

BARRIERS TO UPTAKE

The uptake of crop rotations by farmers faces a number of barriers, mainly related impact of crop rotations over time and across different scales:

- **Lack of knowledge of farmers on the importance of ground cover, residue management and other agronomic benefits influencing land management and yields** (e.g. soil structure, erosion, water retention, etc)
- **Need for a learning period after the implementation of a new crop rotation** to learn on risk management of new crops and related farming practices: yields and work efficacy can be reduced during this period, as timings and products management change according to crop rotations (e.g. nitrogen management is modified when inserting legumes in the rotation).
- **New knowledge and practices may be needed**: Choosing and implementing a crop rotation may require acquiring new knowledge, and may meet resistance to change from farmers who master their agricultural practices.
- **Benefits are most obvious at the large-scale**: Environmental impacts are seen at the landscape level, and not particularly in the farmer's fields.
- **Incentives may be misaligned**: Farmers have little decision-power on regional specialisation of agricultural production and local market opportunities, which both need to be taken into account in the decision-making regarding crops and crop rotations choice.

CROP ROTATION CHOICE

Drivers of crop choice

Above all, financial considerations drive most farmers' choices, as they have to ensure the economic viability of their enterprise. As such, farm management practices such as crop rotation must ensure that the production remains sufficiently profitable if the farmer is expected to implement the practices regularly and consistently.

Good choice of and its proper implementation crop rotation presents an opportunity to reduce agriculture's pressure on the environment, either by reducing its negative impacts or improving its positive impacts, or both. Before the expansion of industrialised agriculture, crop rotations used to be the driving management practice to control pests and weeds. As such, crop rotations serve as a means to reduce chemical inputs, in line with the current agri-environmental policy objectives.

From a historical point of view, different socio-economic and technological drivers have influenced the abandonment and rediscovery of crop rotation over time. From a technological perspective, farmers moved towards simplified or monoculture cropping systems because of innovations in machinery, better performing varieties, increased water availability, chemical fertilisers, efficient chemical weed and pest controls, as well as market prices and market opportunities. Thanks to modern management practices, legumes were no longer indispensable to the rotations. Innovation, relying in particular on breeding and improvement of watering practices allowed the development of more diversified crop rotations. New species appeared in the rotations, such as species with high water needs in irrigated systems, low resistance species with high productivity and profit, and some market crops grown in monocultures. Lastly, as crop rotations proved no longer necessary for weed and pest control, they became simplified, shorter and less structured. Crop rotations then aimed to support the cultivation of the High Yield Varieties (HYV) during a long time period, with a minimum crop return time between two cultivations of the same HYV crop

Geo-political factors have also influenced crop choices and may influence them in the future. For example, when the energy crisis of the 1970s struck, significantly increasing fuel prices, crops imported from distant continents became significantly more expensive, driving European farmers to increase the diversity of their production and to implement crop rotation in their practices.

Policy has also driven choices related to crop rotation. For example, measures to improve productivity, to support certain crops[2] resulted in a shortening of crop rotations..

Sources of information for decision-making and risk management

Opting for long crop rotation periods requires farmers to expand their technical expertise and, potentially, to grow new crops. Growing a new crop always represents a risk to farmers, since it involves a learning period which can translate into potential yields losses. Furthermore, the

[2] "Set-aside areas" are areas of farmland not used for the production of arable crops.

environmental and other economic impacts of a crop rotation are variable, depending on crops, farming practices, local conditions and experience of the farmer.

Some key factors need to be taken into account when deciding on a rotation: farming systems (arable or mixed), local climatic conditions, soil type, water availability, irrigation, crops themselves, potential market opportunities, and the type of farming (organic or conventional). Moreover, crop rotations interact strongly and in many ways with other management practices (tillage, fertilisation, chemical pests and weeds control, etc.).

Farmers need to be continuously provided with access to advice and information to make decisions within the framework established by both EU and national laws and regulations. The Farm Advisory Systems of the EU are constructed as demand-driven information and advice systems including various advisory activities, to be provided to farmers covering "*at least Statutory Management Requirements (SMR) and Good Agricultural and Environmental Condition (GAEC)*", and assessing the specific farm situation via one-to-one advisory services on or off farm. While not all farm advisors discuss crop rotations, in some cases they may specifically promote the practice and encourage farmers to use it, highlighting its beneficial effects on yields and the destructive effects of monoculture.

Beside farm advisory services, a range of actors influence farmers' decisions concerning crop rotations: commercial partners have the largest influence on farmers' choices followed by agricultural institutes and Farm Advisors.

Existing crop rotations in the EU

Different types of crop rotations can be used in different farming systems.

Arable farming systems

In arable farming systems, the most practiced rotations in conventional systems are on average 3- to 4-year-long rotations, and tend not to include legumes, focusing principally on market crops, especially cereals (winter wheat, barley, rye, oat, triticale, etc.), which occupy a high number of the sequences in the rotation (up to 75 to 100%). These rotations may also include root crops, oilseeds, or maize. Rotations including legumes in conventional agriculture are rare, mostly short (2 to 4 years) and are observed in zones with humid or oceanic climates, e.g. Italy, Spain, France, and Austria. In organic farming, rotations observed are longer (6 to 12 years) and present a higher diversity of crop types: legumes, cereals, oilseeds and sometimes root crops or maize.

Conventional cattle rearing systems

In conventional cattle rearing systems, rotations the most practiced are 2- to 4-years-long, and often include sequences of root crops, cereals and oilseeds, with or without legumes (1 year at the beginning of the crop rotation). In organic cattle rearing farming systems, rotations observed are very long, from 9 to 12 years, and often first include a 3- to 4- year-long period of temporary grasslands or a legume crop, followed by sequences of cereals (winter wheat, barley, triticale, cereal mix, etc.) and legumes. The rotation can also include a variety of crop types, such as oilseeds, root crops (potatoes, sugar beet, beet) or maize.

Dairy farming systems

In conventional and organic dairy farming systems, a sequence of temporary grasslands or legumes at the beginning of the rotation appears more often than in other types of systems. In conventional dairy farming systems, the rotations are generally shorter than 5 years and have a high proportion of cereals, with oilcrops, silage maize or root crops potentially appearing in the rotation. In organic dairy farming systems, rotations can be as short as 3 years or as long as 15 years. In long rotations, the proportion of legume crops in the rotation is high (up to 85%); however examples of legume crop proportion as low as 20% are known as well with high proportions of cereals in the rotation. It is common to have one or several 3-5 year long temporary grassland period in the rotation. Similarly to conventional systems, oilcrops, silage maize or root crops may occur in the rotation

Pig farming systems

In pig farming systems, the rotations are based on the crops used to feed pigs, i.e. cereals and crops of high energy value. In conventional systems, the practice of rotations with very limited species diversity (cereal-based, or cereal/root crop) or monoculture is not uncommon in pig farming systems. However, diversified rotations with the presence of root crops, grain, maize, sunflower and cereals are practiced as well within this system in 2- to 8-year-long rotations. There is a limited presence of legume crops in pig farming system crop rotations, however examples of rotations with 2 years of temporary grassland in organic farming systems are known as well in 6-8 year long rotations.

Monoculture

Monoculture refers to the cultivation of a single crop on the same field, year after year and usually over a long time period, without rotating with other crops (i.e. neither market nor cover crops). In France and Poland, monocultures only represent 1% and up to 5% of the area used for farming (Utilised Agricultural Area – UAA) respectively. Crops grown in monoculture are mostly strong crops, which naturally resist to pests and weeds, as well as market crops, which are grown solely for sale rather than for the farmer's own use. Rice in Northern Italy and cotton in Greece, Spain, and Portugal, are exclusively cultivated in monoculture. Maize is a very frequent monoculture, mostly found in Southern Europe. Other monoculture systems include cereals, such as rye, oat, barley or wheat, mostly identified in Northern Europe and in Mediterranean regions specifically for durum wheat.

IMPACTS OF CROP ROTATIONS

Crop rotations can result in highly variable economic and environmental impacts. These impacts should be understood as the sum of the impacts of each of the crops in the rotation, and the impacts of the agricultural practices used on these crops. Therefore, the same rotation can have beneficial or detrimental impacts on the environment, depending on the management practices chosen by the farmer. The economic impacts are related to farm and risk management, as well as to work efficiency.

Environmental impacts

Impact on species diversity

Species diversity is important in farming systems as it provides a number of services that directly favour cultivation practices. For instance:

- soil diversity enhances soil functioning through its impacts on soil structure, soil organic matter and fertility, but also on the water cycle,
- natural predators can regulate crop pests,
- insects pollinate crops.

In general, crop rotations can lead to increased species diversity, though the impact of the rotation on species diversity depends on the rotation itself, and the diversity of crops involved in the rotation. For instance, rotations involving non-intensive management practices, such as grass ley or legumes, intercropping (cover crops), and manure from farm activities (green manure) tend to favour biodiversity. Similarly, a rotation involving a large variety of crops grown and/or involving intercropping may favour biodiversity as it provides habitats and/or food for different species.

Crop rotations also impact species diversity via the management practices used in the rotation. In particular, some crop rotations could reduce the need for tillage and chemical treatments which tend to decrease biodiversity (e.g. through soil compaction and nitrogen inputs that affect the soil biodiversity), while the maintenance of natural spaces creates habitats that favour biodiversity. The effects of management practices may be subtle, such that they may not cause changes in the size of animal and insect populations in the short term, but modify the age or sex structure of these populations, thereby impacting the viability of these populations in the long term. Diversifying farming practices, by using e.g. tillage or harvest, over time can significantly benefit the species living in the fields.

Impact on biodiversity at landscape level

In addition to the effect that crop rotations have on the ecological functions of the landscape, they can change its outward appearance as well. The diversification of crops in both space and time, as well as the presence of un-cropped areas, may necessarily change the way the landscape looks.

The distribution of suitable habitats in space and in time is a key factor for biodiversity in cultivated landscapes. Compared to simple agricultural landscapes, more complex landscapes offer a greater diversity of habitats, food sources and are usually less impacted by intensive practices, thereby favouring biodiversity. For instance, a diverse crop mosaic that combines various cereals, other crops and grasslands, accompanied by a diverse mixture of uncultivated habitats and rural settlement, is an ideal combination for nurturing a diverse and abundant biodiversity over time, especially farmland bird communities.

Crop rotations can participate to a green infrastructure network, when prioritised according to their landscape location so as to provide useful services in terms of water management, habitat connectivity or recreational opportunities.

Impact on soils

Crop rotations impact soil organic matter (SOM) content, physical properties of soil and soil erosion, indirectly through other farming practices that can be particularly harmful to soils, such as extensive use of tillage, synthetic fertilisers, irrigation and tractor traffic on fields. At the same time manure use and crop residues management have beneficial effects on soil.

Rotations may influence SOM mainly by providing plant materials to the soil (above-ground residues, roots and root exudates), e.g. biomass from winter cereals and winter oilseed rape. Soil structure is improved by including grassland in the rotation. Protection against soil erosion can be delivered by rapeseed and cereals, whereas row crops have a low protective function. The rotations with high proportions of winter crops (rapeseed, cereals) appear thus favourable to soils. Continuous meadow is the best for SOM, while sparse fallow is the most risky.

Impact on water

Crop rotations directly impact water through nitrogen leaching (N-leaching), residues of pesticides, erosion, evaporation and irrigation. Crop rotations can help manage N-leaching, if using rotations with a high share of crops with a long vegetation period, which develop a large mass of roots in critical periods for minelral nitrogen losses (N_{min} losses in autumn, spring) thus limiting it. The key practices which may reduce N-leaching are catch crop (cover crop) use, minimum tillage, crop residues management, proper application of organic fertilisers, low application of nitrogen, buffer strips or trees planting along waterways. The factors which determine the indirect impacts of rotations on water include the intensity of production and crop management first, as well as the choice of crops and end use (for grains or green mass).

Crop rotations may help manage pesticides leaching to groundwater and surface waters: the nature of impact depends on the rotation type:

- **Positive impact** – diversified rotations and rotations with a high share of crops with a low dependence on pesticides (e.g. grass, clover, alfalfa),
- **Neutral impact** – rotations with a high share of crops protected with the applications of pesticides in the periods of low precipitation and runoff,
- **Negative impact** – rotations with a dominating share of crops highly dependent on chemicals in the periods of high precipitation and runoff.

Crop rotations can help manage water erosion, especially rotations with a low share of spring crops and root crops result in higher soil cover over the year. Evaporation can also be reduced by implementing crop rotations, especially rotations with several sequences of winter crops which are more likely to use water from the soil, and rotations which provide higher soil cover in the spring (with cover crops or crop residues management), thereby reducing evaporation.

Crop rotations have various impacts on irrigation according to the choice of crops. Crops have different water requirements and can be divided in three types:

- crops with a high need for irrigation, like potato, vegetables, grain maize, are very sensitive to water shortage;
- drought tolerant crops, like sorghum or sunflower, have efficient adaptive process and can adjust their water losses to water availability;

- escaping crops, like winter cereals, which avoid the summer drought periods in Europe, and are generally not irrigated. In rainfed systems, crop rotation is a way to reduce the risk of severe yield loss by combining crops with different degree of drought tolerance, alternating winter and summer crops.

As for monocultures, the impact on water depends on the crop cultivated. While monocultures of maize relies on high water supply, monocultures of rye requires lower water supply, resulting in reduced water evaporation due to long vegetation period and good soil cover, and reduced N-leaching due to limited needs in fertilisation.

Impact on climate change

The choice of particular crop rotations may, in part, determine a given farming system's overall impact on climate change. Important variables in this calculation include choice of crops, use of catch crops (including cover crops) or green manures (less fallow and more winter cover), and use of legumes or sowing new crops on covered soil without ploughing (undersowing).

The key parameters explaining most of a given crop rotation's contribution to climate change are as follows:

- CO_2 sequestration:
  - biomass production
  - cycling of cereals / forage crops /catch crops
- N_2O emissions
  - inclusion of legumes
  - nitrogen fertilisation
- Adaptation to water shortages:
  - irrigation,
  - percentage of winter crops.

Economic impacts

On a longer term, beneficial effects of a rotation, particularly concerning soil quality, lead to increasing yields. Crop rotations are generally characterised by higher fixed costs due to higher machinery investment costs and lower variable costs compared to monoculture, notably due to a lower use of chemical inputs. However, on the short-term, yields per hectare are generally lower for rotations compared to monocultures, and the final impact on profit is uncertain, as it also depends on the farmer's capacity to benefit from the advantages of rotation, i.e. the use of adapted management practices.

Compared to monoculture, rotations allow a diversification of risks related to production and price variations. An appropriate choice of crops may allow farmers to reduce their risk exposure. As a counterpart, market opportunities may not be equal for all crops of the rotation.

If environmental externalities are taken into account, particularly those externalities linked to reduced water use, ecosystem services, and climate change, rotations which are more beneficial to the environment may become more attractive.

MANAGEMENT OF CROP ROTATIONS

EU policy instruments

At the EU level, most policy instruments that have an influence on farmers' crop rotation choices impact them indirectly, e.g. by directing the choice of crops, or by reducing the use of chemical inputs.

The 2003 reform and cross-compliance

The 2003 Common Agriculture Policy (CAP) Reform introduces the mechanism of cross-compliance, which links the granting of CAP payments to the respect of mandatory standards in the fields of the environment, public, animal and plant health, and animal welfare (statutory management requirements). It also requires farmers to maintain their land in Good Agricultural and Environmental Condition. One such standard of GAEC concerns crop rotation..

Set-aside obligation

Set-aside obligations applied to fields used for non-food purposes, fields left fallow, afforested fields and fields used for non-agricultural purposes (e.g. conversion to grassland). In 2006-2007, more than 3.7 million ha of land were registered as "set-aside" in EU-15, i.e. 2.65% of the EU-15 land area which can be used for agriculture (Utilisable Agricultural Area - UAA). Half of this land was included in a rotation, and 20% in a non-food set-aside. In 2007, the set-aside obligation was abolished and it is estimated to have resulted in increased cereal surface areas and in decreased rape surface areas, and the share of rotations including these crops varied accordingly.

In Spain, the increase of fallow land management after 1992 increased the areas subject to soil erosion risk. The response of unseeded fallow, in terms of total runoff and sediment accumulation, is actually considerably higher than for the other management types. With the introduction of mandatory cross-compliance under Regulation 1782/2003 in 2003, member states had to maintain an adequate cover of lands in winter for set-asides, which resulted in beneficial effects on soil quality and preservation.

Agri-Environmental Measures

The Agri-Environmental Measures – (AEM), part of the Rural Development Policy, aim to encourage farmers and other land managers to introduce or continue to apply agricultural production methods compatible with the protection and improvement of the environment, the landscape and its features, natural resources, the soil and genetic resources. Agri-environment payments are granted to beneficiaries who make on a voluntary basis commitments going beyond relevant mandatory standards, as a general rule for a period between 5 and 7 years. This may include measures on crop rotation.

Policy on organic farming

The legislation on organic farming aims to attain sustainable farming practices and is based *inter alia* on certification requirements, which include very restricted use of pesticides/fertilisers, and requirements for a holistic sustainable farming management. As a result, crop rotations were held as a keystone of organic farming, leading to more diversity and longer rotations, and better crop/weed/pest management. Technical constraints remain, and include the poor availability of seeds and difficulties in managing diverse crops.

Chemicals policy

The Nitrates Directive aimed to limit nitrogen impacts to the environment, and was based on nitrogen spreading management. The legislation on pesticides aimed to limit chemical risks to the environment, and was based on synchronising plant and soil cycles. Crop rotations were impacted through better crop management (intercropping, soil covers) and crop-specific guidelines.

KEY CONCLUSIONS

Adopting crop rotations would lead to the global improvement of soil productivity, in the long term. Even though some scientific evidence of the agronomical benefits from successively cultivating a diversified range of specific crops exist, conventional farmers generally continue implementing their usual simplified crop rotations as it is often economically safer and agronomically efficient in most situations. This reluctance to change could be counteracted by information on the benefits and technical feasibility of crop rotations, as well as an improved understanding of the risks involved and how they can be managed.

Therefore, it seems indispensable to encourage the dissemination of information to farmers about the agronomical benefits (i.e. increased productivity) given that it is — prior to environmental benefits — what concerns farmers the most. Using participatory methods could be an efficient promotion approach.

Promotion of crop rotations needs to be supported by the promotion of other good farming practices, given that the level of impacts of a crop rotation on the environment also depends on other farming practices (incl. chemicals management, tillage, etc.). Calculation tools can be useful, such as soil organic matter calculators or nitrates needs calculators. Farming practices are a key element to achieve sustainability and positively impact the environment. Using sustainable practices can maximise the benefits of an environmentally beneficial crop sequence. The following practices can be encouraged:

- Develop an integrated and pest/diseases management
- Minimise tillage and interventions on fields
- Incorporate crop residues into the soil.

Finally, promotion of the farming practices must be linked to the farming systems, such as cattle rearing, dairy farming, and cereal production, as they are related to typical crop rotations.

KEY RECOMMANDATIONS

In order to promote the spread of various crop rotations in the EU-27 and to reduce agriculture's negative impacts on the environment, initiatives promoting the many benefits of crop rotations (agronomical, environmental, economic) should be encouraged. This should be complemented by other approaches which can reduce agriculture's environmental impacts, such as low-input farming systems (e.g. organic farming or conservation agriculture) and other "best farming practices". Further, additional research should be financed on crop rotations at the EU-level.

GLOSSARY

arable farming	Growing crops as opposed to dairy or cattle farming.
arable land	Land cultivated for crop production and land under set-aside, or maintained in good agricultural and environmental condition, irrespective of whether or not that land is under greenhouses or under fixed or mobile cover (Source: CAP).
catch crop	Fast-growing crop that is grown simultaneously with, or between successive plantings of a main crop. Catch crops have a strong rooting system, valuing well nitrates, e.g. mustard, phacelia, rye, raygrass, radish. Catch crops include cover crops and crops mixes.
cereal	Plants of the graminaceous family (with the exception of buckwheat) cultivated mainly for their grain.
fallow	All arable land included in the crop rotation system, whether worked or not, but with no intention to produce a harvest for the duration of a crop year.
forage	Grasses or other herbaceous forage shall mean all herbaceous plants traditionally found in natural pastures or normally included in mixtures of seeds for pastures or meadows in the Member State (whether or not used for grazing animals) (Source: CAP).
legume	Leguminous plant, a plant in the Fabaceae or Leguminosae family, e.g. alfalfa, clover, peas, beans, lentils, lupines, mesquite, carob, soy, peanuts.
market crop	Crop grown solely for sale rather than for the farmer's own use, e.g. coffee, cotton, sugar beet. Also called cash crops.
mixed farm	A farm on which both crop production and livestock—keeping are practised simultaneously (Source: OECD).
monoculture	Monoculture refers to the growing of one single crop on the same area year after year.
oil crop	Crops whose seeds are used for producing vegetable oils.
permanent grasslands	Land used permanently (for five years or more) to grow herbaceous forage crops and that is not included in the crop rotation on the holding.The land can be used for grazing or mown for silage, hay or used for renewable energy production.
permanent pasture or grasslands	Land used to grow grasses or other herbaceous forage naturally (self-seeded) or through cultivation (sown) and that has not been included in the crop rotation of the holding for five years or longer, excluding land under set-aside schemes (Source: CAP).
root crop	Plants which store edible material in a root, corm or tuber; root crops used as food vegetables or fodder include carrots, parsnips, swedes and turnips; starchy root crops include potatoes, cassavas and yams.
temporary grasslands	A cultivated area utilised as pasture as part of a crop rotation.

This page is left intentionally blank

1. INTRODUCTION

BIO Intelligence Service (BIO) is pleased to submit the final report of the study on the "Environmental impacts of different crop rotations in the EU" (Reference: ENV.B.1/ETU/2009/0026) on behalf of the consortium composed of BIO, Warsaw University of Life Sciences, University of Milano, the French Institute for Agricultural and Food Research (INRA) (department of Toulouse), and the French Technical Institute for Organic Farming (ITAB).

1.1. REPORT STRUCTURE

This report is structured as follows:

- The first chapter provides definitions for the key concepts that have been used throughout this study and underlines the importance of crop rotations as regards the control of the environmental impacts of cultural strategies.
- In the second chapter, the main drivers (economic, social and political) explaining major changes in agricultural practices, such as shifts from crop rotations to monoculture, are identified, through a historical overview starting with the Green Revolution in Europe in the 1950's.
- The third part delves into the environmental impacts of crop rotations, with a detailed impact analysis for each of the main environmental impacts. The environmental performance of crop rotations is compared to monoculture with the objective to provide a qualitative ranking of different type of cropping structures, in terms of specific and overall environmental impacts.
- Drawing from the results of the previous chapter, the fourth chapter focuses on the identification of possible trade-offs between economic and environmental aspects of different cropping systems. A detailed comparison of the profitability of crop rotations and monoculture is carried out, both in general terms and for specific rotations. Furthermore, an assessment of the possibility to take into account environmental costs and benefits in the overall economic balance of different cropping systems is also presented, as a first step towards to development of possible compensation schemes.
- In the sixth chapter, existing policies at the EU level with potential significant impacts on crop rotations are identified and analysed, with the aim to provide policy-makers with a better view and understanding of the policy context, especially in terms of effective policy actions that might be undertaken to improve the environmental impacts of European farming practices.
- Acknowledging the importance of information gaps and their importance regarding the effectiveness of agricultural practices, as identified in the previous chapters, especially in chapters 3 and 4, chapter 7 provides a specific focus on farm advisory services and their role for the possible effective development of crop rotations in Europe.
- Chapter 8 concludes and provides a set of practical and targeted policy recommendations, for different levels of governance, with the aim to bridge possible gaps (such as profitability gaps) and overcome trade-offs currently limiting the

development of crop rotations and the adoption of appropriate and effective farming practices.

1.2. KEY CONCEPTS

Around half of the EU's land is farmed. Agriculture is an important economic sector in the EU, with about 42% of the EU budget dedicated to CAP, including market-oriented agriculture (31%) and rural development (11%). Historically, this is derived also from the fact that food security was a major driver in the construction of the EU. The development of modern agriculture practices in response to productivity needs and work simplification has environmental consequences and efforts are needed to reduce the environmental impacts of EU agriculture, while maintaining agricultural productivity.

Crop rotation used to be the driving means of controlling pests and weeds for thousands of years, before the green revolution, however today various management practices exist for this purpose. This report analyseshow a balance can be achieved between this old and performing management practice and the current agriculture methods. Particularly, this report explores the reasons which have led the modern agriculture to turn away from crop rotation, identify the economic and environmental consequences of crop rotations, and identifies how to convery this idea to farmers and approaches to reduce environmental impacts of farming but maintaining food production at the same time.

Crop rotation is the practice of alternating annual crops grown on a specific field in a planned pattern or sequence in successive crop years so that crops of the same species are not grown without interruption on the same field. Normally the crops are changed annually, but they can also be multiannual. Crop rotation is different from crop sequence, which is a mere succession of different crops without a particular order or repetition, as it consists of an ordered sequence of crops that is repeated over time. Monoculture consists of a single crop that is repeated over time, and is considered as a form of crop rotation in this report.

Most crop rotations last between 3 to 5 years in conventional agriculture, compared to a duration of 5 to 10 years in organic agriculture. A typical crop rotation involves a succession of crops, with a first sequence that is often used to prepare and regenerate the soil (e.g. legumes and grasslands) and a second sequence that benefits from the fertility of the regenerated soil. This succession aims to ensure conducive conditions for the development of crops, by promoting soil fertility and minimising the development of pests and weeds, and also by ensuring better nutrients management.

Crop rotations are characterised by the lapse of time between two repetitions of the same sequence of crops (rotations) and by the nature of the first crop, which is called the "head of rotation".

1.3. WHY CROP ROTATION MATTERS

Crop rotation is one of the oldest and most effective pest and weed control strategies. Some pests and disease-causing organisms are host-specific and crop rotation can help in controlling them, for example the rice stem borer which feeds mostly on rice can be eliminated by rotating rice culture with crops belonging to a different family. If crops are not altered the pest problem may continue as food may always be available to the pest. However, with a succession of legumes, maize, beans and bulbs, the host-specific pests are likely to die off in the absence of food. Using crop rotations is a particularly efficient way to fight against the spread of Diabrotica infections in maize fields.

Crop rotations represent several advantages, such as (PAN Germany, 2009):

- preventing rapid soil depletion
- maintaining soil fertility and balancing fertility demands of different crops
- reducing soil erosion
- controlling insect/mite pests3
- reducing reliance on synthetic chemicals
- reducing the pests' build-up
- preventing diseases
- helping weed control
- improving plants resilience to adverse weather conditions

1.4. COLOUR CODES

In this report, colour codes are used to distinguish between the types of crops, and to improve the understanding of the sequences of crops used in the crop rotations (Table 1-1).

Table 1-1: Colour code used for the crops in this report

Type of crop	Colour code
Legumes	Legumes
Grasslands	Grasslands
Fallows	Fallows
Cereals (other than maize)	**Cereals**
Maize	**Maize**
Root crop	**Root crop**
Oilseed	**Oilseed**
Other	Other

[3] Crop rotation as a means to control insects is most effective when the pests are present before the crop is planted; have no wide range of host crops; attack only annual/biennial crops; and do not have the ability to fly from one field to another.

This page is left intentionally blank

2. CROP ROTATIONS ACROSS THE AGES

The practice of crop rotation was developed in prehistoric times. Greek and Roman authors of the Antiquity already mention a yield decreasing effect, as a result of the cultivation of cereals on the same field year after year, as well as a beneficial effect of legumes on the performance of crops that were cultivated on the same field after the legume harvest (Gyuricza, 2001). From the system used by antique Greeks (alternation of plants and fallow on the same field, i.e. two-field rotation) to three-field rotation system in the Middle Ages, the modern crop rotation by the 18th century developed into a system without fallow, thus preventing soil erosion following a sequence of wheat, barley, turnips and clover. This system provided either fodder or grazing pasture for livestock, according to season, and root crops such as turnips, improved the quality of the harvest and the livestock's feed. Barley had a suppressive function on weeds, and row crop helped to weed control in the inter-row. The system became fairly common on the newly enclosed farms by 1800, remaining henceforth a standard practice in most British farms, and was adopted in much of continental Europe (see Annex I - section 1.1).

2.1. THE GREEN REVOLUTION (1950 – 1970)

The green revolution resulted in a shift in farming methods towards a more scientific approach, to raise cereal-grain production. This period affected the approach of farmers significantly, regarding the perceived importance of many aspects of crop production, including crop rotation.

European agriculture went through fundamental changes from the 1950's starting from a principally subsistence farming based system, arriving to the level of industrialised agriculture (see Annex I - section 1.2.1 for more details). The green revolution brought significant changes in terms of farm machinery, chemical fertilisation, pest and weed control, high yielding crop varieties, and irrigation. The linkages between these factors and the resulting changes in the crop rotations are summarised in Table 2-1.

Table 2-1: Summary of drivers and environmental pressures on crop rotations (1950-1970)

Drivers and pressures	Impact on agriculture	Impact on crop rotations
Agricultural machinery, mechanical innovation	Higher work efficiency, work on larger surfaces	Simplification of rotations
Research on the nutrients, development of chemical inputs	Use of chemical inputs as the major weapon against climatic conditions, pests and diseases	‣ Lower importance of the crop rotations as a weapon of resilience ‣ Crop rotations became less structured and no longer necessary
Research on the seeds, high yield varieties (HYV)	One crop became a major source of revenue for the farm.	The crop rotations support the cultivation of the HYV during a long time period, with a short intermediary time between two cultivations of the same HYV crop. The crop rotations were simplified and shortened New species appeared in the rotations

Drivers and pressures	Impact on agriculture	Impact on crop rotations
A better access to water resources, irrigation	On irrigated areas, priority was given to profitable crops needing much water, for a satisfying return on investment	Irrigated areas became often monoculture fields, mostly maize monocultures Better access to water resource allowed a larger set of crops choice
Efficient chemical weed and pest controls	Fragile crops could be cropped, independently from a rotation	Crop rotations were no longer necessary for weed and pest control Weaker species could be inserted in the rotations

2.2. ECONOMIC DRIVERS (1970 – PRESENT)

Choices of crop rotation during the period of 1950 – 1970 were also influenced to a high extent by the changes in the world economic situation. World agricultural trade grew at a spectacular rate between 1950 and 2000, with much faster expansion than in earlier periods due to the facilitated transport between different parts of the world and thus the globalisation of agricultural trade. The main economic factors impacting crop rotations were the good market prices for the basic cereals (maize and wheat) with dropping demand for legume crops which led to their phase out from crop rotations in Europa. This trend was counterbalanced to a certain extent by the global energy crisis of the 1970's and other factors such as protein crop importation to Europe which enhanced the production of one particular legume crop: soybean. Finally, crop rotations aimed to support the cultivation of the High Yield Varieties (HYV) during a long time period, with a minimum crop return time between two cultivations of the same HYV crop (Aubry et al 1998; Navarrete and Le Bail 2007) (see Annex I - section 1.3 for more details on economic drivers).

Table 2-2: Summary of the impacts of economic drivers on crop rotations (1970 to date)

Drivers and economic pressures	Impact on agriculture	Impact on crop rotations
Lack of fuel – energy crisis	Higher prices for soybean	Priority given to soybean production, and crop rotations temporary put between brackets
Good market prices for wheat, maize etc.	Higher production of wheat, maize etc.	Crop rotation should support good production of wheat, maize etc.
Low demand of the markets for legumes	Lower production of legumes	Increase of the crop rotations with few or no legumes

2.3. POLICY DRIVERS (1970 – PRESENT)

The food shortages which occurred in Europe during and after the Second World War called for an urgent and efficient reactivation and stimulation of agricultural production to which the new European agricultural policies responded to. Common regulations on the agriculture of Member States of the European Economic Community have been in force since 1962 with changing priorities throughout the decades such as increasing productivity and production level, agricultural market stabilisation, and later limiting the occurring overproduction and finally the consideration of environmental concerns (see Annex I - section 1.4 on policy drivers). The impacts of the main groups of measures within the EU Common Agricultural Policy (CAP) on agriculture in general and thus on crop rotations are presented in Table 2-3.

Table 2-3: Summary of the impact EU CAP drivers on crop rotations (1970 to date)

Drivers and environmental pressures	Impact on agriculture	Impact on crop rotations
Measures to improve productivity	Choice of High Yield Varieties, higher use of pesticides	Simplification of crop rotations to High Yields Varieties
Measures of support targeted on some crops	Priority choice on the supported crop species	Higher presence of the supported crop species in the rotations, simplification of the rotations
Measures of maintenance of the set-aside areas	Small reduction of the areas dedicated to agricultural production	Potentially more diversified crop rotations. Around 50% farmers decide to leave land fallow as part of rotations
Measures focusing on environmental concerns	Moderation of chemical use, revised management practices	Benefits of crop rotations highlighted again

This page is left intentionally blank

3. CROP ROTATIONS AND FARMING SYSTEMS IN EUROPE: A STATE-OF-THE-ART

Hundreds of various crop rotations exist throughout Europe, however with variable frequencies of use. In France, for example, the 13 most used crop rotations cover 50% of arable land and the last 18 crop rotations used cover 2% of arable land (Arvalis, 2008). In Hungary, four types of crop rotations are used in most of the fields, all of which are two year long rotations alternating different crops (maize, oilseed rape, sunflower or peas) with wheat (Pers. Comm.: Birkas, 2009). Particularly, farmers tend to choose crops depending on the preceding crop, and not following a rotation pattern, which makes them often think in terms of crop successions, and not in terms of crop rotations (Pers. Comm.: Vilain and Pouzet, 2009).

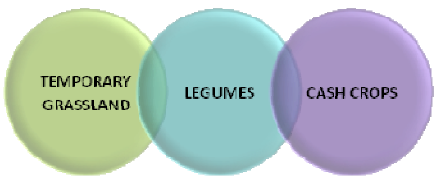
3.1. BASICS OF CROP ROTATIONS

The aims of crop rotations are presented in Box 3-1, and include motivations related to crop and farm management, to sustainable use of resources (knowledge on the subject, to their needs at the farm level and market opportunities (see section 3.2).

Box 3-1: General purposes of crop rotations (VASAT, 2007)

- improving or maintain soil fertility,
- limiting erosion,
- reducing the build-up of pests and weeds,
- spreading the workload on family labor, use of bullocks and farm equipment, hired labor etc.,
- mitigating risk of weather changes,
- limiting dependence on agricultural chemicals, and

Crop rotations in conventional agriculture usually have the following succession of crops:



Temporary grassland cleans the soil from the residues of preceding crops. Legumes contribute to maintaining soil fertility and providing the necessary organic nitrogen source for cultivated plants by fixing atmospheric nitrogen, through a symbiotic relationship with bacteria known as rhizobia, found in legumes root nodules. This provides the nutrients that market crops benefit from. Each crop of the succession may be cultivated during one or several years.

Optimal rotations are supposed to be built respecting several basic rules:

- **A balance of market crops** (e.g. maize) **and soil-conserving cover crops** (e.g. clovers)
- **A balance of deep rooted crops** (e.g. sweet clover, alfalfa) **and shallow-rooting crops** (cereals) to help keep the soil structure open and assist in drainage.

- A balance of **crops with high-root biomass** (e.g. rye) **and low-root biomass** (oats).
- A balance of crops that are **high moisture users** (e.g. maize) **with plants that require lesser amounts of moisture** (e.g. barley).
- Regular use of **allelopathic crops** (e.g. rye and sunflowers) to prevent a build up of their natural chemical toxins.
- A balance of **nitrogen fixers** (legumes) **with high nitrogen consumers** (e.g. maize and winter wheat) (McGill University, 2008).

A minimum delay is necessary to break the cycle of pests, depending on the crop type (Leteinturier, 2006; Table 3-1). Usually at least five years are spent before the same crop is sown on the same field again, so that pests and weeds adapted to the crop disappear from the field. However, with help of chemical control, this 5-years delay tends to be shortened to 2 or 3 years.

Table 3-1: Recommended minimal return time for crops in Belgium (Leteinturier, 2006)

Recommended minimal return time (years)	Cereals	Legumes/grasslands	Root Crops	Oil crops	Fallow	Other
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

3. 1. 1. Duration of crop rotation

The necessity to increase competitiveness has led to simplification and a shortening of crop rotations in several regions of the EU, for example in Germany and in France until recent years (Obst and Diercks, 1971). The average crop rotations in conventional agriculture are between 3 and 4 years long (Pers. Comm.: Emonet, 2009). Long crop rotations are long of 5 to 10 years or more, and are more likely to be found in organic farming systems, where they constitute the main mean of pest and weed control.

3. 1. 2. Legumes

Legumes are introduced in crop rotations in order to increase the amounts of available nitrogen, with reduced use of chemical products. However cropping legumes presents different types of difficulties (Nykaenen, 2009):

- less stable and predictable yields compared to cereals and grasses with inorganic nitrogen fertilisers,
- establishment, management and maintenance of perennial legume-based swards,
- plant diseases of legumes and annual weeds increase in wide row space cultivation,
- bloat, oestrogen problems, and
- environmental risks, e.g. N-leaching.

Further, uncertainties remain regarding the timing of nitrogen mineralisation, leaching risk and the greenhouse gas emissions related to legume cropping (Nykaenen, 2009). Repeating legumes sequences in a rotation is not necessarily a guaranteed solution to reduce N_2O emissions, as the positive effect of N fertiliser's suppression can be counterbalanced by N release during residues decomposition and N leaching. Rationalizing N fertilisation properly can also provide good results in terms of N leaching and N_2O release (Huth et al., 2010).

3. 1. 3. Crop rotations common to various farming systems

Some crop rotations may be found in both the arable cropping systems and the mixed cropping livestock farming systems. Such crop rotations, which apply to both requirements for for markets requirements (e.g. forecasted harvest date and homogeneous products) in arable cropping systems and for feed production in livestock farming systems, are often learnt during farming education. The rotation Oilseed rape/Wheat/Barley is actually one of the most present rotations in France, and is performed both in cropping systems and livestock rearing systems. The same crop rotation may be found in both farming systems, but may present adaptations, such as variations in the sowing/harvest date and input amuonts.

3.2. FACTORS AFFECTING THE CHOICE OF CROP ROTATIONS

There are several factors which lead farmers to choose a given crop rotation, ranging from geographical (climate, soil quality, availability of water) to economic (local market opportunities, needs at the farming system level and farm resources) and socio-cultural, e.g. the education level of the farmer, regarding the way to build a crop rotation (whether himself or whether tradition is structuring cropping production in regions or single farms). See Annex II – section 1. for more details on the factors affecting the choice of crop rotations.

3. 2. 1. Climate

Three types of climates prevail within Europe (Figure 3-1): oceanic, continental and Mediterranean. Secondary climates include the mountain climate, which is not relevant for crop rotations, and the semi-arid climate which is covered under the Mediterranean climate.

The oceanic climate, prevailing in the western parts of Europe (Ireland, the UK, the Netherlands, Belgium, Denmark, most of France, the oceanic coast of Spain, and western Germany), is marked by small temperature range, ample rainfall, cool summers, cool but seldom very cold winters, and no dry season. In oceanic climate, crop rotations may include crops with high needs of water and favoured by mild temperatures, like relatively weak but high yielding varieties, fruits and horticultural species. Further, sewing and harvest dates present flexibility and bring to larger possibilities of crop rotations.

The continental climate, prevailing in Eastern Germany, Poland, Czech Republic, Hungary, Slovakia, Austria and Romania, is marked by warmer summers and cold winters; rainfall is ample, and winters tend to be snowy, especially in the higher areas. Continental climate may benefit crops which need high temperature in summer, and cold winter, for example to end the seeds winter dormancy. Crop rotations in continental climate include very often a sequence of potato and beets, as well as cereals.

The Mediterranean climate, prevailing in areas surrounding the Mediterranean see (Spain, France, Italy, and the whole of Greece, Cyprus), presents cool winters and hot summers, with limited rainfall and dryer summers (Encyclopaedia of the Nations, 2009). Under this climate, permanent cultures like olive and fruit trees, as well as legumes like soybean, faba bean or alfalfa, and maize are common.

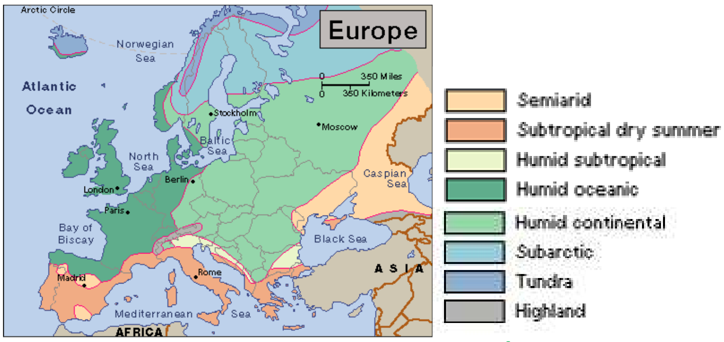


Figure 3-1: Main climates in Europe[4]

3. 2. 2. SOIL QUALITY AND TYPE

Soil quality depends on various parameters, such as soil organic matter or soil deepness. Levels of soil organic matter vary across the EU-27, ranging from 1% of organic carbon in areas of Southern Spain, Southern Portugal, Greece, Italy, to more than 35% of organic carbon in areas of Northern United Kingdom and Ireland, as well as in Sweden and Finland (JRC, 2010)[5].

Further, some soils in arid areas of Europe are subject to desertification especially in the Mediterranean basin, like Southern and central Spain, Southern Italy and Greece (USDA, 2001). In Spain, 31% of the land is under serious threat of desertification (UNCCD, 2009).

Good soils, with stable and high organic carbon levels are able to assure high yields whatever the cropping system or the crop rotation might be, and are well adapted to short rotations and monoculture. On the contrary, crop yields on soils with low organic carbon content are more dependent on the rotations types and management practices.

[4] printable-maps.blogspot.com/2008_09_01_archive.html
[5] eusoils.jrc.ec.europa.eu/esdb_archive/octop/octop_download.html

3. 2. 3. AVAILABILITY OF WATER / IRRIGATION

The major sources of water for crops are piped water from rivers, lakes and groundwater. The European hydrographical network appears dense and well connected in most European countries (JRC, 2007), and present good levels of annual precipitations[6]. The share of agriculture in the national water extraction varies between a few percent in Eastern Europe to 50–70% in South-western European countries (EEA, 2003).

Irrigation systems can be installed in order to comply with insufficient water availability (see Annex II – section 1.1). In irrigated areas, a tendency of applying shorter rotations can be observed (Table 3-2; ITAB, 2008 and Villain, 2009), e.g. in the Pays de la Loire region of Western France, rotations practiced on irrigable fields in organic farms are shorter than rotations based on similar crops but applied on non-irrigable lands (ITAB, 2008). This is also the case in intensive conventional agriculture farming systems.

Table 3-2: Variations of a crop rotation with and without irrigation (ITAB, 2008)

Crop	Irrigated rotation	Non irrigated rotation
1	Faba bean/Peas	Faba bean/Peas
2	Wheat	Wheat/Maize
3	catch crop	Sunflower
4	Maize	Wheat
5		catch crop
6		Maize

The choice of crop rotation has important implications for both irrigation and drainage management. The drainage criteria also depend on the crop rotation, the irrigation supply, the irrigation water quality and the leaching fraction (Croon, 1996). Lower yearly drain flow and lower flow-weighted N concentration in drain flow under maize–soybean and soybean–maize than under continuous maize (Ma, 2007).

3. 2. 4. CROPS AND FARMING SYSTEMS

The most cultivated crops in Europe are cereals (wheat, barley and grain maize), root crops (sugar beets and potatoes) as well as rapes (Eurostat, 2009). These crops correspond to an optimal adequacy between the climatic and soil conditions encountered in Europe, as well as to the local and international market conditions. Further, some crops like forage species, triticale, grain maize and numerous legumes are partly or completely consumed on farm, as feed for livestock. As a consequence, the choice of these crops is less dependent on the market opportunities and they are consistently inserted in the crop rotations.

The activity of a significant part of farms in the EU involves livestock rearing (e.g. pigs, cows or sheep) besides crop production. These farms are commonly referred to as "mixed farms" which account for 55% of all farms in the EU (Figure 3-2) and are found on close to 40% of the EU UAA (Eurostat database). In the EU, most farming systems cover arable farming systems (36%) and mixed farms (55%).

[6] printable-maps, 2009, annual precipitations in Europe

This report focuses on the most practiced types of farming systems at the EU level, which are thus expected to impact most the crop rotations choices at the EU level, i.e.:

- arable farming systems (36% of the EU UAA - see section 3.3),
- mixed farming systems involving cattle rearing and fattening farms (19% of the EU UAA - see section 3. 4. 1),
- mixed farming systems specialised on pigs (4% of the EU UAA - see section 3. 4. 3), and
- mixed farming systems involving dairy farms (27% of the EU UAA - see section 3. 4. 2).

Other mixed cropping livestock farming systems include notably sheep, geese, ducks, and poultry, which are all expected to involve specific aspects on crops needs and crop rotations choices (Figure 3-3; see Annex II – section 1.2 for more details on crops and farming systems).

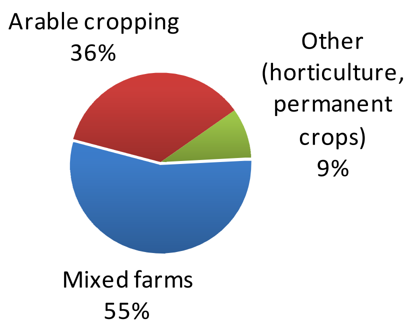


Figure 3-2: Farming systems in the EU (Eurostat database, data for 2007)

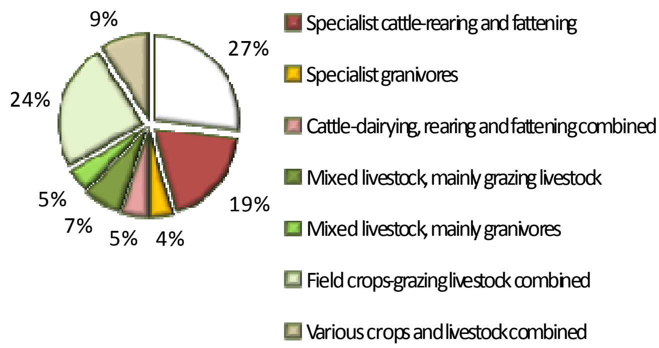


Figure 3-3: Share of mixed livestock farming systems (Eurostat database, data for 2007)

Lastly, the choice of crops and crop rotations can also depend on the cropping systems. In conventional agriculture, chemical compounds are critical management tools to compensate unsatisfactory soil and climate conditions, apart from their expected effect on yields. The farmer can therefore choose crops less limited by natural conditions. As a result, crop rotation is not a compulsory management practice under conventional agriculture. On the contrary, organic agriculture standards limit the use of chemicals and crops have to be chosen with attention, according to the natural conditions, and crop rotations are used as a major type of management tool regarding pest and disease control.

3. 2. 5. Market opportunities

Long-term trends in the share of crops in the cropping areas reflect changes in the markets of agricultural commodities, which play an important role in farmers' decisions when they choose the crops to grow. Agricultural policies have a strong potential in modifying cropping trends. For example, the quota system applied to sugar beet production from 2006/2007 had a major impact on Central European, European sugar beet production, reorganising crop rotation patterns in many cases by causing the disappearance of sugarbeet from crop rotations (Macàk, 2009). This resulted in changes in crop rotations to favour winter wheat and winter barley as opposed to other break crops, and therefore overall levels of fertilisers and pesticides uses increased with the restructured crop rotations and replacement crops.

3.3. ARABLE FARMING SYSTEMS

Arable farming addresses a farm type specialised in growing crops as opposed to dairy farming, cattle farming, etc. There is a significant variability regarding the farm characteristics among the Member States, e.g. in the areas dedicated to arable cropping systems, numbers and size of holdings in each Member State. For example, Bulgaria and Hungary have the highest proportion of agricultural land dedicated to arable crop production, with frequent and big farms covering respectively 76% and 59% of national total Utilised Agricultural Area (UAA) (Eurostat, 2007). In parallel, France, Spain, Germany and the United Kingdom own half of the EU-27 UAA dedicated to arable cropping systems, distributed among a few very big farms. Finally, arable farming systems are least represented in Ireland and Luxemburg. This section may base the analysis on data collected for each of these farms types (see Annex II – section 2. for more details on arable farming systems). The crop rotations collected in the MS and regions identified as relevant with regards to arable cropping lead to the inventory in Box 3-2.

Poland is the Member State with the second highest number of farms specialised in arable crops (4^{th} MS in terms of surface area – Eurostat, 2009).The polish rotations counting one or more legumes are the most practiced in arable cropping systems, covering more than 45 % of the cultivated surfaces (Majewski, 2009). The results of this survey help identify a very common rotation in arable cropping farms (Majewski, 2009; Figure 3-4):

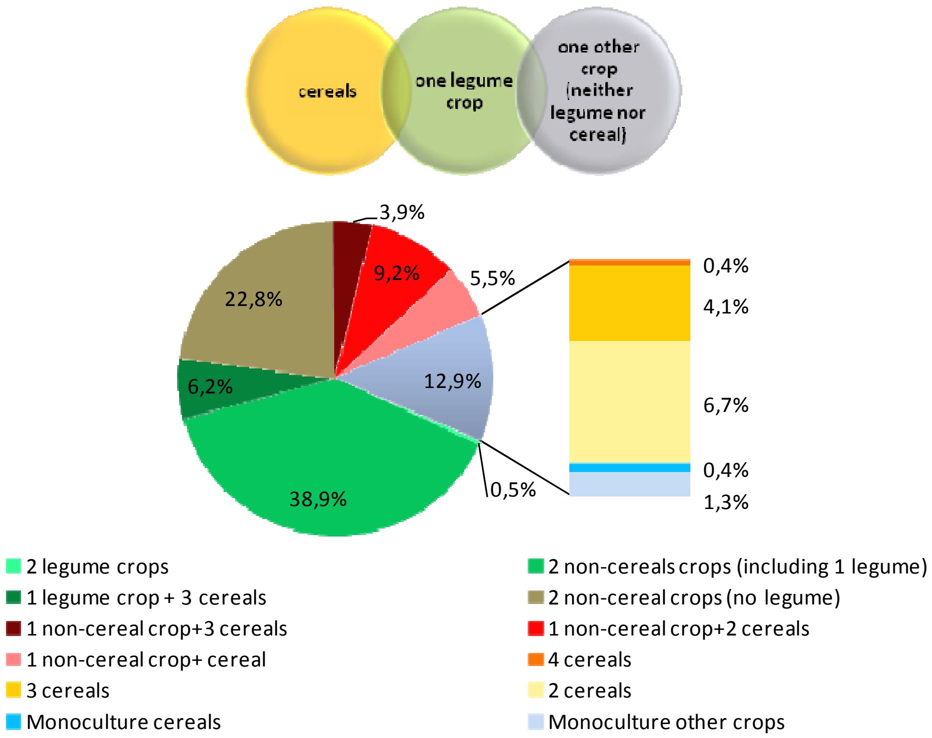


Figure 3-4: Rotation schemes in a sample of polish arable crop farms (Majewski, 2009)

3. 3. 1. CROP ROTATIONS WITH LEGUMES

Legumes contribute to maintaining soil fertility and provide the necessary organic nitrogen source for cultivated plants by fixing atmospheric nitrogen, thanks to a symbiotic relationship with certain bacteria (rhizobia), which are found in the root nodules of these plants. In crop rotations with legumes, crop management is actually based on reduced use of synthetic fertilisers, and soil fertility maintenance requires specific attention, which applies well to organic farming systems. As there is no organic manure produced within the farming activity, arable crop farms tend to apply crop rotations including legume crops.

3.3.1.1 Long crop rotations

Long crop rotations are long of 5 to 10 years and more, and more present in organic farming systems. The rotations described in this section are presented in Annex II – section 2.1.1.1.1.

- **Medium/rich soils**

The Ile-de-France region of France is specialised in arable cropping. In this region, two main types of rotations prevail, depending on the pedoclimatic conditions:

- The rotations with alfalfa, which cultivation occurs more likely on the very mildly acid soils, with a pH of 6.2 - 7.8
- The rotations with other types of legumes on more acidic soils.

Alfalfa appears in the longest rotations (length 6 to 11 years), as a leguminous head of rotation for 2 or 3 years (see Table 3-3). Approximately 50% of rotations practiced by organic farmers in the Ile-de-France region include alfalfa, which is commercialised either dehydrated or as hay (ITAB, 2008). Depending on the market conditions and the soil quality, the rotations can be shorter or longer, with the possible insertion of secondary crops in deep soils. Rotation 1 in Table 3-3 is performed on approximately 80% of the Ile-de-France organic surfaces with a rotation including alfalfa, and usually counts three repetitions of wheat. An alternative rotation (Rotation 2 in Table 3-3) enables the insertion of a fourth wheat sequence in the rotation as well as the insertion of a complementary crop, e.g. oil crop like Oilseed rape or Flax (ITAB, 2008).

Table 3-3: Rotations in organic arable cropping systems in France (ITAB, 2008)

		Oceanic climate			*Continental climate*
		Deep and mildly acid soils	*mildly acid soils*		*mildly acid soils*
		Ile de France			
year	*Type of crops*	*Rotation 1 3x Wheat*	*Rotation 2 4x Wheat*	*year*	*Rhone-Alpes 4x Wheat*
1	Alfalfa	Alfalfa		1	Alfalfa
2				2	
3	(Alfalfa)	(Alfalfa)		3	
4	Wheat	Wheat		4	Wheat
5	Secondary Cereal or Oil crop	Spring Barley, Spring Wheat or Triticale	Oilseed rape Or *Flax* in very specific cases	5	Common Wheat, *Barley*, *Triticale*, *Rye* or Maize
-	Oil crop	-		6	Sunflower or Oilseed rape
6	Wheat or (Secondary Cereal)	(Oat, Rye or Sunflower)	Wheat	7	Wheat
-	(Secondary Cereal)	-		8	Barley, Triticale, Rye or Maize *(on deep soils)*
7	Legume	Fava bean, Peas or Lentils		9	Clover or *Fava bean*
8	Wheat	Wheat		10	Common Wheat
-	Wheat	-		11	Common Wheat

		Oceanic climate			*Continental climate*
		Deep and mildly acid soils	*mildly acid soils*		*mildly acid soils*
year	*Type of crops*	*Ile de France*		*year*	*Rhone-Alpes 4x Wheat*
		Rotation 1 3x Wheat	*Rotation 2 4x Wheat*		
9	(Secondary Cereal)	(Triticale or Spelt)		12	Barley, Triticale or Rye
10	Legume	Fava bean, Clover or Winter Peas			
11	Wheat	Wheat			

In the course of this research, two main variants of the rotation type with legume but without alfalfa were identified, in different climate and soil conditions. In the former, sunflower is inserted in the rotation after wheat and the potential secondary cereal. This rotation is practiced mostly in the drier soils of the South of the Ile-de-France region, under oceanic climate, on 25% of the organic parcels. In Austria, a similar rotation is commonly practiced in the foothills of the Alps, in medium to good soils, under continental climate. In this case, the optional secondary cereal is inserted after the row crop, as opposed to the rotation in the Ile-de-France region.

In the second variant, the insertion of an oilseed rape sequence between the first and the second wheat sequences enables the cultivation of an additional 3rd wheat sequence within the rotation. Oilseed rape production under such conditions can lead to nitrogen deficit in soils, which requires external organic manure application on fields. This rotation is less frequently practiced, accounting for approximately 15% of the organic parcels in Ile-de-France (ITAB, 2008).

For Polish farms specialised in conventional arable cropping, sugar beet is one very important crop. Poland actually produced 8,715,000 tonnes of sugar beet in 2008, i.e. more than 8.5% of the EU production. Limited by the sugar quota and the latest sugar reform, the polish sugar beet production shows a down trend as observed in Europe in general (Eurostat database). A transition to oilseed rape can be observed in the same time. Typical rotations were identified in Poland including legumes; they are presented in Table 3-4.

Table 3-4: Main rotation types in arable cropping systems in Poland (Majewski, 2009)

	Humid continental climate			
	Poland			
year	*Rotation 1*	*Rotation 2*	*Rotation 3*	*Rotation 4*
1	Peas	Peas	Alfalfa	Peas
-	-	-		Triticale
2	Winter Wheat	Oilseed rape	Wheat	Triticale
3	Rye	Wheat	Wheat	Wheat
4	Sugar beet	Sugar beet	Sugar beet	Potato
5	Barley	Mixed Cereals	Barley	Barley

- **Poor soils**

In the course of this research, no long rotations including legumes were specifically mentioned for poor quality soils.

3.3.1.2 Short crop rotations

Short crop rotations of less than 5 years are mainly found in conventional farming systems, and the average crop rotation length in conventional farming systems is close to 3 to 4 years (Pers. Comm.: E. Emonet, and P. Guillaume, 2009).

Medium/rich soils

A sequence of legume crops is most commonly followed by a sequence of cereal or maize, generally the crop that is supposed to benefit the most from the nitrogen enriched soil the legume leaves behind (see Figure 3-5). Wheat being the principal product of the EU, both in terms of harvested area and volume, examples of short rotations are often limited to a sequence of a legume crop and the wheat or durum wheat itself (Italy, Spain and Hungary).

Table 3-5: Short rotations with legumes and wheat in conventional arable cropping systems in Member States (diverse sources, 2009)

		Subtropical dry climate						*Humid continental climate*	*Oceanic climate*			*Humid continental climate/ Oceanic climate*
		Italy				*Spain*			*France*			
Year	***Type of crops***	***R 1***	***R 2***	***R 3 less common***	***R 4***	***R 1***	***R 2***	***Hungary***	***R 1***	***R 2 Ile de France***	***R 3 Picardie***	***Austria /France***
1	Legume	Soybean	Fava bean	Bean	Alfalfa **3 years**	Fava bean	Fallow	Peas	Peas	Legume	Legume	Peas
2	**Wheat**	**Durum Wheat**	**Durum Wheat**	**Durum Wheat**	**Wheat** or *(irrigated)*Maize	**Wheat**	**Wheat**	**Wheat**	**Wheat**	**Cereal**	**Cereal**	**Wheat**
(3)	*(other crop)*				**Bread Wheat or Durum Wheat**				Maize or **Barley**	**Oilseed rape**	**Beet**	**Oilseed rape**
(4)	*(other crop)*									**Cereal**	**Cereal**	**Winter Barley**

The rotation pea followed by wheat is one of the most practiced rotations in Hungary (Birkas, 2009). The rotation R4 is practiced in Italy, with bread wheat in Northern Italy and either bread wheat or durum wheat in the other regions. In Italy and France, the rotation includes maize, where irrigation water is available. The presence of alfalfa in arable farming systems is justified by the fact that alfalfa is sold outside the farm as dehydrated hay. In the Ile-de-France region and Picardie region (France) the most popular rotations, accounting each for 11% of the rotations practiced in these regions are R2 and R3 (Arvalis, 2008). The rotation peas/wheat/oilseed rape/winter barley accounts for 8.4 – 11.4 % of rotations practiced in the Centre, Picardie and Haute-Normandie regions. These rotations show the same crop pattern as the typical rotations of arable cropping farms performed in Poland, which is subject to a continental climate with medium soils (Majewski, 2009).

Short rotations also include the sequence "legume followed by cereal or maize" (see Annex II – section 2.1.1.1.2 for more detail), with an additional root crop, oilseed rape or secondary cereal in the 3rd year and even in the 4th year. In some regions, where maize is frequently cultivated in monocultural systems (for grain or for silage), maize may also be rotated, e.g. with soybean. However, since the apparition of the quarantine pest *Diabrotica virgifera virgifera* (Western corn rootworm) in several EU Member States (e.g. Italy Veneto, Piemonte or eastern France), maize monoculture may no longer be possible, and may even be forbidden locally (see section 3.3).

Poor soils

In the course of this research, no short rotations including legumes were specifically mentioned for poor quality soils.

3. 3. 2. Crop rotations without legumes

3.3.2.1 Long crop rotations

Long rotations allow limiting the use of chemical inputs, including nitrogen fertiliser. Therefore, legumes, which provide naturally nitrogen to soils and crops, are fully integrated in long rotations, and long rotations without legumes appeared rarely in the course of this research.

- **Medium/rich soils**

The encountered long crop rotations are longer than 5 years without legume crops in arable cropping systems and they principally involve cereals in France and Sweden (see Table 3-6). The sequence of cereals is occasionally broken by a root crop (beets or potatoes), turnip or fallow.

In Poland, long rotations performed in the arable farming systems also present a succession of cereals (winter wheat and triticale) after oilseed rape as the head of rotation (see Annex II – section 2.1.1.2.1.). Interestingly, this crop rotation is also present in Austria in mixed livestock farming systems.

Table 3-6: Long rotation types without legume and root crop in arable cropping systems (Majewski, 2009; Pers. Comm.: Oberforster, 2009)

<table>
<tr><th></th><th></th><th colspan="6">Humid continental climate</th></tr>
<tr><th rowspan="2">year</th><th rowspan="2">Type of crops</th><th rowspan="2">Poland</th><th colspan="5">Austria (mixed livestock farming systems)</th></tr>
<tr><th>Rotation 1</th><th>Rotation 2</th><th>Rotation 3</th><th>Rotation 4</th><th>Rotation 5</th></tr>
<tr><td>1</td><td>Oilseed rape or Maize</td><td colspan="5">Oilseed rape</td><td>Maize</td></tr>
<tr><td>2</td><td>Winter Cereal</td><td colspan="4">Winter Wheat</td><td>Winter Rye</td><td>Winter Wheat</td></tr>
<tr><td>3</td><td>Cereal</td><td>Triticale</td><td>Spring Barley</td><td>Winter Wheat</td><td>Winter Barley</td><td>Silage Maize</td><td>Oilseed rape</td></tr>
<tr><td>4</td><td>Cereal</td><td>Winter Wheat</td><td>Winter Wheat</td><td>Spring Barley</td><td>Grain Maize</td><td>Winter Wheat</td><td>Winter Barley</td></tr>
<tr><td>5</td><td>Cereal</td><td>Triticale</td><td>Grain Maize</td><td>Durum Wheat</td><td>Winter Wheat</td><td>Spring Barley</td><td>Maize</td></tr>
</table>

- **Poor soils**

No long rotations without legumes were specifically mentioned for poor quality soils in the course of our research.

3.3.2.2 Short crop rotations

- **Medium/rich soils**

In several MS of the EU, short rotations without legumes involving only cereals are present. The rotations do not include more than two cereal species, and not longer than 2 years each (see Annex II – section 2.1.1.2.2 for rotations descriptions).

Another type of short rotation without legumes practiced on good quality soils includes beet as a head of rotation and was identified in different climate and soil conditions: in the clay-calcareous soils in the centre and north of France, facing an oceanic climate, in the medium soil of Poland, facing a continental climate, in the alluvial plain of the north of Italy, facing a continental climate, as well as in the mountain regions of Austria, facing a continental climate. In this rotation, beet is systematically followed by a cereal (Austria, Poland and France) or maize (Italy). Most of the time, one secondary cereal (France) or two (Poland) are added after the first cereal. This rotation is highly present in the Northern regions of France, and represents 13.4% of the rotations in the Nord Pas de Calais region, and 6.8% in the Picardie region, which makes it the second crop rotation in both regions (Arvalis, 2009).

Two rotations: oilseed rape – wheat and sunflower – wheat, were cited as the most practiced rotations in Hungarian arable cropping systems, where wheat, oilseed rape and sunflower are the three out of the four most grown crops after maize.

- **Poor soils**

A typical crop of the poorer soils and cold climate in Poland is potato. Short rotations without legumes and including potato were identified in Poland and also in Hungary. The rotations begin with potato as the head of rotation, followed by two or three years of cereals, for example, rye in Hungary or barley, oat, rye or triticale in Poland (see Annex II – section 2.1.1.2.2).

Box 3-2: Main crop rotations in arable farming systems

In arable farms, the most practiced rotations in conventional systems are on average 3 to 4 years long rotations (from 2 to 6 years), and tend not to include legume crops, focusing principally on market crops, especially cereals (winter wheat, barley, rye, oat, triticale etc.), which occupy high proportions in the rotation (up to 75 to 100%).These rotations may also include root crops, oilseeds or maize. Rotations including legumes in conventional agriculture are rare, mostly short (2 to 4 years) and were observed in zones with humid or oceanic climates.

In organic farming, rotations observed are longer (6 to 12 years long) and present a higher diversity of crop types: legumes, cereals, oilseeds and sometimes root crops or maize.

3. 3. 3. Monocultures

Monoculture refers to the cultivation of a single crop on the same field, year after year and usually over a long time period, without rotating with other crops (i.e. neither market nor cover crops). In France and Poland, monocultures only represent 1% and up to 5% of UAA respectively. Crops grown in monoculture are mostly strong crops, which naturally resist to pests and weeds and which management do not depend on chemicals only, as well as market crops, i.e. crops with a good economic performance. For example, rice in Northern Italy and cotton in Southern countries (Greece, Spain, Portugal) are exclusively cultivated in monoculture. Maize is a very frequent monoculture, mostly found in Southern Europe, and its high water needs make its spread depend on the price and availability of water, notably irrigation. Other monoculture systems include cereals, such as rye, oat, barley or wheat, mostly identified in Northern Europe and in Mediterranean regions specifically for durum wheat (see Annex II – section 2.2).

Monoculture actually increases the risks of extended contaminations, due to the maintenance of an environment favourable to the same pests and weeds, year after year, leading to negative allelopathy effects, stimulation of diseases and yield decline. A recent report of Alliance Environnement (2007) estimated that maize and legumes are the only viable intensive crops that would have better environmental benefits than cotton. Farmers may thus periodically introduce a break crop, in order to break the cycle of pests and weeds adapted to the crop grown in monoculture (see Annex II – section 2.2). For example, farmers in the South West of France (Landes region) use to insert sunflower during one year on the field usually dedicated to maize monoculture, every 15th to 20th year. Continuous cultivation of maize actually provides good conditions for an increase in *Diabrotica* population size over time, if not properly managed. Therefore in recent years, the proportion of monoculture of maize has largely decreased in Hungary and Slovakia, which are the MS the most infected with Diabrotica.

3. 3. 4. CONSERVATION AGRICULTURE AND CROP ROTATIONS

Crop rotations may be used as a complementary technique to conservation agriculture (Roth, 1996). Conservation agriculture refers to several practices which permit the management of the soil for agrarian uses, altering as little as possible its composition, structure and natural biodiversity and defending soil from degradation processes (e.g. soil erosion and compaction). Crop rotations can help avoid many of the problems associated with conventional tillage pratices, e.g. increased soil compaction, perennial weeds plant diseases, and slow early season growth (Roth, 1996). The biomass yields increase more than with conventional tillage only (Lopez Cedron, 2009). Similarly to crop rotations under certain circumstances, conservation tillage also provides economic benefits to the farmer by reducing machinery use frequency (see Annex II – section 2.3 for more details on conservation agriculture). Also, conservation agriculture may reduce the negative impacts of monoculture on the environment.

3.4. MIXED LIVESTOCK FARMING SYSTEMS

This section will focus on the most practiced types of mixed farming systems at the EU level, thus expected to impact most the crop rotations choices at the EU level (see Figure 3-3):

- mixed farming systems involving cattle rearing and fattening farms,
- mixed farming systems specialised on pigs, and
- mixed farming systems involving dairy farms.

3. 4. 1. CATTLE REARING AND FATTENING FARMING SYSTEMS

Spread of cattle rearing and fattening farming systems in the EU

In absolute number of heads, almost half of the cattle in the EU is owned by France, Germany and the United Kingdom. Then five MS (ES, IE, IT, NL, PL) account for 30% of heads of the EU, each between four (NL) and six million (IT) heads. The 12 new MS own only 15% of cattle heads in the EU (Eurostat, 2007; see Annex II – section 3.1). The largest surface areas of cattle rearing specialised farms in the EU are in France, Ireland, Spain and the UK (70% of EU cattle rearing farm area), while Hungary and Poland account each less than 1% of cattle rearing farms (see Annex II – section 3.1 for more details on cattle rearing and fattening farming systems location).

Impact of cattle feed on crop rotations

The specific needs of ruminants in feed are reflected in the composition of crop rotations in cattle rearing farms. If cattle rearing farms generally practice rotations of a higher level of diversity, the relatively low share of rotations with legume can be explained by the habit of not inserting fallow lands in the rotation, but attributing a fix area to grazing (ITAB, 2008).

As for France, a general characteristic of rotations in this system is the presence of either 3-4 years of temporary grasslands or a legume crop or both in the rotation (Pers. Comm.: Villain, 2009) followed by cereals, which in several cases appear as “cereal mix”, i.e. several cereals are sown in the same time on the same field. In Poland, over 20% of cereal surfaces are cereals mix, important especially in livestock farms as a component of the feed ratio and used for producing farm made concentrates for animals. The most commonly grown mixes are oats and spring barley, or on better soils spring wheat, oats and spring barley. Further, about 30% of the area of cereals mix is covered by protein crops, e.g. peas or vicia sativa (Majewski, 2009).

The crop rotations performed in cattle rearing and farming systems are summarised in Box 3-3.

3.4.1.1 Crop rotations with legumes

See introduction to section 3. 3. 1 for details on legume benefits.

- **Long crop rotations**

In the typical French regions of cattle rearing, i.e. the hilly Centre, Franche Comté and Auvergne, long rotations with several years of temporary grassland characterise rotations in organic farms. Some examples are presented in Annex II – section 3.2. In many cases, 3 to 5 years of temporary grassland is followed by wheat, then a variety of other crops. The temporary grassland period begins the rotation in order to improve soil fertility by reactivating soil microbial activity as well as mobilising minerals while enriching the soil’s biomass content. These rotations of 7 to 11 years include at least one supplementary sequence of legume crop after the temporary grassland, for example soybean, fava bean, peas alone or sawn mixed with cereals (see Annex II – section 3.2).

While maize is not a determinant crop of rotations in Centre, Franche Comté and Auvergne regions, rotations including silage or grain maize are the most practiced in Normandy, Aquitaine and Pays de la Loire regions in organic cattle rearing farms, and maize takes the place of wheat in the rotation, after the grassland sequence (see Annex II – section 3.2). A cereal mixed with protein crop (catch crop) is present in these rotations as well, generally before the temporary grassland. In Aquitaine, variants of this rotation exist, in regions with poor soils, where it is limited to zones with poor soils, and focuses mostly on the production of row plants with deeper roots, such as maize (two repetitions) and sunflower. In oceanic regions, variants include an extra period of wheat after the maize sequence.

In the cattle rearing region on Castile and León (Spain), soils rich in clay and a high average altitude allow 5-year rotations, with alfalfa, followed by two years of root crops (sugarbeet or beet, then potato) with a season of wheat or maize at the end of the rotation (see Annex II – section 3.2).

- **Short rotations**

Short rotations with legumes in cattle rearing farms are rare, as the temporary grassland period usually makes the rotations at least 7 years long. In the examples found in France either the temporary grassland period is missing (Centre, Champagne) or it is only followed by one other crop (see Table 3-7).

Table 3-7: Short rotations of cattle rearing farms (FNE, 2009; ITAB, 2008; Arvalis, 2009)

<table>
<tr><th></th><th colspan="3">Oceanic climate</th><th colspan="2">Oceanic / subtropical climate</th></tr>
<tr><th rowspan="2">year</th><th>France - Centre region</th><th>France - Champagne, Beauce</th><th>France - Morvan</th><th colspan="2">Spain, Castile and León</th></tr>
<tr><th>Organic agriculture</th><th colspan="2">Conventional agriculture</th><th colspan="2">Conventional agriculture</th></tr>
<tr><td>1</td><td>Legume</td><td>Peas</td><td rowspan="3">Temporary grassland</td><td>Legume</td><td>Chickpea</td></tr>
<tr><td>2</td><td>Winter Wheat</td><td>Winter Wheat</td><td>Cereal</td><td>Winter Wheat</td></tr>
<tr><td>3</td><td>Barley</td><td>Beet</td><td></td><td></td></tr>
<tr><td>4</td><td>Sunflower or Potato</td><td>Winter Wheat</td><td>Oilseed rape</td><td></td><td></td></tr>
</table>

In the Centre region of France, a four year long rotation is widely in use, with one sequence of legume, followed by a sequence of wheat, a secondary cereal (barley), and completed with a sequence of sunflower or potato (root crop). A similar rotation exists in conventional farming systems in Champagne with an inverted order of the second cereal and the root crop which accounts for approximately 9 % of rotations in the region (Arvalis, 2009).

In Northern France and in the Morvan region, a simple version of rotations with temporary grassland is practiced, and is composed of 3 years of pasture, in alternation with one year of winter wheat or oilseed rape production.

3.4.1.2 Crop rotations without legumes

Rotations without legumes, based on wheat and other cereals, are not typical of livestock rearing systems where temporary grasslands for grazing are generally used in the rotation.

In France and Belgium, rotations of 2 to 3 years can practically be built from one or two years of cereals (wheat or barley) followed by one or two years of root crop (beet or potato), maize and oilseed rape. The rotation including cereals followed by beet is, with 9% of rotations, the most used in the Ile-de-France region. The following rotations are the most practiced in Wallonia (Belgium): wheat/beet 11%, wheat/maize 6% wheat/potato 2.8 % and wheat/oilseed rape 2.5%.

A rotation of root crop (potato or beet) and one or two years of cereals is widely practiced in Nord Pas de Calais and Picardie regions (France), accounting for respectively 13.4% and 11.4% of local rotations. Rotations without wheat, with a focus on other cereals (triticale, maize) or root crops (potato or beet) are practiced in Belgium and Poland (see Annex II – section 3.2.1.1). Flax or oilseed rape can complete these rotations.

- **Monocultures**

Monoculture of silage maize is frequent in cattle rearing farms, notably in Poland, Northern Italy and Begium, as it provides forage for the animals (Majewski, 2009). A tendency towards more monoculture in cattle rearing farming systems can be observed in Poland, although the share of monoculture is under 1 % of Polish UAA. This actually means that cattle rearing farms have the lowest share of monocultures amongst all observed farm types in Poland.

Box 3-3: Main crop rotations in cattle farming systems

In conventional cattle rearing systems, the most practiced rotations are 2 to 4 years long, and often include sequences of root crops, cereals and oilseeds, with or without legumes (1 year at the beginning of the crop rotation). Monoculture of silage maize is also frequent.

In organic cattle rearing farming systems, rotations observed are very long, from 9 to 12 years, and often begin with a 3-4 years long period of temporary grasslands or a legume crop, followed by sequences of cereals (winter wheat, barley, triticale, "cereal mix", etc.) and legumes. The rotation can also include a variety of crop types, such as oilseeds, rootcrops (potatoe, sugar beet, beet) or maize.

3. 4. 2. Dairy farming systems

About 28% of mixed livestock farming systems surface areas are dairy farming systems. This specialisation is strongly regionalised, over 80% of dairy production being produced to the north of a line joining Bordeaux (France) and Venice (Italy) especially concentrated in Lombardy (Italy), Schleswig-Holstein (Germany), South-West and North West regions of the UK, Southern and Eastern Ireland, most of Belgium and the Netherlands, Cantabria (Spain) and Malta (FADN EU 1999; Centre d'Information des Viandes, 2009 - see Annex II – section 4.1).

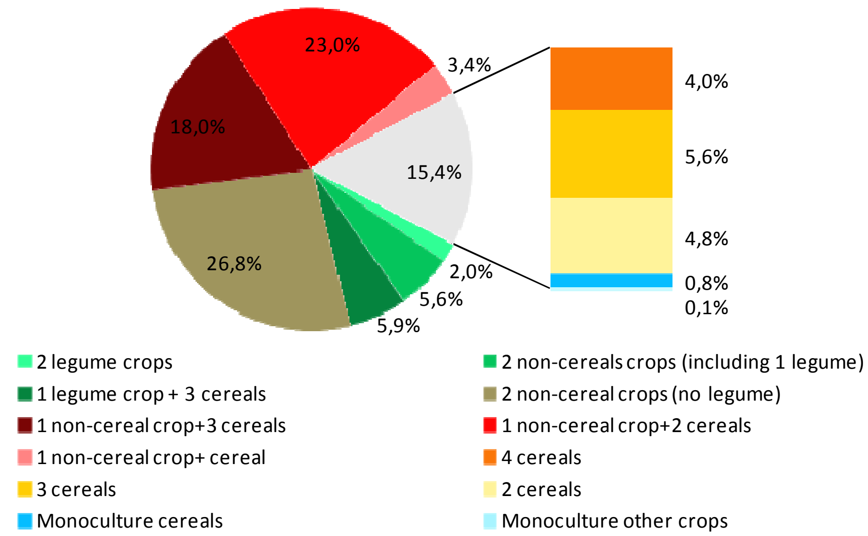


Figure 3-5: Rotation schemes in a sample of Polish dairy farming systems (Majewski, 2009)

In Poland, the share of dairy farms practicing rotations with legumes was evaluated to 15%, another 15% of rotations being composed exclusively of cereals and 27% of rotations including no legume and two crops other than cereals. Monoculture was practiced on less than 1% (bright blue-0.4% and light blue-0.4% on the figure) of the fields, which is the lowest share of monocultures amongst all observed farm types (Figure 3-5).

The crop rotations performed in dairy farming systems are summarised in Box 3-4.

3.4.2.1 Crop rotations with legumes

See introduction to section 3. 3. 1 for details on legume benefits.

- **Long crop rotations**

  - **Medium/rich soils**

Some rotations common to organic dairy farming systems contain only legumes and cereals, and appear in regions specialised in dairy farming systems, such as Brittany and Normandy (France) and Denmark, but similar rotation patterns can also be observed in less specialised regions such as Centre and Pays de la Loire regions (France) (see Annex II – section 4.2.1.1).

The succession of 2-3 years of alfalfa and one year of wheat is characteristic in Brittany and the Centre region. Wheat can be followed by either another cereal sequence (wheat or oat) or a legume sequence (e.g. fava bean) or both in the form of a mix of triticale and peas. Generally, rotations alternate one or two years of cereals and a legume crop.

Some rotations, present in equally humid regions, begin with 2 to 4 years of temporary grassland, followed by either maize (France) or cereals (France, Denmark). Cereal and protein crop mixes are often used in the rotation after cereals, most often performed before the period of temporary grasslands. In Normandy, rotations include two periods of temporary grassland.

Variants of this rotation also include a sequence of sunflower (France, organic) or marrow and spelt (typical of British organic dairy farming systems).

Typical rotations of dairy farming systems also include oilseed rape followed by wheat, particularly on good and humid soils (Poland and Denmark). Oilseed rape actually provides beneficial effect as a preceding crop for wheat, such as breaking wheat pest and weeds cycles (Orlovius, 2003). This rotation can also include a legume sequence: spring fava bean in France (organic dairy farming systems) and peas in West Denmark (conventional dairy farming systems), followed by cereals and maize. A variant in Poland and Denmark includes a root crop well (sugar beet and potato respectively).

  - **Poor soils**

On poor soils of Nord Pas de Calais region (France, see Annex II – section 4.2.1.1), a five year rotation is composed of two repetitions of cereals (wheat, spelt or triticale) sawn after a root crop (potato, beet or endive) or a legume (fava bean).

- **Short crop rotations**

A short and widely used rotation type alternates maize and wheat, and optionally a legume (soybean or alfalfa) (Table 3-8), and was recorded in Germany, France and Italy. Insertion of legumes depends on market conditions. Maize is cultivated either for grain or silage, and can be rotated with alfalfa (which lasts normally 3 years in Northern Italy).

Silage maize can be cultivated in a double cropping system (i.e. two crops are cultivated in 12 months), thus being associated either with Italian ryegrass (for hay or silage), barley for silage or winter wheat for silage. This double cropping system ensures continuous soil cover during the year and a higher dry matter production compared to maize alone. In the double cropping system, maize hybrids are normally shorter (e.g. FAO class 500 or 600) than those used when maize is cultivated alone (FAO class 700).

Table 3-8: Rotations in conventional dairy farming systems (Pers. Com.: Roux, 2009 ; Clinkspoor, 2009; Bechini, 2009)

	Oceanic/Humid continental climate	*Oceanic climate*	*Subtropical dry climate*	
			Italy	
year	***Germany***	***France***	***Rotation 1***	***Rotation 2***
1	(Soybean)	-	Alfalfa (3 years)	-
2	Maize	Maize	Maize	Maize
3	Wheat	Wheat	Maize	Winter Wheat, Barley or Italian Raygrass
			Maize	

Another rotation alternating legumes and cereals is practiced in France. In one variant, in conventional farming systems of Normandy (France), one legume sequence is followed by three years of cereals. In another variant, in organic dairy farming systems of Brittany (France), a sequence of cereal mix is followed by two sequences of legume (see Annex II – section 4.2.1.1).

3.4.2.2 Crop rotations without legumes

In dairy farming systems, few rotations exclude legumes strictly, and include in this case either a root crop (Poland) or rye (East Denmark) (see Annex II – section 4.2.1.1).

In Poland, two rotations without legumes and root crops relevant to dairy farming systems were identified, and are practically sequences of different cereals such as triticale, barley, rye, and maize, which is close to monoculture of cereals.

Box 3-4: Main crop rotations in dairy farming systems

A general characteristic of mixed farms appears more significantly in dairy farms, rotations begin with a sequence of temporary grasslands or legume crop, both in conventional and organic farming systems. Also, monoculture is not common to dairy farming systems.

In conventional farming systems the rotations are generally shorter than 5 years and have a high proportion of cereals, with optional occurrence of oilcrops, silage maize or root crops in the rotation.

In organic dairy farming systems, rotations can be as short as 3 years or as long as 15 years. Long rotations usually include high proportions of legumes (up to 85%), but sometimes low (20%) with high proportions of cereals. Rotations commonly include one or several 3-5 year long temporary grassland period. Similarly to conventional systems, rotations may include oilcrops, silage maize or root crops.

3. 4. 3. PIG REARING AND FATTENING FARMING SYSTEMS

At the EU level, a notable disparity appears among MS regarding the granivore specialist farms[7]. This agricultural activity appears intensive, covering 3.5% of EU UAA but involving more than 11.2% of farms. Granivore rearing appears mostly extensive in Hungary, with 36.1% of farms specialised in granivore rearing, and in Poland, with 11.1% of UAA of granivore rearing farming systems (Eurostat, 2007). Granivore rearing appears mostly intensive in a few MS owning more than half of the pigs reared in the EU: Germany, Spain, France, Poland and the Netherlands (Eurostat database, data of 2008; see Annex II – section 5.1 for more details).

Pig feed being principally based on cereals and crops of high energy value, the rotations practiced on pig farms are principally based on these crops. In a survey carried out in Poland, the share of farms practicing rotations with legumes is evaluated to 15%, i.e. one third of this rotations share in arable cropping systems. 29% of rotations are composed exclusively of cereals and 21,5% were run without legume and with one crop other than cereals (mostly root crops). Monoculture was practiced on 2% of the fields, which is the highest share amongst farming systems (Figure 3-6).

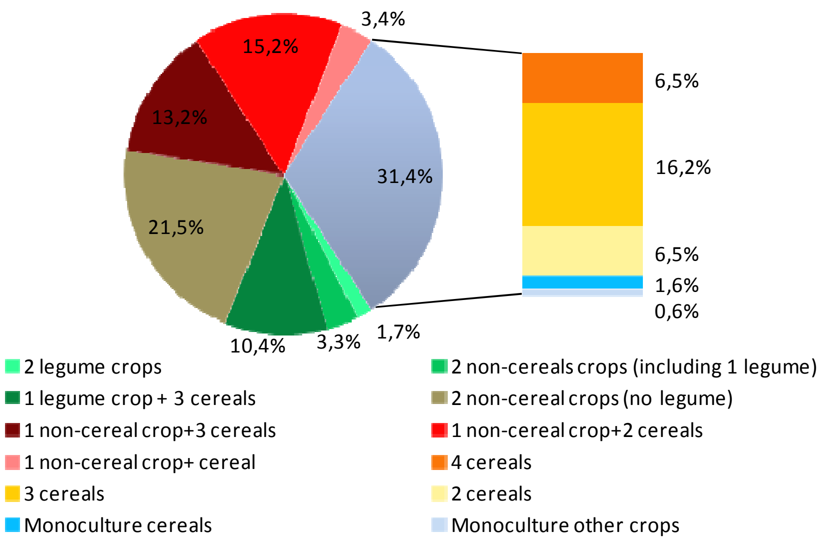


Figure 3-6: The share of rotation schemes in a sample of Polish pig farms (Majewski, 2009)

The crop rotations performed in pig rearing and fattening farming systems are summarised in Box 3-5.

3.4.3.1 Crop rotations with legumes

In the course of this research, no rotation with legumes, specific to pig farms, has been identified. Without specification of farming system, one rotation with peas was identified in Denmark, one of the countries with the highest share in area of pig farms. This rotation includes

[7] EU data are only available for specialist granivores, which include pig rearing and fattening farming systems.

the typical crops of Danish pig rearing and fattening farming systems: wheat and oilseed rape (see Annex II – section 5.2.1.1).

Organic farming systems are highly dependent on the soil enriching effect of legumes. In Brittany, the region of France where pig farming is the most significant, organic farmers practice a diversified 5 years long rotation, incuding notably maize, oilseed rape, spring and winter cereals and legumes (see Annex II – section 5.2.1.1).

3.4.3.2 Crop rotations without legumes

Rotations that are specific to pig farms generally lack legumes, which are not necessary to pigs feeding. This slightly reduces the diversity in crop types and a certain level of simplification can be observed in the rotations. These rotations include usually sequences of one or several cereal species, with either a sequence of Maize or of a root crop every 2-4 years in the rotation.

- **Long crop rotations**

Due to the simplified structure of rotations in pig farms, long rotations are not common to this farming system. In Denmark, a 8 year rotation practiced under humid climate includes 7 years of cereals of diverse species (winter wheat, (winter) barley, and rye), with 3 repetitions of wheat and 3 repetitions of Barley, illustrating the limited level of diversification of this rotation. The sequence of cereals is broken once in the rotation with a sugar beet sequence (see Annex II – section 5.2.1.1).

Five year rotations can be found in medium or rich soils of Northern Austria, and are more diversified, including notably cereals oil crops (oilseed rape or sunflower) and root crops (sugar beet). Variants of this rotation can be as short as 3 years (see Annex II – section 5.2.1.1).

On less fertile soils of Poland, a five year rotation includes four years of cereals and one year of root crop. The rotation includes particularly rye and potato, i.e. crops that can adapt to poor soils (see Annex II – section 5.2.1.1).

- **Short crop rotations**

Rotations of pig rearing and fattening farming systems are usually short and include maize, rotated either with cereals or with root crops, oilseed or sunflower (Table 3-9). Maize is actually very common in the Northern regions where pig farms are significant. A variant of this rotation dominates in the Low Countries and in Western Europe, and includes a sequence of oilseed rape.

Table 3-9: Typical Maize based rotation of pig farms in Western Europe (Pers. Comm.: Bechini, 2009; Guillaume, 2009)

	Oceanic climate/Subtropical dry climate	
year	*Crop*	
1	Maize	
2	Barley, Common Wheat or Durum Wheat	Sugar Beet, Soybean, Oilseed rape or Sunflower

Another variant exists where pig feed is largely based on grains produced on farm, supplemented with high protein content components (mainly soybean), e.g. in Poland or in Italy. As a consequence, the rotation may finally include only two to three cereals (see Annex II – section 5.2.1.1), such as maize, barley, soft wheat or durum wheat. Maize can also be rotated with an industrial crop, such as sugar beet, soybean and sunflower in a two year rotation. However, the dominating tendency, more than in other farming systems, goes towards monoculture of silage maize, for the Western Europe MS, such as Belgium, Germany, Italy and France (Pers. Comm.: Bechini, 2009; see Annex II – section 5.2.1.1).

In Germany and in Belgium, several variants exist of a three year rotation, based on a cereal sequence (without maize) and on a root crop sequence, the third sequence being another cereal (without maize), root crop, oilseed rape or maize (see Annex II – section 5.2.1.1).

3.4.3.3 Monocultures

Predominance of maize growing is typical of (pigs and dairy) mixed livestock farming systems in several MS, such as Italy, Poland, Germany and France. Maize actually provides extremely high dry matter yields and allows cultivating a limited number of crop species. However, maize is preferably rotated in short rotations, and monoculture of silage maize accounts for less than 2% of the Utilised Arable Area (Belgium and Poland). Farmers buy then the complementary feed for pigs from external sources.

In Belgium, a noteworthy monoculture of root crops begins with a year of beets, and finishes with one year of potato, the second year involving third root crop, either beet or potato.

Box 3-5: Main crop rotations in pig rearing and fattening farming systems

Pig feed being based on cereals and crops of high energy value, the rotations practiced on pig farms are principally based on these crops. Pig rearing and fattening farming systems are the most likely to apply monoculture amongst farm types.

In conventional systems, the practice of rotations with very limited species diversity (cereal based, or cereal/root crop) or monoculture is not uncommon in pig farms, however diversified rotations with the presence of root crops grain maize, sunflower and cereals are practiced as well within this system in 2-8 year long rotations.

There is a limited presence of legume crops in pig farm crop rotations, however examples of rotations with 2 years of temporary grassland in organic farms are known as well in 6-8 year long rotations.

This page is left intentionally blank

4. ENVIRONMENTAL IMPACTS OF CROP ROTATIONS

The links between the quality of the natural environment and farming practices are complex. While many valuable habitats in Europe are maintained by extensive farming, and a wide range of wild species rely on this for their survival, pollution of soil, water and air, fragmentation of habitats and loss of wildlife can result from agricultural practices and land use changes. Crop rotations, as a management tool, can help modify the effects of agriculture on several environmental aspects, through its beneficial impact on the whole cropping systems, soil, the reduced uses of chemical products, or through the choice of crops involved in the rotation.

In this chapter, environmental dimensions of crop rotations are explored, including biodiversity (species and landscape levels), soils, water, and climate change. The impacts of biodiversity are looked at separately at the species level and at the landscape level, throughout the report. Rules for diversification of crop rotations are presented in Box 4-1.

Box 4-1: Rules for diversification of crop rotations

The first rule for diversification is to have various crops from different families, at least three families of plants over seven consecutive years. The point is to alternate characteristics of plants:

- Rotate deep-rooted crops with superficial-rooted ones, to optimise the exploration of nutrients in soil. Moreover the insertion of deep-rooted crops helps to maintain the structure of the soil.
- Rotate spring-sown and autumn-sown crops, to break cycles of weeds, pests and pathogens.
- Avoid following a crop with a closely related species, to avoid common pests and pathogens.
- Rotate crops with a high level of ground cover, which maintain weeds at low level, and crops where weeds are well controlled mechanically (hoeing);
- Include crops that leave significant amount of residue, in particular if most arable crops are exported.
- Include legumes in order to catch atmospheric nitrogen in the system.
- Include intercropping (catch crop/cover crop), which helps to manage nutrient cycles between two crops, which cover the ground and protect soil structure and which provides habitat to fauna, including beneficial insects.

4.1. SPECIES DIVERSITY

Biodiversity is defined in the Convention on Biological Diversity (1992) as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". Biodiversity in farming systems includes:

- the genetic diversity of organisms above and below ground;

- a variety of micro and macro flora, i.e. weeds and plants in and around the fields;
- a variety of micro and macro fungi and fauna, including soil microorganisms, invertebrates, birds and small mammals; and
- a variety of ecosystems, at field scale and landscape scale (covered in section 4.2).

Species diversity is important in farming systems as it provides a number of services that directly favour cultivation practices. For instance: (1) soil biodiversity enhances soil functioning through its impacts on soil structure, soil organic matter and fertility, but also on the water cycle, (2) natural predators can regulate crop pest, (3) insects pollinate crops, (4) symbiosis between microorganisms and legumes releases nitrogen in the ground for future crops, etc. Crop rotations actually affect three parameters of biodiversity: soil biodiversity, fauna above soil and plant biodiversity (Figure 4-1). The nature of the crops influences the type of weeds that may grow in the fields, but also around the fields (according to field margin management). The most critical practices to plant biodiversity are the crop rotations and crop diversity, tillage practices and weed control pesticides. Other impacting practices are drainage, and mechanical operations on field (see Annex III – section 1.3 for an overview of the parameters influencing the three aspects of Species diversity). See Annex III – section 1.1 for details on the scale of impact.

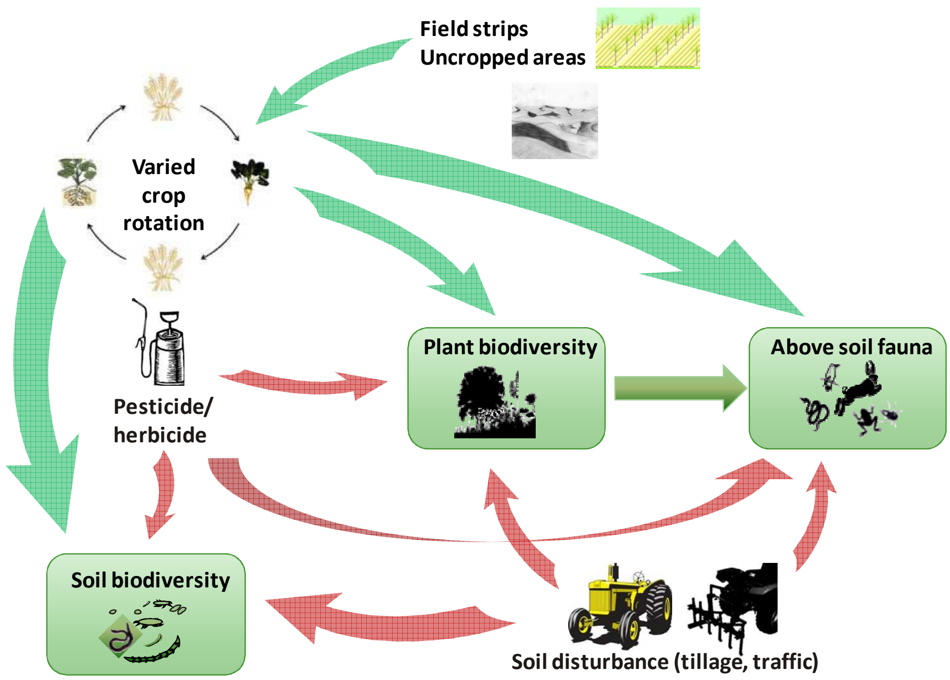


Figure 4-1: Parameters influencing the impacts of crop rotations on species diversity

The following crop rotations types generally have an increasing positive impact (or decreasing negative impact) on global species diversity:

Positive impact on biodiversity

1. Monoculture, i.e. the cultivation of the same crop each year on the same field
2. Arable crops rotation, most common case for EU arable farming
3. Arable crops rotations with grass leys, most common for EU mixed farming
4. "Multifunctional crop rotation", i.e. a sequence of crops planned to maintain soil fertility and secure crop vitality, and minimise the use of chemical inputs.

Permanent meadows generally have an overall positive impact on all diversity aspects whereas monoculture is the cropping system with the most negative impacts on species diversity due to a high level of soil disturbance and chemical use and lack of diversity of cultivated crops.

Even if agriculture can favour species specialised in cultivated fields, agriculture intensification and complete abandonment of fields generally lead biodiversity decrease compared to a field under sustainable agricultural management (Figure 4-2). Agriculture thus impacts species diversity in fields, but relevant crop rotations can be developed in order to provide habitats and breeding areas for many fauna and flora species.

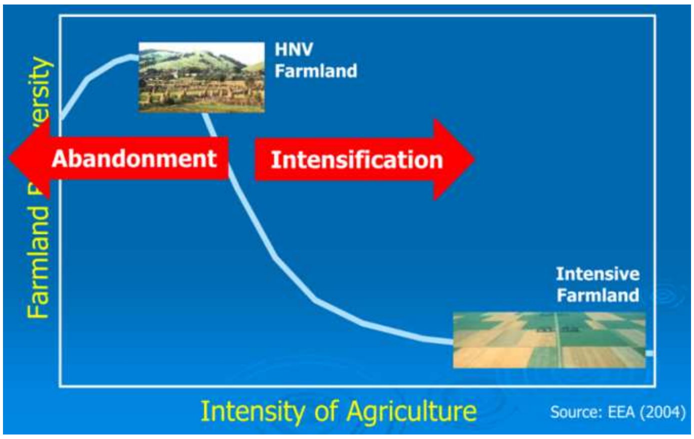


Figure 4-2: Agricultural intensity and farmland biodiversity (EEA, 2004 in Redman, 2010)

Crop rotation is efficient for weed control as it changes the pattern of disturbance and diversifies the selection pressure (Seibutis and Deveikyte, 2006). This is beneficial for weed diversity but also for reducing the pressure of weeds on cultivated crops, providing weeds also compete with each other. Further, this genetic diversity of weeds leads to more efficient use of herbicides, and therefore reduces the risks of selecting weeds with a genetic resistance to the herbicide active substance. Weed populations are for instance more abundant on cereal rotations receiving lower inputs of herbicides (e.g. El Titi, 1991; MAFF, 1998 in Gardner et al., 1998). Tillage also helps for weed control, with various levels of impacts according to tillage types (Murphy, 2006; McLaughlin and Mineau, 2000 - Figure 4-3 and Figure 4-4).

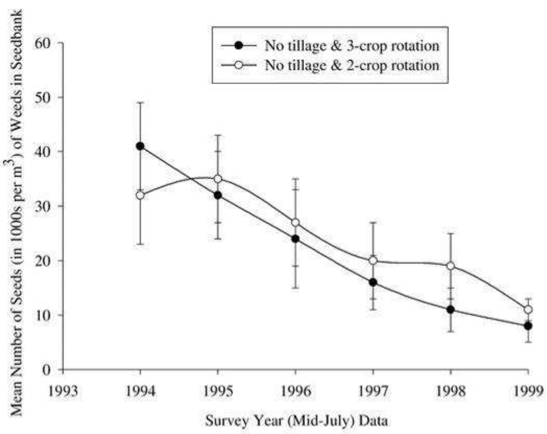


Figure 4-3: Number of seeds with no-tillage and rotations (Murphy, 2006)

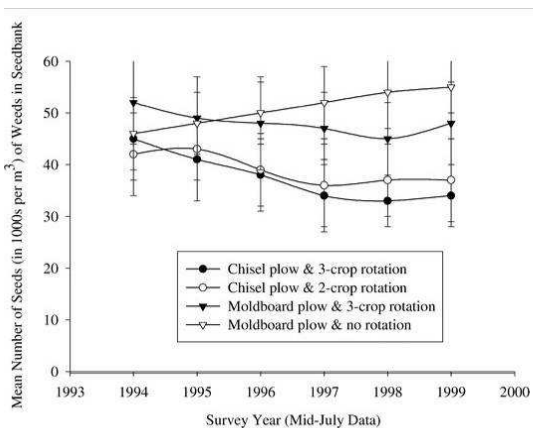


Figure 4-4: Number of seeds with rotations ploughed with chisel plough or mouldboard (Murphy, 2006)

Management of field margins is also important: species diversity is higher in farms with grass strips or hedges between fields, rather than in a monocultural area with limited stripes between fields, where herbicides are applied.

4. 1. 1. IMPACTS OF CROP ROTATIONS ON SOIL BIODIVERSITY

Below ground, practices affecting the soil may influence the richness and abundance of species of soil organisms and invertebrates. Thus, crop rotations impact soil biodiversity depending on the management practices related to the rotation cultivation, especially tillage, chemical treatments and the maintenance of natural spaces such as leys or field trips (see Annex III – section 1.3).

Crop rotations which require tillage and ploughing have a negative effect on soil biodiversity (Rovillé and Aufray), especially soil fungi (Diffley, 2007). On the contrary, conservation tillage and crop rotations with legume support diversity of soil microbial communities (Lupway et al., 1998). However, tillage impact can be mitigated on farms where population reservoirs for wildlife are provided by uncropped habitats (through management of field margins) that enable the recolonisation of cropped areas to occur rapidly (Glen, 1997 in Gardner et al., 1998).

Rotations with reduced fertilisers needs benefit to soil biodiversity, providing fertilisers were involved in the suppression of mycorrhizae, in interaction with many other factors (Reddersen, 1995a, 1995b and Macdonald & Smith, 1991 in Gardner et al., 1998). Mycorrhizae, involved in nitrogen and phosphorus uptake of certain plants, are beneficial for the next crops. Crop rotations, by limiting the use of pesticides, especially systemic pesticides, can also reduce its negative effect on soil biodiversity (Filser, 1995; Hüther, 1961; Kaluz, 1984).

Other parameters of crop rotations impact soil biodiversity, for instance alternating roots lengths species, provide diverse habitats and types of mycorrhizae, and leave different nutrients in the soil. Levels and types of impacts of crop rotations are variable according to species (Armstrong, 2000). Lastly, rotations keeping a cover all year around (catch crops) impact both soil bacteria and earthworms survival positively (Rovillé and Aufray).

4. 1. 2. IMPACTS OF CROP ROTATIONS ON FAUNA ABOVE SOIL

Above ground, practices affect the habitats and thus the richness and abundance of species of invertebrates, birds, mammals, etc.: diversification of habitats (in time and space) enhances diversification of fauna (see Annex III – section 1.3). Practices also influence the richness and abundance of species by impacting direct food supplies for animals (seeds, invertebrates, etc.) or indirect food supplies (seeds/plants feed insects that feed other insects or birds). Farm work can cause direct negative effects if it coincides with critical periods of bird breeding and the timing of such work impacts the temporal and spatial heterogeneity of crops, which in turn impacts the suitability of these habitats for bird nest sites (Vepsalainen, 2007).

Long and diverse crop rotations lead to a diversity of plants in and around the cultivated field, and facilitate the presence of arthropod species, notably pollinating insects (Huyghe, 2009). Intercropping also encourages a greater diversity of faunal species by providing more niches (presence of mixed ground cover). Crop rotations involving tillage or reducing tillage favour differently birds species, small foraging mammals etc. (Bretagnolle and Houte, 2005; Gardner et al., 1998). Similarly, early mowing impacts species differently, as some prefer living in high crops while other species prefer living in low crops (Bretagnolle and Houte, 2005).

By a good understanding of the life cycle and needs of both pests and beneficial insects, practices can help favour advantages of nature's insect ecosystem services (Diffley, 2007). In particular, matching crops (in relation to plant families) to the margins plant composition helps maximise predator performance (Gardner et al., 1998). Lastly, trap cropping and row cover may be used for pest control (Diffley, 2007), if needed.

Rotations involving crops with high pesticides needs also have a general negative impact on fauna above soil, such as birds and arthropods. Insecticides and herbicides actually reduce available food for birds, such as invertebrates, weeds and seeds (Vepsalainen 2007). Insects' diversity is directly impacted by insecticides use, especially systemic insecticides. The impact of combined pesticides on wild species, or of pesticides at sub-lethal doses, is currently a research area. Impacts of fungicides on fungi in the soils are not well-known. Fungicides with direct toxicity, e.g. containing pyrazophos, are no longer used in arable crops. Here again the use of pesticides can select genetically resistant crop enemies, reducing genetic diversity.

Presence of bare soil in the winter may also have a negative impact on less mobile arthropod species, which decline in spring crops, unless stubble is left (Holland et al., 1996 in Gardner et al., 1998). On the other hand, species which over-winter in neighbouring habitats or underground, or live close to the soil are less susceptible to chemical treatments than species that remain in the crop or field throughout the year (Greig-Smith et al., 1992 in Gardner et al., 1998). Therefore crop rotations should also involve conserving margins, cutting fields with strips of grasses and/or flowers, which have positive impacts on biodiversity (Gardner et al., 1998, Diffley, 2007). Set-aside may have the same type of impacts and this practice provided for instance stubble and winter food for some seed-eating birds species (Gardner et al., 1998).

4. 1. 3. IMPACTS OF CROP ROTATIONS ON PLANT BIODIVERSITY

Farming practices that preserve species diversity are associated with low intensity grazing or mowing practices on semi-natural vegetation, compatible with crop rotations. Farming practices that enhance species diversity include crop rotations, the management of field margins, maintenance and restoration of hedges, trees, wetlands, permanent pastures, and uncropped areas (IFORE, 2008, Gardner et al., 2008, Rovillé and Aufray; see Annex III – section 1.3).

Impacts of crop rotations may not be evaluated easily independently from other factors which also impact species diversity. Various and long rotations are generally recognised to have a positive impact on species diversity, but most of the time they complement the effects of other positive practices, in particular: (1) reduced use of herbicides and other pesticides, leading to reduced impacts on wild flora and fauna, including beneficial insects; (2) management of field margins such as hedges, grass strips, ditches, and stream, wetland, providing overwintering sites for invertebrates and vertebrates, areas of floristic diversity, refuges/reservoir habitats for species after harvest and ecological corridors to other habitat patches; (3) reduced ploughing (conservation or zero tillage), diminishing disturbances to soil organisms. The size of the field is also an important factor to consider (see Annex III – section 1.3)

From a general perspective, rotations, including grass ley or legumes, and intercropping (catch crops/cover crops) and green manure particularly favour species diversity (Gardner et al., 1998). A rotation involving a large variety of crops grown and/or involving intercropping may favour biodiversity as it provides habitats and/or food for more species than a monoculture. On the contrary, management practices may cause positive, neutral or negative effects on species diversity, by causing distinct alterations of the population structure, without altering the population size (Filser, 1995).

Box 4-2: Summary – impacts of crop rotations on species diversity

Diversified sequence of crops, which rotates crops from different botanic families with opposed characteristics, encourages species diversity below and above ground: systems that tend to support a wider variety of crops provide greater structural diversity and habitat diversity for flora and fauna. Integrated production and organic agriculture regimes give good examples of such systems and combine them with a lessened use of inputs, which also is positive for species diversity.

4.2. LANDSCAPE

From a human perspective, landscape is a "broad area composed of a mosaic of patches, ecotopes and cultural elements" (Farina 2006). From an ecologic perspective, landscape is "a particular configuration of topography, vegetation cover, land use and settlement pattern which delimits some coherence of natural and cultural processes and activities" (Green et al., 1996). Landscapes are actually perceived as an important public good, with aesthetic and cultural values. In this report, focus may be on ecosystems and environmental aspects of landscape, and aesthetics and cultural aspects may not be treated.

Crop rotations impact landscape and ecosystems through crops diversification in both space and time, and through the conservation of uncropped areas and interconnection between them, by allowing species to move along landscape gradients. Impacts include both the aesthetic and the ecological functions (Figure 4-5). Heterogeneous cultivated ecosystems provide a diversified environment, generally favourable for biodiversity's richness at the landscape level (Jeanneret et al., 2003), where farm and field characteristics interact over time (Thenail, 2002; Piorr, 2003). Crop rotations, likewise all other components of landscape mosaics, influence significantly crop-mosaic connectedness over space and time (Thenail, 2002, Gaucherel et al., 2006; Castellazzi et al., 2007). This can lead to gradual marginalisation of farmland in areas with very arduous farming conditions. Abundant flora may be replaced by semi-ligneous species, leading to an impoverishment from both aesthetical and ecological points of view, and to the disappearance of traditional landscapes of cultural and ecological importance.

Finally, three ecological keynotes exist regarding landscape (see Figure 4-5 and see Annex III – section 2.2 for more details on the parameters influencing landscape.):

- Patches diversification and variation potential
- Discontinuous timings
- Uncropped areas in the vicinity of fields

Most short crop rotations and monoculture reduce the diversity of patches at the landscape level. In general, all crop rotations with only winter crops or spring crops have a depleting effect on patches diversification, especially in rotations without catch crops (Annex III – section 2.1).

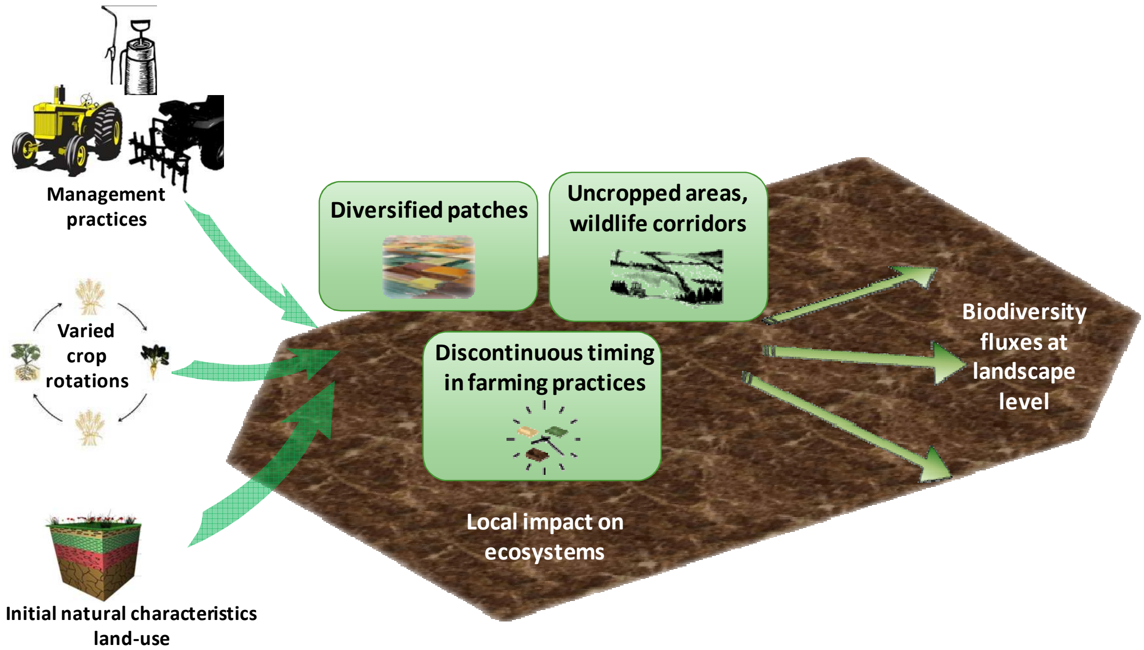


Figure 4-5: Parameters influencing the impacts of crop rotations on landscape

4. 2. 1. Impacts of crop rotations on diversified patches[8]

Diversity of a landscape and crop-mosaic can be assessed in terms of colours, patterns or textures covering the landscape which are also related to the cultivation of a great variety of crops. Farming activities influence both non-arable and arable landscape elements and are major drivers of the ecological patterns of landscape (i.e. the design and configuration of ecosystems present in the landscape). As a result, effects of spreading or clustering crops are multiple at landscape scale, and also influenced by (Thenail, 2009):

- spatial distribution of crop-rotations allocation factors over the field mosaic,
- specialisation of crop rotations to their allocation factors, and
- key dates in crop rotations planning.

Local landscapes perceptions can influence the design of rotations. For instance, farmers may choose a rotations according to the crop sequence properties and production requirements (e.g. on homogeneous and deep soils of Haute-Normandie, France), or according to various combinations of environmental conditions perceived (e.g. in heterogeneous soils and constraining environment of Poitou-Charentes, France), which leads to specialised crop rotations, adapted to the physical environment conditions (Thénail, 2009).

At the landscape level, the sum of present crops remains stable, crop rotations being run as regular crop sequences over time, but switching crops from fields to fields leads to significant

[8] i.e. a various soil cover types and land uses at the landscape scale

crop-mosaic year after year variability (Thenail, 2009). Rotations can be very fragmented, and fragmented crop mosaics are actually considered more suitable for regulating ecological movements and fluxes (Helenius, 1997; Benton et al., 2003; Leteinturier et al., 2006). In traditional mixed farming systems, diverse crop rotations ensure heterogeneous cultivation mosaics presence, continuously in space and time. Habitats heterogeneity and diversity, in both cultivated fields and non-cropped areas, is of great importance to the abundance and diversity of species, especially birds (Vepsalainen, 2006). A diverse crop mosaic that combines various cereals, other crops and grasslands, accompanied by a diverse mixture of uncultivated habitats and rural settlement, is an ideal combination for nurturing diverse and abundant biodiversity, especially farmland bird communities (Vepsalainen, 2007; Hendrickx et al. 2007 in Huyghe 2009).

Crop rotations may also offer several opportunities to contribute to green infrastructures. Indeed, agriculture land, under appropriate practices, may provide several services, such as flood and water management, erosion prevention, increased habitat connectivity and recreation opportunities. Depending on farm location, some of these services could be prioritised and enhanced by appropriate rotation choices. For instance, priorities for a farm located in the proximity of an urban area could be water management, while in the proximity of natural areas it would be connectivity. In the first case, any rotation would favour water infiltration and management as the land remains permeable and vegetation helps stabilise the soil. Rotations with low intensity management may offer added potential in terms of water purification and storage. In the second case, rotations involving more natural management, such as fallow land, grasslands or organic agriculture should be favoured.

4. 2. 2. Impacts of crop rotations on discontinuous timings

Spatial and temporal distribution of suitable habitats is a key factor for biodiversity in cultivated landscapes (Jeanneret et al. 2003). Important parameters of influence of the crop rotations on these timings are the temporal distribution of habitats, the presence of uncropped areas and the various harvest times (see Annex III- section 2.2).

On a given set of fields, farming practices such as tillage or harvest can significantly impact species living in the fields, and need to be diversified over time. At the landscape level, diversified patches would allow sensitive species to be hosted in close patches during the disturbance, and their abundance and diversity would recover after detrimental practices. Similar impact exists for edges: woody edges are very important for over-wintering beetles, but less important, later in the growing season (Hunter, 2002). On the opposite, Carabid beetle movement are negatively affected by hedgerows (Mauremoto et al., 1995 in Hunter, 2002).

Lastly, diversity covers a time period beyond the vegetation period of plants, and also includes seedbanks, which remain in soil over time. Indeed, the vegetation period is important in producing flowers and seeds, for sexual reproduction of species, but bare soil also participates in maintaining the growing potential of species.

Growing plants with different harvest time is preferred in order to avoid a monotonous bare soil cover over the landscape. This may also benefit ecological connectivity as bare soil does not provide connectivity with habitat patches in different locations or links between edges.

4. 2. 3. IMPACTS OF CROP ROTATIONS ON THE PRESENCE OF UNCROPPED AREAS, EDGES AND OTHER NON-AGRICULTURAL LANDSCAPES FEATURES

Marginal and non-agricultural habitats are valuable for biodiversity on farmland and at the landscape level, and provide the following attributes (Frieben and Kopke, 1996):

- Refuges for endangered plant species, especially arable weeds
- Overwintering sites for invertebrates and vertebrates
- Areas of floristic diversity
- Refuges for species after harvest
- Areas with network links to other habitats

Box 4-3: Summary – impacts of crop rotations on landscape

Farming activities and practices have a strong impact on the patches diversity at the landscape level, and farming practices generally lead to work simplification:

- use of machines over large areas of field (e.g. tractors, combine harvester)
- monoculture and short crop rotations
- use of common seeds and growing of common species, which is easier given well-known management practices.

Hence, the following practices enhance the harmony of crop patches at the landscape level:

- long and diversified crop rotations, with various species, sewing and harvest dates,
- use of catch crops, cropped on the same field than the cash crop
- reduced farming practices, with a reduced level of mechanisation and tillage
- fragmented spaces, i.e. rather numerous and little fields than a few large fields,
- uncropped areas, woodlots, edges etc. maintained in the vicinity of fields

However, uncertainties remain about how farmers' decisions and aggregation of their activities in space contribute to these mosaics at local landscape scales (Thenail, 2009), and possible levers of action in farms for ensuring sustainable landscapes are not well known.

Coherence between the structure and distribution of the non-productive (green) habitats on the farm and in the surrounding landscape should be promoted. Indeed, conditions supporting biodiversity on the farm are strongly related to processes and structures at the landscape level (Smeding 1999).

This covers e.g. sown grass strips, grass margins, conservation headlands, uncropped wildlife strips and flower strips, hedges, ditch and bank habitats. Uncropped areas actually tend to be the major reservoirs for both floral and faunal diversity, while arable lands are valuable for particular species or groups (Gardner and Brown, 1998). A landscape providing different types of uncropped areas is a key in determining the overall biodiversity of its agricultural areas (Gardner et al., 1998). For instance, the presence of arthropods and birds, which are useful auxiliaries for crop protection, is strongly correlated with semi-natural areas (Jeanneret et al., 2003 in Clergue et al., 2005). A high diversity of habitat was also shown to increase the occupancy rate of bumblebees (Barron and Wratten, 2000 in Clergue et al., 2005).

Although semi-natural pasture is in general the most species-rich habitat, only preserving semi-natural pastures is not sufficient to sustain species richness in the agricultural landscape (Weibull et al., 2003). Therefore, enhancing of natural habitat and conservation of wildlife on a wider environment is important for biodiversity, and this can be done also through ecological connectivity in form of grass stripes, hedges, etc (see Annex III - section 2.2). Stepping stones, corridors and stop-overs provide important provide important ecological connections, which allow mobile species to move in the landscape to find habitat and food sources in different patches of the landscape or escape local competitive dynamics (Victorian Government, 2008).

Monocultures often occupy a large part of the landscape and field separations may not be clearly made. The landscape may thus not include corridors for species to move across the landscape with the risk of local populations extinction. Also the general landscape features such as groups of trees, hedges, etc. are much less present in monoculture areas.

4.3. SOIL

This section discusses the environmental impacts of crop rotations on soils, particularly soil organic matter content, soil structure and soil erosion. Figure 4-6 gives an overview of the interactions between the studied factors and aspects of soil quality. Impacts of some crop rotations on soil organic matter content, soil structure and soil erosion are summarized in Annex III – section 3.1. Determining farming practices are tillage, irrigation, traffic on fields, as well as the quantity of organic fertiliser, the biomass production potential of each crop (crop residues).

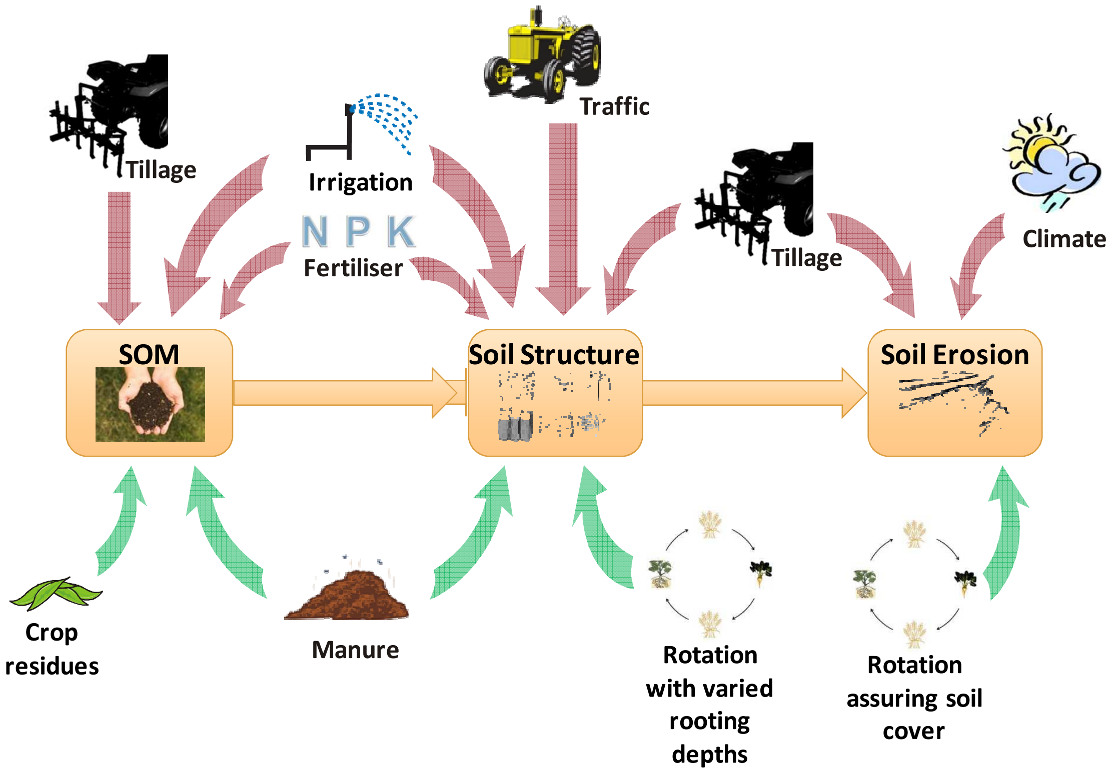


Figure 4-6: Parameters influencing the impacts of crop rotations on soil

4. 3. 1. IMPACTS OF CERTAIN CROP ROTATIONS ON SOIL ORGANIC MATTER

Soil organic matter (SOM) is essential to soil functions because: i) it provides nutrients to plants, through mineralisation; ii) it contributes to the cation exchange capacity of the soil, i.e. to its capacity to retain cations; iii) it stimulates microbial activity; iv) it improves soil physical properties, by promoting the formation of stable aggregates, and improving aeration and water retention and infiltration.

Due to the important functions of SOM, we consider that rotations have a positive effect when SOM is increased and negative when SOM is decreased.

4.3.1.1 Scale of impact

The spatial scale of impacts of SOM changes is restricted to the land unit and no attention is paid to soil losses in the outer environment (as for soil erosion). The temporal scale can reach years or decades to measure significant effects of crop rotations on SOM, and even hundreds of years to reach equilibrium (Karlen et al., 1994). The parameters influencing the impacts of crop rotations on soil organic matter are presented in Annex III – section 3.3).

4.3.1.2 Mineralisation and humification

Soil organic matter is submitted to the action of two opposite processes:

- **Mineralisation**

Mineralisation of SOM is an aerobic microbial-mediated process that converts organic substances (with variable degrees of complexity) used as a food source into mineral compounds, like water, CO_2 and inorganic ions like ammonium. Mineralisation is of great importance because it makes inorganic compounds available to plants and micro-organisms (Jarvis et al., 1996). Besides the environmental constraints like soil temperature and water content, mineralisation is also influenced by the association between SOM and clay and other inorganic components, which reduces the mineralisation potential (Jarvis et al., 1996), because SOM remains protected from microbial attack.

- **Humification**

Humification is the formation of humus from the products of the decomposition of plant and animal residues.

The amount of organic matter that is humified depends

- on the amount of organic residues returned to soil ('C inputs'),
- on their chemical structure and physical status (which influence their decomposition potential), and
- on the local conditions affecting the biological process of decomposition and re-synthesis into humus.

The linear relation that is frequently found in experiments between the increase of SOM and the addition of C inputs to soil (e.g. Kumar and Goh, 1999; Morari et al., 2006; Grignani et al., 2007) demonstrates the importance of the addition of organic materials to soil in order to maintain and improve SOM. This explains why rotations and their associated crop and soil management are important determinants of SOM.

Animal and plant residues returned to soil bring a wide range of materials: above-ground crop residues (leaves, stems), roots, root exudates, manures (mix of faeces and urine stored in aerobic or anaerobic conditions), compost and biosolids from sewage treatment plants. The amount of plant materials available for humification depends very much on the cultivated crop and on its management. Bolinder et al. (2007) have reviewed the coefficients that can be used to estimate the amount of above- and below-ground crop biomass that can be returned to soil. These values are helpful to compare the capacity of different crops to provide organic materials to soil. The three types of organic returns of plant materials to soil are: i) unharvested above-ground biomass; ii) roots; iii) extra-root materials (root exudates, root hairs and fine roots not included in the 'root' fraction).

The second direct contribution of crops to SOM is made through roots: Bolinder et al. (2007) have found that the shoot:root ratio for annual crops was typically around 5, while it was 1-2 for forages; within forages, legume species had a shoot:root ratio that was twice that of grasses; and long-term prairie grasslands and pastures had a shoot:root ratio of 0.5. This indicates that, at similar above-ground biomass levels, rotations with forage crops (and long-term grasslands in particular) may tend to have more root biomass and thus likely more dry matter that may be humified after root death.

The third direct contribution of crops to SOM is through extra-root materials. The conservative estimate provided by Bolinder et al. (2007) is that these materials contain roughly 65% of carbon allocated to roots, regardless of crop type.

Overall, the three pathways indicate that crops can provide substantial amounts of organic residues to soil. Crops with high yields and crops leaving high amounts of root materials may contribute more to SOM maintenance. Therefore, rotations may vary for the frequency with which this type of crops is present in the sequence.

How these organic returns of biomass to soil influence the formation of humus depends on their decomposition in the soil: humification is frequently estimated (on a yearly basis) by multiplying the amount of materials returned to soil by a 'humification coefficient', which represents the fraction of C contained in the material that is not respired during decomposition and thus becomes humus (Saffih-Hdadi and Mary, 2008). Therefore, the humification coefficient depends on the chemical and physical structure of the materials and on the local conditions where decomposition takes place. Values commonly used are in the range of 0.20 - 0.30 (Boiffin et al., 1986; Saffih-Hdadi and Mary, 2008).

See Annex III – section 3.2 for more details on soil organic matter.

4.3.1.3 Impacts of crop rotations on soil organic matter

The facts presented above make it possible to understand the important, even if not exclusive, role of crop rotation in increasing or decreasing SOM.

- **Impact via modification of environment**

First of all, crop rotations strongly impact soil temperature and soil water content, depending on crop transpiration, rainfall and eventual irrigation. Crops like maize, which is irrigated in most environments in Southern Europe, are therefore likely to promote microbial activity, both because the soil is maintained at an intermediate temperature which is neither extremely low (due to the spring-summer cultivation period) nor extremely high (due to soil cover), and because the soil water content is relatively high, due to irrigation.

While these principles can be easily stated in theory, practical examples of the effect of crop types on mineralisation via their influence on soil conditions are difficult to find.

- **Impact via tillage practices**

Tillage may be conventional tillage (CT), normally involving ploughing followed by secondary tillage operations like harrowing), which has been shown to increase mineralisation compared to other practices, like no-tillage (NT), which is a technique consisting on sowing an untilled soil (Jarvis et al., 1996; West and Post, 2002). The difference is due to the fact that CT inverts and mixes the soil, disrupts soil aggregates, increases aeration, and increases the contact between micro-organisms and soil organic matter, thus promoting aerobic SOM mineralisation. Conventionally tilled rotations, therefore, normally tend to accumulate less SOM in the ploughed layer, which is commonly 20 to 30 cm deep (West and Post, 2002). No-tillage can reduce the rate of SOM loss, but does not completely stop it (Karlen et al., 1994; Reeves, 1997).

West and Post (2002) have carried out an extensive literature review of long-term experiments. Their results show that SOM under NT is significantly higher, for the 0-30 cm depth, than SOM under CT. On average, moving from CT to NT can sequester (i.e. increase SOM) 0.48 ± 0.13 t C ha^{-1} yr^{-1}. This value is increased to 0.57 ± 0.14 t C ha^{-1} yr^{-1} if wheat-fallow rotations (which do not sequester significant amounts of C with a change from CT to NT) are excluded from analysis.

However this general result is susceptible to nuance, depending on the range of other management practices and local pedoclimatic conditions, as well as to crops characteristics (López-Bellido et al., 1997). For example, short rotations of wheat showed no significant effect of tillage on soil organic matter, where small amounts of crop residues are returned to soil under rainfed and semi-arid conditions of Southern Spain.

These results also depend on the depth in soil, e.g. the soil organic matter increase being higher in the most superficial layer than bellow for maize-soybean rotation (Poirier et al., 2009).

- **Impact via crop above- and below-ground crop residues and other added organic materials**

Soil organic matter management results from the interaction of several and complex parameters, including the local conditions (climate, soil type), the production choices (arable or mixed farming system, irrigation or not, choice to insert catch crops (cover crops), legumes, cereals, maize etc., organic or intensive production), the management practices (tillage, fertilisation choices, including manure, residues management, rotations management), as well as other parameters, such as soil biodiversity, which vary in close interaction with the other parameters (see Annex III – section 3.2). However, each choice for a parameter value results from a thought, personal to each farmer, and which has consequences on the global farm management.

4.3.1.4 Impacting crop rotations

As a result of the previous findings, rotations that maintain SOM relatively constant over time, or well counteract the natural decrease of SOM with cultivation: permanent grasslands and the 6-year rotation maize - sugar beet - maize - wheat - alfalfa – alfalfa, which may be generalised as “long rotations including temporary grasslands”.

Continuous grain maize or silage maize (in particular if not fertilised with manure), maize-soybean and continuous wheat had a negative effect. However, the way crop residues are managed (removed or buried), and the presence of legumes in the rotation, are of fundamental importance for that classification of crop rotations.

Other rotations like the 2-year rotations including one sequence of wheat (e.g. wheat-sunflower, wheat-faba bean), may have variable effects depending on the duration of the observation, and on the local conditions (climate and soils), though wheat-fallow had rather poor results.

4. 3. 2. IMPACTS OF CERTAIN CROP ROTATIONS ON SOIL STRUCTURE

Soil is made of particles of various size and composition which are aggregated together by various soil-stabilising agents as SOM (Singer and Munns, 1996; Ball et al., 2005). This aggregation controls the number and size of soil pores. Soil pores can be filled either with air or with the soil solution (water and nutrients), or can be used by microorganisms, animals and roots during their growth and movement. Therefore, soil structure is essential for soil functions, because soil pores make possible the flows of gases, water, nutrients and organic compounds in the soil (Singer and Munns, 1996), allow water storage and microbial activity, influence soil temperature and mechanical properties. An improvement in soil structure generally represents an increase in soil quality.

The porous structure of soil can be described by a number of quantitative variables such as aggregate stability, porosity, bulk density. A high bulk density (a lower porosity) is detrimental to soil functions, because it reduces gas and liquid flow, root growth and water infiltration (Singer and Munns, 1996). Depending on the size of the pores, water can be held with different force (the smaller the pores, the higher may be the holding force exerted by the soil matrix). Finally, also water infiltration into the soil depends on the distribution of pore sizes.

4.3.2.1 Summary of the impacts on soil structure

Besides the choice of crops and their sequence in the rotation, several crop management operations may have a strong impact on soil structure and on related soil physical properties. These are tillage, traffic and organic fertilisation.

Tillage depth and frequency are very important: every tillage operation modifies soil structure (in particular by increasing the amount of macropores and decreasing bulk density); however, under the action of gravity and rainfall, porosity decreases again subsequently. No-tillage does not disturb the soil, increases the number of earthworms (Ball et al., 2005) and improves soil structure, at least in the medium-long term (in the short term soil structure can be damaged by NT practices).

An important farming practice that damages soil structure is traffic: even under NT, machinery is frequently used for various crop operations (e.g. pesticide and fertiliser applications, mechanical weeding, harvest). Agricultural machines are heavy and thus cause damage to soil structure (increase of bulk density, reduction of porosity) in the zones where wheels pass. The degree of compaction caused by machinery depends strongly on the soil water content at the moment of the wheel passes, and also on the SOM content (Hamza and Anderson, 2005). Compaction can be strongly reduced if operations are carried out when the soil is dry.

One last important farming practice influencing soil structure is the addition to soil of organic materials (e.g. composts, manure) and crop residues. Karlen et al. (1994) report that the cropping systems returning the most residues to soil usually have the lowest bulk density. For example, they report that continuous grain maize frequently has lower soil bulk density (i.e. a better structure) compared to maize - soybean rotations. The same is valid for manure and sewage sludge applications: Karlen et al. (1994) cite an experiment where the combined effect of alternative practices (crop rotation, application of organic fertilisers, ridge-tillage) improved soil structure (i.e. increased water stability) compared to conventional practices (shorter rotation, reduced tillage).

A complementary aspect, permanent meadows are globally good at maintaining and improving soil structure (Giardini and Morari, 2004). Also rotations including temporary grasslands have a positive role on soil structure (Karlen et al., 1994). Rotations with many years of sod, pasture or hay crops tend to build a good structure, which is reduced by short rotations (Karlen et al., 1994). However, crop rotation did not significantly influence soil structure in some cases.

4.3.2.2 Impacts of some rotations on soil physical properties

The soil physical properties mentioned in the previous paragraph are strongly interconnected because they all depend on the pore size distribution. Rotations may impact on soil physical properties through a number of factors, namely root growth, return of organic residues to soil, root exudates, crop cover, tillage type and frequency, traffic and other actions compacting soil. As already mentioned for the accumulation of soil organic matter, also for soil physical properties the interaction between rotation, crop management and soil type is extremely important. For example, clay is a soil-stabilising agent, and soils with little clay do not have easily structure as those that are rich in clay (Singer and Munns, 1996).

The formation of soil aggregates depends on the availability of SOM. As rotations may influence SOM by providing residues to soils (above-ground residues, roots and root exudates). While below-ground materials are by definition already incorporated in the soil throughout its volume, above-ground materials are incorporated either via soil cultivation or, in a small proportion, through leaching of organic compounds (Ball et al., 2005). Below-ground materials represent a continuous food source for microbial communities in the soil, which can produce labile organic matter fractions that are considered very important in contributing to development and stabilisation of soil structure. Ball et al. (2005) suggest that roots may decompose less rapidly than shoots, then providing short-term benefits to soil structure.

Root growth is important because roots can release stabilising or destabilising substances in the rhizosphere (Kirkegaard et al., 2008) and create stable biopores in the soil; moreover, when roots die they remain in place and can leave organic materials acting as stabilising agents. Roots of different crops can grow at different depths; in particular, they can grow deeper than tillage depth, thus acting on soil structure where tillage practices would not act (Karlen et al., 1994); this requires that subsoil is not limiting root elongation (Ball et al., 2005). Also, crops differ for the vertical distribution of root density: root density decreases with depth, but differently in different species. Moreover, crops may provide root materials with different resistance to decomposition, which impacts on the effect duration after root death (Karlen et al., 1994).

Above-ground residues are important for structure: Ball et al. (2005) cite experiments where wheat straw has improved aggregation and pore continuity. Also composts were effective at increasing soil porosity.

Crops differ for their contribution to structure formation and improvement. Most of their contribution depends on the amount and type of above- and below-ground materials that the crop leaves in or on the soil. The presence of temporary grassland (e.g. alfalfa, phalaris) in the rotation is one of the main factors contributing to structure (Ball et al., 2005). The other crops, as already mentioned when discussing SOM, differ widely for their biomass productivity. Ball et al. (2005) indicate that winter cereals and winter oilseed rape have a good biomass production potential. Legume crops are rated differently in various works, as reported by Ball et al. (2005).

Another important aspect of rotation impact on soil structure is the extent of crop cover across the year. The use of cover crops and double cropping systems makes it possible to increase primary productivity and organic matter returns to soil. Ball et al. (2005) cite the example of winter cover cropping, which increased SOM and improved soil structure in intensively managed summer vegetable cropping systems.

Lazányi (2006) did not find conclusive results about the effect of rotation on soil penetration resistance, which is a measure of soil compaction: in the long-term Westsik experiment, the effect on penetration resistance of lupine (a catch crop added to a fallow - rye - potato rotation) was not evident. Lazányi (2006) concluded that Westsik's data should be interpreted semi-qualitatively.

Giardini and Morari (2004) reported the stability of soil structure for the rotations established since 1966 in Padova. They found a significant rotation effect, with higher stability (40%) for the 1-yr rotation and lower stability (about 37%) for the 2-yr, 4-yr and 6-yr rotations. However, the initial situation was better for the 1-yr than for the other rotations, due to positive effect of previous cultivation with Italian ryegrass. On the other hand, the significant year × rotation effect shows that only the 1-yr rotation had a slight decrease of stability between 1974 and 2000 (from 41 to 39%). The permanent grassland had a very different structure stability (54% in 1967, 74% in 2000), thus confirming its beneficial effects on soil quality. Finally, conversion of permanent grassland to cereal monoculture caused a strong reduction of stability (down to 40% for wheat and 37% for maize, in 2000) from the starting value of 50% in 1967.

See Annex III – section 3.4 for more details, and Annex III – section 3.5 presents the parameters influencing the impacts of crop rotations on soil structure.

4. 3. 3. IMPACTS OF CERTAIN CROP ROTATIONS ON SOIL EROSION

Soil erosion processes depend (i) on the magnitude and timing of precipitation events, (ii) of soil surface roughness (type and timing of soil tillage, soil texture…), (iii) of soil cover with crop residues, and (iv) of plant canopy cover (potential leaf area index, dynamics of canopy growth, periods of growth) (see Annex III – section 3.6).

Row crops have a low protective function in general (e.g. maize, sunflower, sugar beet, vegetables) while rapeseed and cereals cover rapidly the soil at a period where rainfall intensity is generally lower than in spring or summer. In addition, crops leaving low crop residues (as potatoes or peas for instance) contribute to high erosion risk in the following crop.

The spatial arrangement of the rotation within the landscape should play on the amount of soil loss. The rotations which maximize the time during which the soil surface is efficiently protected from strong precipitation events have lower erosion risks in the conditions (slope, texture, weather…) prone to water erosion.

The rotations with high proportions of winter crops (rapeseed, cereals) should be favourable while increasing the proportion of spring (row) crops would be detrimental in general. Continuous meadow is optimal, while sparse fallow is the most risky situation. This interferes with soil roughness and crop residue management: no tillage and high amount of surface residue could mitigate the low protective effect of spring sown row crops.

For the spatial scale, the same considerations already presented for SOM are valid. The temporal scale of changes of soil structure is relatively quicker than for SOM (Kay, 1990), with very fast changes occurring when structure is damaged (e.g. compaction due to traffic), and slower changes when structure is improved.

Figure 4-6 summarises the different parameters influencing the impacts of crop rotations on soil organic matter, soil structure and soil erosion.

Box 4-4: Summary – impacts of crop rotations on soils

The farming practices that can interact with crop rotation to determine SOM levels are: tillage, fertilisation, and residue management. Conservation agriculture, as well as organic agriculture can impact SOM levels, as both practices come in favour of soft approaches regarding these farming practices. Importantly, C inputs are critical for the maintenance of SOM, and additions of organic materials need to be specified when classifying rotations.

4.4. WATER

This section focuses on the impacts of crop rotations on the quality of groundwater and rivers and on the impacts on water resources (shortage, reduced needs for irrigation water). A general remark is that rotations impact water indirectly. Decisive factors are the selection of crops, their use (for grains or green mass), but mainly the level of intensity of production and crop management in general.

Five main impacts are addressed in this section:

- N leaching
- Residues of pesticides
- Erosion
- Evaporation (Evapotranspiration)
- Irrigation

Annex III - section 4.1 summarises the environmental impacts of some crop rotations within the aspects of N/P-leaching, pesticide residue accumulation, water erosion, evaporation and irrigation. The length of land cover by crops throughout the year affects highly the intensity of water loss by evaporation and water erosion. The quantity of N fertiliser and plant protection chemicals required by/applied on crops determines to a high extent the N leakage as well as pesticide accumulation in waters. Water consumption of a rotation is directly linked to the fact whether the system is irrigated or not.

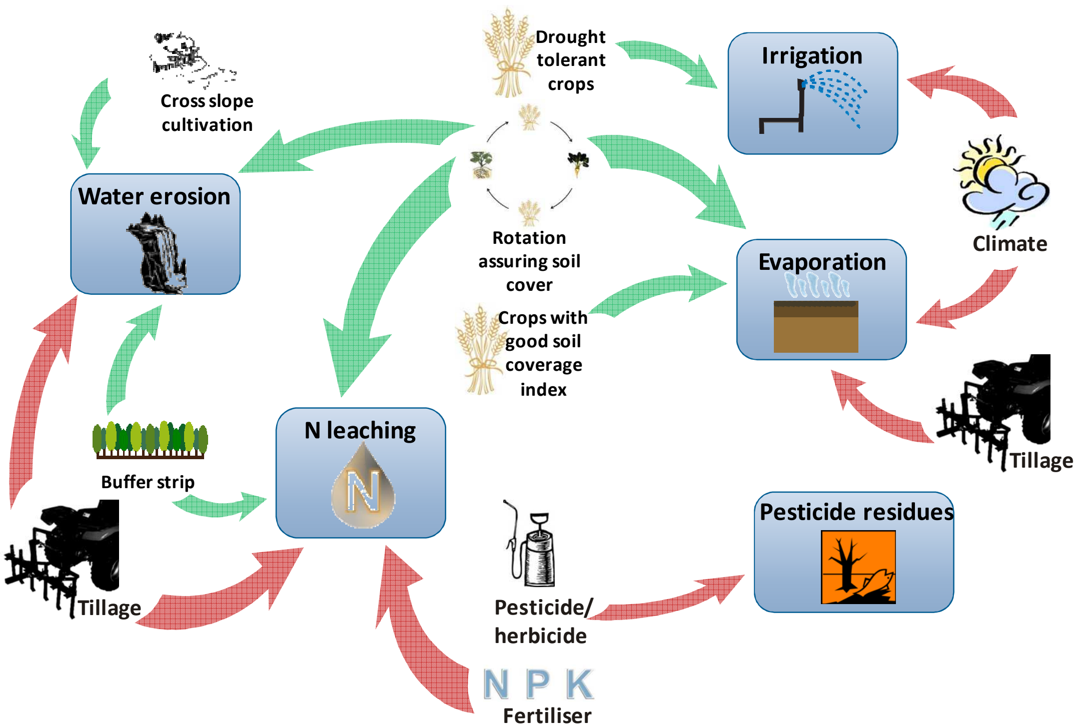


Figure 4-7: Parameters influencing the impacts of crop rotations on water

4. 4. 1. Impacts of crop rotations on N leaching

The key practices which may reduce N-leaching are (see Annex III – section 4.3):

- Catch crops/cover crops
- Minimum tillage
- Underploughing the straw
- Cultivation of crops producing a large mass of roots in the autumn
- Proper application of organic fertilisers
- Non-excessive application of Nitrogen
- Establishing buffer strip or planting trees along waterways

Positive impact characterises rotation with a high share of crops with a long vegetation period, which in critical periods for N_{min} losses (autumn, spring) develop a large mass of roots. On the opposite, rotations which contain crops with a short vegetation period have a negative impact.

4. 4. 2. Impacts of crop rotations on residues of pesticides

The most frequent method used to reduce the risk of polluting waters with pesticides is, in general, Integrated Pest Management (IPM). The main objective of Integrated Pest Management is to maintain good productivity levels as well as reduced levels of risks on human health and the environment, including water. IPM brings together a wide range of different control methods (biological, genetic, and mechanical), thus reducing the use of pesticides in crop protection. Selected practices presented in Annex III – section 4.3 reduce the dependence on chemical means of protection and result in a lower load of pesticide residues in waters.

Crop rotations with a high diversity and a proper sequence of crops in the rotation may play an important role in controlling pathogens, thus allowing for a reduction of pesticide use in crop protection. The most sensitive to crop rotations are soilborne diseases, nematodes and weeds with transient seed banks. Less sensitive are airborne species (insects, foliar diseases) and weeds having persistent seed banks. Crop rotation is considered as an efficient method to support pest management (Vereijken, 1994).

In general, different types of rotations may have an impact on emission of pesticides to groundwater and rivers:

- Positive – diversified rotations and rotations with a high share of crops with a low dependence on pesticides (e.g. grass, clover, Lucerne);
- Neutral – rotations with a high share of crops protected with the applications of pesticides in the periods of low precipitation and runoff;
- Negative – strongly simplified rotations (including monocultures) and rotations with a dominating share of crops that are highly dependent on chemical crop protection and requiring applications of pesticides in the periods of high precipitation and runoff.

4. 4. 3. Impacts of crop rotations on water Erosion

Water erosion changes the relations between runoff and infiltration of water, thus it has a direct impact on reducing the amount of water retained in the soil. An indirect effect of erosion is related to removal of nutrients from the soil (both soluble – N, K, and less soluble – P). This contributes to pollution of rivers and water reservoirs and, as a consequence – eutrophication, which is an increase in the concentration of chemical nutrients in an ecosystem to an extent that it generates effects such as anoxia and severe reductions in water quality, which may harm to fish populations, while other species may experience an increase in population that may negatively affect the direct ecosystem (e.g. Nomura Jellyfish overpopulation in Japanese waters). In addition, organic matter washed out from the top soil is another source of pollution and increases water turbidity.

Crop rotations play a role regarding water erosion depending on the soil cover provided by crops (soil cover index) and along teh year (presence of catch crops/cover crops in the rotation). Other practices such as mulching and planting rows of trees, which prevent for evaporation (see Annex III – section 4.3).

4. 4. 4. IMPACTS OF CROP ROTATIONS ON EVAPORATION

Importance to store water from autumn and winter rain or snow falls and protect the soil from evaporation depends on the local water availability, as it is needed in Eastern and Southern Europe, and less critic in other regions of Europe, with a mild climate and high precipitations.

Rotations have relatively indirect impacts on evaporation, but can play a central role in evaporation control, mainly through soil cover management. Rotations could actually be organised with the aim to cover soil rapidly during the periods of crop establishment, or including long season crops, in order to limit evaporation (see Annex III – section 4.3). Finally, different aspects of rotations are of importance regarding their impacts on evaporation:

- selection of crops with a high soil cover index (including catch crops/cover crops) in the periods of intensive runoff. This practice reduces losses of water;
- agronomic operations that reduce evaporation. For instance first ploughing, then harrowing, destroy the capillary structure at the surface of the soil and mitigate evaporation in the result;
- planting rows of trees in areas with sandy soils mitigates circulation of the air, thus reducing evaporation and losses of water in adjacent crops;
- practices increasing organic matter content in the soil, e.g. fertilisation with organic manure, increasing share of crops which in turn increase organic matter in the soil (legume, grass). It is important on the sandy soils characterized by a small water storage capacity. The organic matter content is one of the key factors of soil water holding capacity, due to improved structure of the soil. This has a positive long-term effect on the water storage capacity of the soil, although an immediate consumption of water by crops producing large amounts of organic matter is high.

Rotations which have the lowest impact on water resources extraction are rotations which include a greater share of winter crops, which have a higher potential to use available water from the soil, as well as those farming practices providing higher soil cover in the spring and thus reducing evaporation.

4. 4. 5. IMPACTS OF CROP ROTATIONS ON IRRIGATION

In Europe, irrigation is mainly practiced in Mediterranean regions where it covered 12 % (Portugal) to 33 % (Greece) of the arable land in 2005 (Eurostat, 2005). However, in Northern countries, irrigation may account for a significant part of the arable land: up to 10 % in Denmark (sandy soils), 5 % in the Netherlands (high value products). In France, 6 % of the arable land is irrigated with strong regional disparities between North and South.

In the regions where cereals and oil-protein crops are predominant, grain maize is the main irrigated crop (France, Spain, Italy); it represents 70 to 80 % of the irrigated areas in SW France. In SE France (Mediterranean part), 35-45 % of the irrigated land is devoted to horticulture and fruit production. Figure 4-8 gives values of the % of irrigated areas for a range of crops in France (Gleyses and Rieu, 2004).

In these perimeters, water is delivered by centre pivot systems or by furrow systems.

In Southern regions, irrigation is a way to increase the diversity of crops. But, in spite of this theoretical diversity, crop rotations are less diverse than expected because water responsive and drought tolerant crops are grown separately according to available water resource. However, except maize monoculture in some regions, irrigation generally increases the diversity of crops, because “seed production” crops or fresh vegetables can be inserted in crop rotation when irrigation is secured. Double cropping is also possible using summer crops soon after harvest of winter-sown crops provided irrigation is fully available. In some regions, rotations in dryland conditions are generally shorter because only drought-tolerant crops are planted, limiting the range of possible crops while in irrigated land, a profusion of crops with high economic return are cropped (Andalucia for instance). In other regions, because of specialised cereal systems, irrigation may lead to monoculture (e.g. SW of France: continuous maize).

Both crops and the crop sequence influence irrigation requirements of crop rotations:

- the composition of crop rotation (and consequently of farm cropping plan)
- crops differ by their water requirements for achieving maximal production. They also differ by their irrigation needs because the ability of crops to extract water from soil and the availability of soil water during the growing season are different from one crop to another.
- the crop sequence
- some effects of preceding (or previous) crops on water availability for the next crop have been reported in the literature but it is not clear whether they change significantly the irrigation requirements of the next crop.

Further, crops vary in their water needs, and crops could be classified by (See Annex III – section 4.3 for more details on irrigation):

- high needs of irrigation for water efficient crops, like potato, vegetables, grain maize, which are very sensible to water shortage
- drought tolerant crops, like sorghum or sunflower, have efficient adaptive process and can adjust transpiration to water availability, and need reduced amounts of water when irrigated

* escaping crops, like winter cereals, escape the summer drought periods in Europe, and are generally not irrigated.

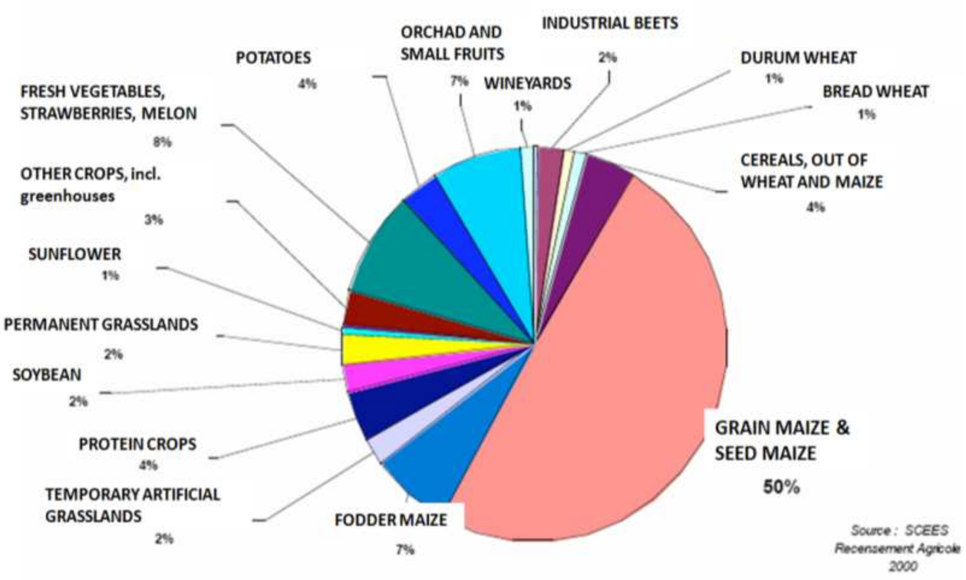


Figure 4-8: % of irrigation for major productions in France.

In Southern Europe, some crops are completely excluded from cultivation if irrigation is not available (maize for instance). There is a trend to irrigate crops which were generally managed in dryland systems 10-15 years ago (ex. potato in Northern Europe).

Box 4-5: Summary – impacts of crop rotations on water

In Southern Europe**,** irrigation availability may result in crop diversification (including vegetables, cotton…) or in monoculture of maize according to regions. Irrigated and rainfed systems are clearly separated in the landscape.

In Central, Western and North Europe, irrigated and rainfed crops are generally combined in the same rotation. Irrigation increases the diversity of possible crops, but may result in maize or horticulture monoculture anyway.

Cereal monoculture is often the only alternative in rainfed systems of Southern Europe while maize monoculture is the main option in irrigated systems of Europe. In rainfed systems, crop rotation (and resulting crop plan) is a way to reduce the risk of severe yield loss (by combining crops with different degree of drought tolerance, Alternating winter and summer crops...). Only in limited parts of Europe, the introduction of fallow has a role in water storage for next crop.

Differences in irrigation amounts and water use efficiency (WUE) may be observed between crop rotations. Some crop rotations are preserving quantitative soil resources, some are more efficient than others to use total available water.

The linkages between the environmental impacts on water, crop rotations and the related farming practices are presented in **Erreur ! Source du renvoi introuvable.**.

The preceding crop can influence the available soil water use from following crop, probably through its water consumption, type and amount of residue generated and the physical effect of its root system on soil (see Annex III – section 4.2.1.1.2 for more details on preceding crops effect on available soil water use). For instance, in Southern Europe (Spain), introducing an annual fallow in the rotation for storing soil moisture can be necessary but breaks the cereal monoculture. See Annex III – section 4.3 for details on the impacts of different parameters of crop rotations on irrigation needs.

4.5. CLIMATE CHANGE

Key indicators of change such as increased mean temperatures, changes in patterns of precipitation, and extreme events are widely accepted to be due, at least in part, to the radiative-forcing effects of increased concentrations of atmospheric greenhouse gases (GHGs), exacerbated by land-use changes (Robertson et al., 2000). Carbon dioxide (CO_2) is the principal GHG by virtue of its high atmospheric concentration, which has increased by 30 % since circa 1750. Methane (CH_4) and nitrous oxide (N_2O) are the two other main GHGs and have also increased over the same period. In general terms, vulnerability is greatest in the Mediterranean area and in Southern Europe (Schroter et al., 2005), because of summer heat and drought.

Climate change-induced effects like droughts can be felt locally, whereas the effects of higher temperatures and enhanced atmospheric CO_2 concentrations in situations where water is not the limiting resource, e.g. in Northern and northwest Europe, could be generally positive for agricultural production.

Agriculture contributes to emissions of CO_2 through its use of fossil fuels during cultivations (machinery), and indirectly through energy-intensive inputs, such as fertilisers (especially N), and farming practices, from a general perspective, such as conversion of grassland or peatlands into arable land, tillage practices, etc (Hopkins and Del Prado, 2007). As CH_4 and N_2O have a much greater radiative-forcing potential than CO_2, there is now increasing pressure to curb their emissions in agriculture (see Figure 4-9).

Climate change may harm to crop production (see Annex III – section 5.1), however, crop rotations may be an effective measure in adaptation and mitigation to climate change (see case studies in Annex III – section 5.4.). Box 4-6 summarises the environmental impacts of some crop rotations on C sequestration, N_20 emissions and water shortage (see also Annex III – section 5.2).

4. 5. 1. IMPACTS OF CROP ROTATIONS ON CARBON SEQUESTRATION

The primary aim of the mitigation options is to reduce emissions of methane or nitrous oxide or to increase soil carbon storage. Carbon sequestration can be defined as the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere.

Key considerations regarding soil C balance and greenhouse gases emission from soils are: (1) the potential increase of CO_2 emissions from soil contributing to greenhouse effect increase, (2) the potential increase in other gas emissions (e.g., N_2O and CH_4) from soil as a consequence of land management practices and fertiliser use, and (3) the potential for increasing C (as CO_2) storage into soils, and to help reduce future increases of CO_2 in the atmosphere (Al Kaisi, 2008).

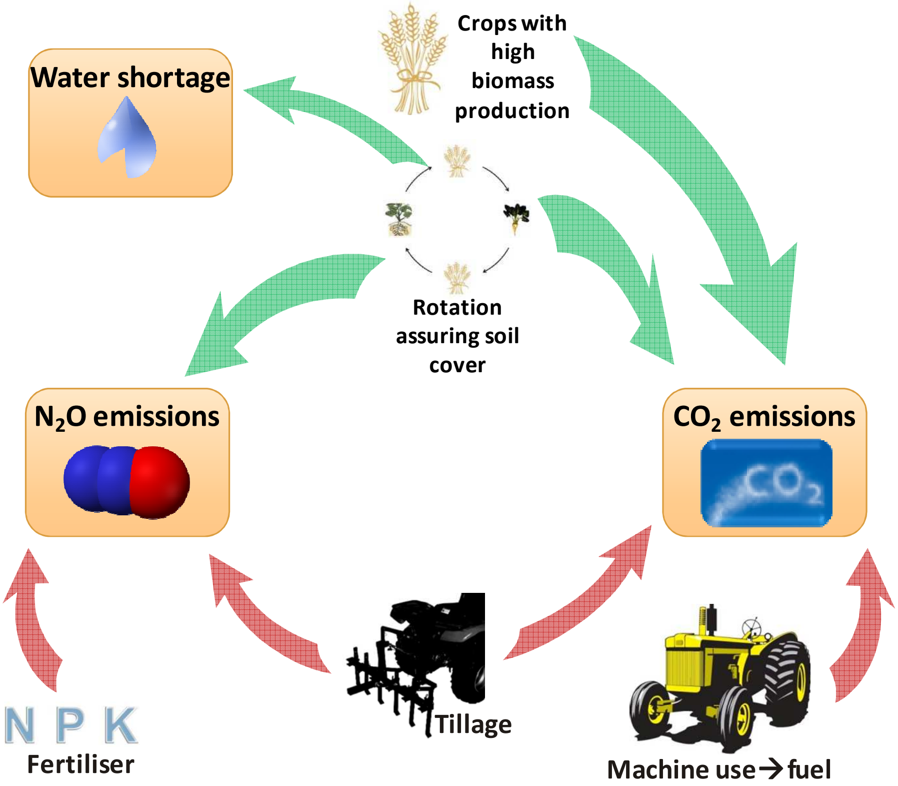


Figure 4-9: Parameters influencing the impacts of crop rotations on climate change

A key option for GHG mitigation is carbon sequestration in soils in spite of modest contribution by itself to mitigation (3–6% of fossil fuel contributions). In temperate regions, management changes for an increase in C involve increase in cropping frequency (reducing bare fallow), increasing use of forages in crop rotations, reducing tillage intensity and frequency, better crop residue management, and adopting agroforestry (Hutchinson et al., 2007).

Flynn et al. (2009) in the PICCMAT project analysed the effectiveness, costs, side effects and social barriers of some components of crop rotations in mitigation:

- reducing bare soil by the inclusion of catch crops or green manures
- changing the composition of the crop rotation (winter covering)
- adding N fixing crops in the rotation.

The most critical parameters influencing the impacts of crop rotations on climate change are reported in Annex III – section 5.3 consist mainly of:

- Including catch crops or green manures: less fallow and more winter cover
- Rotation species selection
- Adding legumes / N fixing crops to rotation or undersowing.

Many of the options available for adapting agricultural activities may influence the emissions of greenhouse gases either by enhancing or reducing the fluxes (Olesen and Porter, 2007). However, agricultural activities affect several greenhouse gases simultaneously; therefore the net effect on the global warming potential of all gases should be considered. There may also be differences between short- and long-term responses to introduction of system and management changes, in particular for measures that involve changes in soil management and input of carbon and nitrogen to the soil (Figure 4-9).

Criteria for assessing mitigation of farming practices to climate changes cover crop residues, period of active vegetation for C sequestration, and for N_2O emission, they cover the rate of N fertilization, and the N use efficiency including N leaching. For water resources, areas with limited resources should focus on reducing water needs and water losses, while areas with available resources should focus on reducing the environmental impacts of rotations, mainly through diversification (see Annex III - section 5.3)

4. 5. 2. IMPACTS OF CROP ROTATIONS ON N_2O EMISSIONS

The impacts of rotations on N_2O emissions depend largely on the type of crops included in the rotation and the soil coverage assured by the rotation. The presence of legumes and crops that require lower doses or no N fertilization can make a rotation beneficial in this aspect as well as rotations assuring year-round coverage of soil, especially in winter time by catch crops/cover crops to limit N leaching. Therefore monocultures are rated particularly low in this aspect while rotations with legumes have beneficial impact (see Annex III - section 5.3)

4. 5. 3. IMPACTS OF CROP ROTATIONS ON WATER SHORTAGES

The practice of rotations in regions threatened by water shortage can contribute to water savings, depending principally on the water needs of crops in the rotation and the soil coverage in order to prevent extensive evaporation. Monocultures as systems with high water needs are particularly badly rated regarding this aspect, while rotations performing well without irrigation such as oilseed rape/wheat or legume/wheat/cereal contribute to water savings. Drought tolerant crops can be an asset in this aspect as well as no tillage (see Annex III – section 5.3).

Box 4-6: Summary – impacts of crop rotations on climate change

A few critical parameters explain most of the environmental impacts of crop rotations on climate change: the production of crop residues and return of carbon to soils, N fertilisation, and irrigation are some parameters important to anticipate potential impacts of rotations on C sequestration, N_2O emissions and adaptation to water shortage. A crop with high biomass production (silage maize) contributes to CO_2 sequestration to a higher extent than one with low biomass production (e.g. legumes). Legumes on the other hand are beneficial for mitigating N_2O emissions as they require no N fertilisation, while high N fertilisation doses contribute to N_2O losses.

This page is left intentionally blank

5. ECONOMIC DIMENSION OF CROP ROTATIONS

In this chapter, the economic performance crop rotation is assessed at the cropping system level. Building upon the main environmental impacts of crop rotations identified in Chapter 4. , the environmental externalities that are relevant at the farm level and at the society level are also presented, which might be integrated in a cost-benefit analysis of crop rotations.

5.1. ECONOMIC IMPACTS OF MONOCULTURE AND CROP ROTATIONS

Measuring and comparing economic performance of rotations and monoculture

The economic performance of crop rotations systems is compared at the micro-level from the farmer's standpoint, using profitability as a common measure of economic return to the farm. Profitability is a function of costs, yields and output prices, and is calculated as the value of production (yield multiplied by its output price) minus the total costs (fixed and variable costs).

For crops grown in rotations, profitability is measured for all the crops included in the rotation sequence, and the total profitability of the cropping system is then given by the average profitability across crops. This measure of economic performance of the rotation is compared to the profitability of the crop in monoculture.

Time-horizon chosen for the comparison

The economic analysis of cropping systems is carried out within a dynamic framework, i.e. comparing monoculture and crop rotations over time. This means that profitability is averaged across the entire duration of the rotation.

5. 1. 1. IMPACTS ON COSTS

5.1.1.1 Fixed costs

Definition

Fixed costs can be defined as expenses that are independent from the amount of production. The combination of fixed costs and variable costs gives the total cost of the farm.

The main category of fixed costs in farming is the depreciation of fixed assets, such as:

- Buildings (e.g. warehouses)
- Infrastructure (e.g. irrigation systems)
- Machinery (e.g. farm tractors)

Comparison of fixed costs between monoculture and crop rotations

The difference in fixed costs between two different cropping systems depends mainly on the characteristics of the cropping system, i.e. on the use of chemical inputs (which require machinery), the needs for irrigation (that may translate into a specific dimensioning of the irrigation system), the need for tillage and the need for harvest. Tillage and harvest operations, in particular, are carried out with expensive machinery (powerful tractors and combine machines, respectively), which represent significant fixed costs. A change in rotation may or may not involve a significant change in fixed costs, depending on the type of operations required by the crops, the size of machinery already present on the farm, and the areas devoted to different crops: the choice of crops in the rotation has important consequences on the fixed costs of the cropping system.

In the case of long and diversified rotations, investments in machinery might be significant, thus generating higher depreciation costs[9]. On the other hand, simplifications in cropping structures might allow for a reduction of variety of equipment for field operations and allow a reduction in related fixed costs. This may suggest, in theory, that monocultures tend to exhibit lower fixed costs than rotations and that this gap increases with the degree of diversification of the rotation.

Empirical findings based on a sample of FADN farms in Poland[10] (Table 5-1) tend to confirm that cropping structures with lower levels of concentration (i.e. rotations) have somewhat higher depreciation costs. However the difference is not statistically significant[11] and is also highly dependant on the sensivity of the results to the types of crops in the rotation. In this sample, as a vast majority of the crops were cereals, maize and oil seed rape, the impact on depreciation of rotating different cereals or grow one of those in monoculture was not significant because the equipment used was the same. Fixed costs are likely to differ if the two compared systems include crops that require different machines or infrastructure (for example a cereal harvested with a combine machine and a temporary meadow harvested as hay).

Table 5-1: Depreciation costs and concentration of the cropping structure (average data)12

Concentration of cropping structure[13]	Ha/farm	Livestock units/farm	Depreciation costs (€)	Depreciation costs/ha (€)	Depreciation costs/unit of production value
High	120,6	0,83	10,432	109	0,184
Low	126,5	1,50	13,728	86	0,201
All farms	125,0	1,33	12,884	103	0,197

5.1.1.2 Variable costs

- **Definition**

Variable costs are defined as expenses that depend on the production volumes.

- **External inputs**

In agriculture the main variable costs are external inputs, i.e. inputs from off-farm sources such as fertilisers (nitrogen, phosphorus and potassium), plant protection products (herbicides,

[9] Defined as the decline in the value of tangible assets overtime. Depreciation is accounted as an additional cost in the balance sheet of businesses..

[10] epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/ad_hoc_tables_farm_structure_survey

[11] The 95% confidence interval for the difference in average depreciation costs is [-0.25 ; +0.28].

[12] Authors' calculations based on the Polish FADN sample (data for the year 2007). Only farms of the economic size more than 8 ESU and with the number of Livestock Units less than 10 LU/100 hectares were considered.

[13] Note: the concentration of the cropping structure has been calculated for each farm using the Herfindahl-Hirschman Index (HHI). $HHI = \sum_{i=1}^{I} s_i^2$, where I is the number of crops in the rotation and s_i the share of crop i in the cropping structure of the farm (for example, $s_i = 100\%$ in monoculture). The HHI has been calculated for all 496

fungicides and insecticides) and energy (electricity, fuel).

- **Labour**

The quantity of labour is measured as the number of working hours times the number of employees and depends on the production volumes. However, the quantity of labour at the farm level cannot be adjusted to production volumes perfectly because of rigidities, e.g. contracts imposing lags for laying off employees, and imperfections, e.g. mismatches between offer and demand for labour, due to problems in qualifying the labour force. In this sense, labour cannot be considered as a perfect variable cost.

- **Energy**

Energy is needed at every stage in the crop production process, from fuel for farm tractors to electricity for providing power to irrigation pumps. Energy use is directly and positively related to the intensity of the cropping system in chemical inputs and machinery use.

- **Machinery use**

Costs related to machinery use, excluding energy use, can also be considered as a variable cost. Although the stock of machinery (e.g. number of tractors) can be considered as a fixed cost on the short to medium term (if operations are carried out from contractors), repair costs and to some extent maintenance costs can be considered as variable. However, the cost of the capital spent to purchase agricultural machinery, which is extremely expensive, is relevant and strongly impacts the economic budget of a crop production system; in most cases, therefore, it cannot be considered small relative to variable costs and especially the cost of external inputs.

5.1.1.3 Exploiting the rotation effect to reduce variable costs

- **Definition**

Rotational effect is due to the interaction between different crops. The crop that is cultivated first: the "preceding crop" produces some modifications to the environment (especially to the soil), which may affect the growth of the crop that follows: the "subsequent crop". On the other hand, simplification of cropping structure, especially monoculture, requires higher inputs to mitigate negative effects of sequences lacking mutual support of crops. For example, Katsvairo and Cox from Cornell University (2000) show that growers who substitute soybean–maize and soybean–maize–maize (in ridge) rotations for continuous maize can reduce starter fertiliser use by 33 to 50%, N fertiliser by 60 to 70%, herbicides by about 60%, and insecticides by 65 to 100%".

However, savings on fixed costs, labour etc. may even compensate greater variable costs (of fertilisers, pesticides). If this is true, than loss of yields would be a key factor for financial results. Critical parameters are thus the fertiliser inputs (general), nitrogen needs, phosphorus and potassium needs, water needs, plant protection chemical inputs, labour requirements and energy use (see Table 5-2).

---

farms of the Polish FADN sample.The farms with an HHI above (resp. under) 80% where considered as having a high (resp. low) level of concentration of their cropping structure.

Crop rotations and inputs of technical means

The inputs of technical means in crop production may be affected by crop rotations; however, the relationship between rotation and inputs, as described here, are only theoretical and not necessarily real. For a crop combination to be beneficial either for weed control, nitrogen availability, water availability or disease reduction, it needs to be complemented by adequate management choice by the farmer. In other words, to exploit the rotation effect the farmer must use less herbicide, less nitrogen, less water or less fungicide/insecticide, respectively. If this choice is not made, the effect does not take place, i.e. the profitability of the rotated crop is similar to that of the continuous crop. Input costs are also impacted by crop characteristics.

Influencing crop characteristics

Regardless of their interaction, crops have intrinsically different properties that require different levels of chemical inputs, irrigation water and labour. For example, some crops, or some varieties of crops, are more competitive than others against weeds and thus need less herbicide applications, while others are high-yielding species that require more water to sustain transpiration during growth. Generally, high-yielding species – typically crops that require higher inputs (of labour, means of production) are more profitable due to higher output prices. Critical parameters are thus the amount of fertiliser inputs, needs for irrigation water, plant protection chemical inputs and labour (see Table 5-2).

Table 5-2: Effect of monoculture and rotations on input costs

Input	Effect	Comments	Reference
Fertilisers	**- to +**	‣ Fertiliser applications are generally higher for high-yielding crops (e.g. maize; wheat) → continuous maize rotation requires more N inputs than a more diversified rotation. ‣ Rotation effects on the fertiliser requirements of a crop are operated through the decomposition of preceding crop's biomass that can contribute to the nutrition of the subsequent crop.	Grignani et al., 2003 Karlen et al., 1994 Ceotto and Spallacci, 2006 Kirkegaard et al., 2008
N	**+**	‣ N requirements may be lower if the crop fixes atmospheric N, i.e. legumes. ‣ An alfalfa meadow of at least 3 years makes 80-120 kg N/ha available for the subsequent crop and residues of legume grains (soybean, pea, chickpea, etc.) 0-40 kg N/ha. ‣ N-poor residues can induce increased fertiliser application. ‣ different rooting depths affects N uptake at different depths in the soil profile, and (in interaction with water movement) influences N recovery and diminishes the need for N fertilisation for the following crop (e.g. alfalfa)	
P-K	**= to +**	‣ Evidence of rotation effects on P and K requirements is less strong than for N ‣ A crop may act on soil P and K availability for the subsequent crop	

Input	Effect	Comments	Reference
Irrigation	**-/+ to =/+**	‣ Depending on water inputs (precipitation and irrigation) and outputs (evapotranspiration, runoff, deep drainage), a crop affects the amount of residual water remaining in the soil, available for the following crop. ‣ Consumption of water during cultivation depends on climatic conditions, crop yield (high yielding crops need more water) and water use efficiency and farming practices (e.g. use of cover crops). ‣ The lower the water consumed by the preceding crop (either fallow or a real crop) is, the higher the water available for the following crop may be. ‣ When water is scarce and therefore limits crop yield, rotation effects on other aspects than water are not obvious	Kirkegaard et al., 2008
Plant protection	**- to +**	‣ Competitivity of the crop against weeds is the most important crop characteristic that determines the required amount of herbicides (e.g. cereals have good competitivity). ‣ The higher the diversity of crops in the rotation, the lower the pressure of weeds, pests and fungi on the crop and the easier their control. ‣ The economic consequence of a positive rotation effect on weeds and diseases can be either a decreased quantity of plant protection related inputs or an increase of yield (if the continuous crop was not treated and therefore its yield was limited by weeds or diseases).	Karlen et al., 1994
Labour	**-/= to +**	‣ Machine use frequency (apart from seedbed preparation and tillage) is directly proportional to the application of the inputs (fertilisers, water, plant protection). The crop characteristics that influence the amount of labour are linked to the complexity of the management required by the crop (e.g. presence of irrigation or not, depth of tillage) and by the amount of inputs to be applied. ‣ Shifting from monoculture to crop rotations needs an adaptation of farming practices, which may result in higher labour costs per unit of harvested product due to lower productivity, or to lower labour cost per unit of harvested product if productivity is higher. Lower productivity may occur when crop rotations involves alternative farming practices, without the knowledge base of more conventional practices. additional labour costs associated to the shift from monoculture to crop rotations may be gradually reduced as the farmer gains experience in the new practices . In addition, indicates that the diverse management skills and knowledge needed in diversified systems like crop rotations can on the long-term have a synergistic effect which may result in higher gains than from a specified system.	Fox et al., 1991 Ikerd, 1991 Gebremedhin, 1998
Energy	**- to +**	‣ Energy use is directly linked to the intensity of the cropping system in chemical inputs, irrigation needs and tillage practices and depends on farming and management practices. In the long-term there is uncertainty about the availability and cost of most energy-related agricultural inputs (fertilisers, agrochemicals, fuel) being produced from non-renewable energy resources and an increase in their price can be projected.	Ikerd, 1991 Chou, 1993 Tietenberg, 1992

Note: A "-" sign (respectively a "+") means that the input cost is lower (respectively higher) for rotation compared to monoculture.

Moreover, as already mentioned in Chapter 4. , it is necessary to mention the importance of crop management on these effects. For example, a rotation effect on N inputs of the subsequent crop depends not only on the preceding crop, but also on how N inputs and needs were managed during preceding crop cultivation (date, type and amount of N fertilisers applied; N uptake of preceding crop).

When specifically switching from monoculture to rotations, the critical parameters influencing the variable costs are detailed in Table 5-3.

Table 5-3: Impacts of switching from monoculture to rotations on input cost[14]

Type of input	Typology	Comments
Fertilisers	- to +	- for rotations including crops with reduced nutrient uptake, and/or legume crops leaving N credits + for vice versa
Pesticides/ Herbicides	- to +	- for very diversified rotations (with sufficient time between two occurrences of the same crop to break the cycle of pests/weeds) to + for less diversified (with insufficient time between two occurrences)
Water	-/+ to =/+	= when water is abundant +/- depends on the crops that are rotated and irrigation needs
Energy	- to +	Depending on the intensity in the use of chemical inputs
Labour	-/= to +	+ on the short-term and -/= on the long-term

Note: A "-" sign (respectively a "+") means that the input cost is lower (respectively higher) for rotation compared to monoculture.

Cropping systems with the same crop in monoculture or in rotations present variable profitability levels, and according to complementary parameters such as the level of fertilisation scheme, margins may be higher for monoculture or for rotations. A short rotation including maize would thus be more profitable than maize monoculture of a longer rotation including maize. In the meanwhile, wheat was more profitable in monoculture in a high fertilisation scheme, but in the low fertilisation scheme it was more profitable included in a rotation (see Table 5-4).

Table 5-4: Profitability of different cropping systems (€/ha/year)

Type of rotation	Production cost	Gross revenues	Margin	Sources	Comments
Continuous maize	1301	1634	313	L. Giardini, 40 years of experiments in Veneto Region (Italy), 2004	Results presented for average fertilisation schemes
2-year maize rotation	934	1701	767		
4-year maize rotation	1055	1798	743		
Continuous wheat	-	-	264	D. Forristal, Rotations: a New Role in a New Era?, 2005	Results of an experiment conducted in Knockberg, Ireland, *high fertilization schemes*
Cereal rotation	-	-	271		

[14] Input costs from rotations minus input costs from monoculture

Type of rotation	Production cost	Gross revenues	Margin	Sources	Comments
Continuous wheat	-	-	341		Results of an experiment conducted in Knockberg, Ireland, *low fertilization schemes*
Cereal rotation	-	-	301		

*Maize once every 2 years or 4 years, combined with other crops

5.1.1.4 Trends in the price of inputs

According to Eurostat, total input prices have risen significantly (+15%) between 2000 and 2008 in the EU, in real terms (i.e. corrected for inflation) (Figure 5-1). This increase can be attributed to the steep rise in the price of energy (e.g. electricity, motor and heating fuels) and energy related products such as fertilisers. The real price of fertilisers almost doubled between 2000 and 2008.

During the same period, the real price of herbicides and pesticides decreased by approximately 10%, while the purchasing price of machinery and other equipment remained broadly flat (Figure 5-1). But these did not offset the rise in energy and energy related products, given their weight in overall input costs.

Therefore, the trend in the price of inputs has had a strong impact on the variable costs.

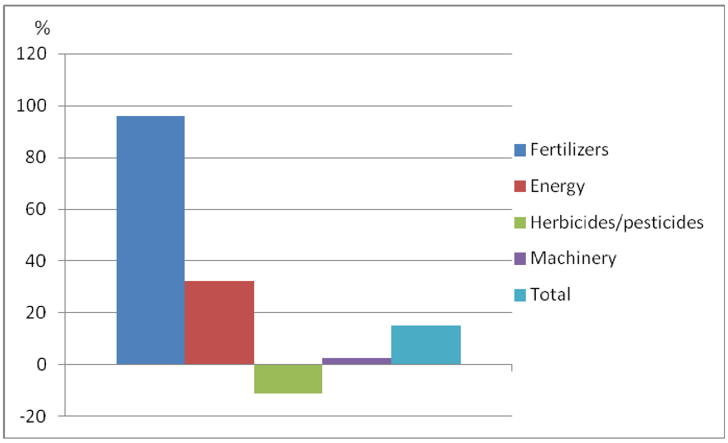


Figure 5-1: Change in the real purchasing price of inputs between 2000 and 2008 in the EU[15]

5. 1. 2. IMPACTS ON INCOME

5.1.2.1 Farm turnover

- **Definitions**

The turnover (or gross income) is defined as the product of the yield of the product obtained from cultivation by its selling price. For rotations, the turnover is calculated as the average turnover of each of the crops composing the cropping sequence.

- **Yield**

In a given environment (i.e. under certain pedoclimatic conditions, and with a certain availability of inputs), crop yield depends on three main factors: crop characteristics, crop management and a true "rotation effect". Crop characteristics include potential crop production (which depends on climatic factors and crop physiology, for example the photosynthetic type C3 vs. C4), and crop management use of inputs (irrigation, application of chemicals to control weeds, insects, and fungi, use of fertilisers, tillage practices). The true rotation effect consists in a higher yield of a rotated compared to a continuous crop, due to a number of factors already described above.

The impacts of rotations on yields depend to a high extent on farming practices. For example, as shown by Jones (1996), crop rotations combined with cover crops are likely to result in an increase in yields through their effect on soil quality and fertility. When used in combination with conservation tillage, reducing soil loss and decreasing soil compaction induced by machinery use may also have a positive impact on yield (Lavoie et al., 1991). D. Forristal et al. (2005) show for example that wheat cultivated in rotation outperforms continuous wheat in terms of yield by 5-10% overtime.

- **Average output prices**

Average output prices depend on two factors: the quality and the type of crops included in the rotation.

Monoculture systems are generally based on high value crops whereas crop rotations generally include in the sequence crops that have lower output prices (but that are necessary in order to capture the rotation effect, for example). It follows that average output prices for crop rotations might be comparatively lower than for monoculture.

As illustrated by Figure 5-2, the level and variability in prices for different crops often differ significantly, reflecting different market conditions. They affect revenues depending on the importance of the different crops in the rotation. In the example of wheat and sugar beet, average revenues generated by a wheat/sugar beet rotation compared to wheat in monoculture are likely to have decreased since mid-2005, as wheat prices started to surge whereas sugar beet prices remained broadly stable.

There is a relationship between the price structure and the quality of the crop, where, for example, a premium is payable according to a measurable quality characteristic. This may affect the economic comparison between cropping systems where quality characteristics are influenced by the fertiliser dose. The intensity of this relationship is variable according to the type of crops. Detailed analysis of these relationships can be found in Theobald C. Et al (2004)[16]. Preliminary evidence based on a sample of FADN farms from Poland suggest that crops grown in monoculture have roughly the same indicators in terms of quality as crops grown in rotations.

[15] Source: European Commission (Eurostat)

[16] Bayesian selection of fertiliser level when crop price depends on quality, Journal of Computational statistics and data analysis, 2004, vol. 47, no4, pp. 867-880

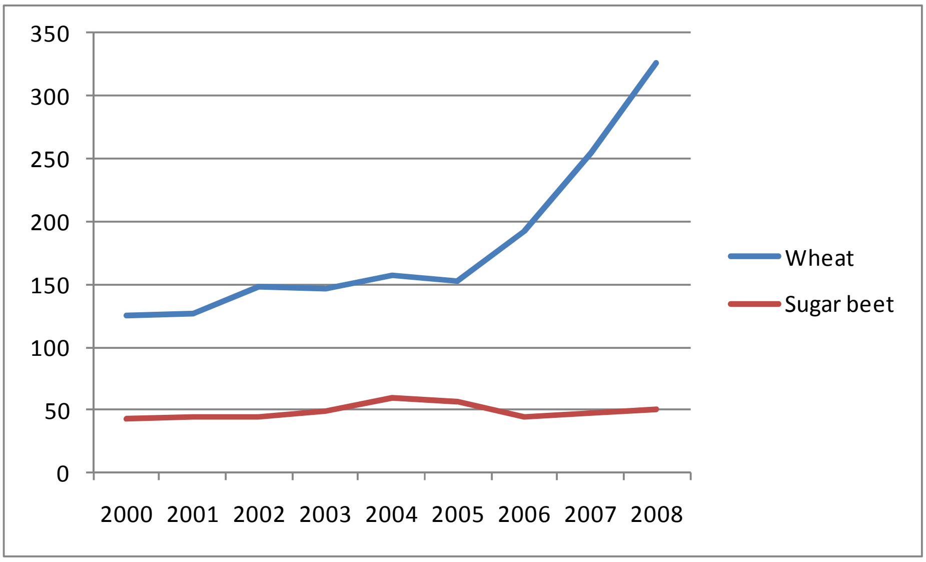


Figure 5-2: Evolution of the price of wheat17 and sugar beet ($/ton)
(Source: IMF commodity statistics, UK agriculture statistics)

- **Market conditions**

The selection of crops in a rotation is crucial because the income of the farm is averaged across all crops of the rotation, unlike the revenues from monoculture which depend on only one - generally high-value - crop. Rotations might include crops for which the market is limited (if existent at all) in order to exploit the full potential of the rotation effect, thereby reducing the average income of the farm.Market conditions need to be taken into account by farmers when choosing among different type of cropping systems, especially for rotation-based cropping systems. These relate to market characteristics, which are likely to vary significantly across crops, such as:

- The nature and level of demand (niche/wide market, existence of foreign demand, etc.);
- The average price in the market;
- The identification of the main actors/buyers;
- The level of concentration in the market;
- The way consumers/buyers react to changes in market prices.

5.1.2.2 Income variability and uncertainty

- **Definition**

Income variability is a function of yield and price variability in outputs and inputs. Variability can be measured using statistics such as the standard error[18]. The variability we are considering here is the variability in time, that is, the fact that a certain product does not have the same price on the market every year (due to changing market conditions), and that its yield is not the same every year, due for example to different meteorological conditions.

[17] Hard Red Winter, ordinary protein, FOB Gulf of Mexico

[18] Average distance of observations to the mean of the distribution

In theory, risk-averse farmers may choose cropping systems that minimise the variability of their income given a certain level of expected output (Young and Westcott, 1996). When choosing among different cropping systems, producers are often faced with a trade-off between higher revenues and higher income variability (Trenton F; Stanger et al., 2008). As producers become increasingly risk-averse, they tend to choose cropping systems which display lower income variability (Meyer-Aurich et al., 2006). Therefore it seems relevant to take into account the expected uncertainty (measured by historical variability) affecting crop yields and revenues as part of the drivers explaining the choice between different cropping systems.

From the farmer's point of view, the revenues generated by crops grown in monoculture are completely determined by yields as the price of the crop is considered as given by the market. In the case of crops grown in rotations, however, the average output price is the yield-weighted average of the prices of the crops. Hence, choosing rotation-based cropping systems gives the farmer the possibility to modify the average output price of his production by modifying the mix of the crop structure.

- **A simple framework for analysing income variability for different rotations**

Consider one rotation composed of I crops (a monoculture would be characterised by $I = 1$, i.e. a one year rotation). p_i is the price of the crop i and q_i the corresponding output. The average gross revenue generated by this rotation is given by: $\overline{pq} = \sum_{i=1}^{I} \theta_i p_i q_i$ where θ_i is the share of revenues of crop i in the farm's total revenues. A natural measure of the variability affecting revenues from this rotation is given by the standard error of $\overline{pq}$, $\sigma_{\overline{pq}}$, which can be expressed as:

$$\sigma_{\overline{pq}} = \sqrt{\sum_{i=1}^{I} \theta_i^2 \sigma_{p_i}^2 \sigma_{q_i}^2 + \sum_{i \neq j}^{I} \theta_i \theta_j cov(p_i q_i, p_j q_j)} \quad (1).$$

This variability has to be compared to the variability of the crop in monoculture: $\sigma_{p_1 q_1} = \sigma_{p_1} \sigma_{q_1}$ (2).

The compared impacts in terms of income variability of crop rotations and monoculture depend on the absolute risk specific to each crop ($\sigma_{p_i} \sigma_{q_i}$), their respective weight in terms of revenues (θ_i) and the correlation between crops (second term of equation (1)).

An appropriate selection of crops can help minimise the expected variability in revenues, for example by choosing uncorrelated crops that exhibit lower level of absolute variability in terms of revenues.

- **Yield variability**

Table 5-5 illustrates the extent to which yield variability is dependent on the type of rotation. This example of the Polish case study shows that potatoes grown in a four-year rotation (potato-rye-barley-wheat) are characterised by lower yield-variability than potatoes grown in monoculture and five-year rotations. In addition, as absolute variability is lower for rye, barley and wheat, it reduces further the average variability of the rotation.

Compared to monoculture, the 5-year rotation also exhibits a lower level of variability, but not as significant as for the 4-year rotation. Taking into account correlation among crops brings the overall variability for the 5-year rotation further down, by an additional 39%. This effect illustrates the fact that yields are negatively correlated between crops and the head crop and that yields for rye, barley and wheat are negatively correlated.

Additional evidence on the importance of the cropping system on the variability of production margins is given by D. Forristal et al (2005)[19]. This study shows for example that a decrease in yields by 15% for wheat grown in monoculture result in a decrease of more than 60% of the production margin. For the same reduction in wheat yield the rotation wheat/barley/oats sees its margin reduced by just over 20%.

Table 5-5: Variability of yields and risks for different potatoes rotations[20]

Difference in variability		TOTAL	Due to :	
			Absolute risk level of crops	Risk compensation among crops
4-year rotation vs. monoculture	t/ha	-4,38	-4,38	0
	%	-51%	100%	0%
5-year rotation vs. monoculture	t/ha	-0,55	-0,34	-0,22
	%	-6%	61%	39%

As mentioned for the other economic impacts of crop rotations, farming practices play a decisive role in the actual variability of revenues. For example, Schoney and Thorson (1986) and Johnson and Ali (1982) showed that fallowing used in combination with crop rotations leads to stabilisation of yields. These findings are confirmed by Hoskins (1981) who indicates that crop rotations spread machinery and labour requirements across a season, which may result in risk reduction due to yield variations. Monoculture systems are characterised by peak periods in terms of labour requirements (e.g. tillage, sowing, harvesting) while for crop rotations these peaks are less pronounced and more dispersed across the year (e.g. harvesting periods are dispersed throughout the year due to crop diversity). However, investments in the machinery needed for the various crops may be higher in case of rotations/ more crop diversity.

- **Variability in output prices**

Output prices for a given crop are those given by the market, as individual farmers cannot have an impact on market prices due to the highly competitive structure of this sector. But the diversity of the crops cultivated has an impact on the average output price of the farm: in monoculture systems, the variability and uncertainty in output prices is completely dependent on the price expectations of one crop. In crop rotation systems, the diversity of the crops cultivated allows risk to be shared across crops.

[19] Rotations: a New Role in a New Era?, 2005

[20] Data: Experimental farm Skierniewice (Poland), CaNPK fertilization scheme, yields expressed in fresh mass

Choosing rotation-based cropping systems gives the farmer the possibility to reduce overall expected variability in prices by modifying the mix in crops and/or the types of crops. If crop prices are uncorrelated or negatively correlated with the head crop, average output prices in crop rotations systems can exhibit lower uncertainty and less variability.

- **Variability in input prices**

Variability in input prices depends on the dependence of the cropping system to inputs, which, as discussed in section 5.1.1.2, are characterised by highly volatile prices and high uncertainty regarding their long-term availability at a reasonable cost.

Lowering the use of energy-related inputs such as fertilisers, herbicides or pesticides would provide a reduction of the exposition of the farm to the uncertainty affecting input prices, which in turn also would reduce the expected variability in costs and overall profitability. This overall reduction of uncertainty stimulates long-term investment and productivity gains and lead to more profitable cropping systems.

Illustration from the Polish experiment (farm Skierniewice):

Calculations based on data from the rotation experiments in the Experimental Farm Skierniewice (Poland) provide some insight into the financial performance of monocutures and rotations within different rotation patterns (Table 5-6). Total value of Gross Margin from 5 years rotation is higher compared to 4 years rotation, comparable with the Gross Margin from potatoes in monoculture under intensive (Ca, N, P, K) fertilisation scheme. Given the similarity in overall profitability, farmers may tend to choose togrow potatoes in rotation, which are characterised by lower variability in Gross Margins. Farmers with higher levels of risk aversion may even consider less performing rotations (such as four year rotations), given the significant difference in variability (31% compared to 92% for monoculture).

Table 5-6: Variability of gross margins for different potatoes rotations[21]

Crop/Rotation	Ca NPK		Ca
	Gross Margin [€/ha]	Coefficient of Variation	Gross Margin
Wheat 4Y	217	43%	93
Wheat 5Y	198	57%	181
Potatoes 4Y	1657	38%	594
Potatoes 5Y	2447	47%	1680
Potatoes M	752	92%	294
Rye 4Y	95	50%	29
Rye 5Y	70	75%	94
Rye M	53	89%	60
Rotation 4Y – total	519	31%	193
Rotation 5Y – total	715	39%	524

[21] Data: Experimental farm Skierniewice (Poland), CaNPK fertilisation scheme

5. 1. 3. CONCLUDING REMARKS

Profitability is a function of yields, prices and costs. As long as a chosen rotation system does not change significantly relations between those variables, there are no clear conclusions regarding financial performance of different rotation systems. The relationship between these variables remains broadly stable on the short-term, explaining why short-term comparisons do not yield significant results regarding the financial performance of different cropping systems. Gebremedhin and Schwab (1998) emphasise that "caution must be exercised while interpreting the results of comparative static economic analysis of cropping systems as results can be distorted by the production of multiple products, expanded performance criteria which are not easily valued, and use of different technologies. There is a need to analyse cropping systems as they generate their physical and financial performance over time". For instance, Katsvairo and Cox from Cornell University (USA, 2000) presented 6-year study results show, that "continuous maize under high chemical and soybean–maize–maize and soybean–maize rotations under low chemical management had similar net returns in ridge tillage (26€, 20€ and 13€/ha, respectively).

By adopting a long-term perspective and provided that the rotation effect, as defined in previous sections, is well captured by the farmer, the review of existing literature (see section 9. for the references on the economic analysis of cropping systems) strongly suggests that rotations allow for synergic effects in terms of yielding potential and reduced dependence on external inputs, thus resulting in higher profitability for rotations overtime, compared to monoculture.

However, the fact that the variability in profitability is significant both between cropping systems and within cropping systems illustrates the importance of farming practices in the overall economic balance of the farm. An adequate choice of varieties, cultivation techniques, and intensity of production is essential in increasing the economic returns of cropping systems.

5.2. INTEGRATING ENVIRONMENTAL EXTERNALITIES IN THE ECONOMIC ANALYSIS OF CROP ROTATIONS

From the farmer's standpoint, the choice between two different cropping systems is mostly based on their expected direct economic profitability. Nonetheless, some environmental issues are considered by farmers. The extent to which environmental impacts of different crop rotations are taken into account in the decision process depends on the following factors:

- The producers' degree of awareness and consciousness of environmental issues, which affects the weight given to environmental impacts relative to profitability. Rotations which are more beneficial to the environment but less profitable (at least on the short-term) might be preferred depending on the level of awareness on environmental issues.
- The potential linkages between environmental impacts and the profitability of the farm. Farmers naturally tend to take into account the environmental externalities that are directly linked to their production costs: they may choose rotations that are less intensive in water use because this may translate directly into lower costs. From an economic point of view, the environment is considered by the farmer as just another input in its production function. However, due to a lack of information on the set of

relevant environmental inputs and their effect on the farm's income, farmers may choose rotations which are both less profitable and more harmful to the environment. For example, ecosystems can provide protection services (e.g. against natural hazards) that may reduce the vulnerability of the crop production and increase its resilience to natural hazards. The extent to which the farmers take advantage of these multiple services depends to a great extent on their knowledge of regulatory mechanisms within ecosystems.

- Identifying the linkages between environmental externalities and yields would enable to identify the potential trade-offs between environmental and economic concerns as well as potential win/win situations at the farm level. This section attempts to provide evidence on these linkages, in qualitative terms.
- The existence of legislations aiming to give financial incentives to preserve the environment and protect ecosystems, for example by giving a price to environmental assets and bridging market failures. In order to integrate environmental impacts in a cost-benefit analysis of the cropping systems, a value has to be given to the different externalities. The question of the valuation of environmental externalities is a great challenge, since it depends on the preferences of economic agents, which are very diverse (for example, economic agents have very diverse views on the relative importance they give to present and future welfare), and is confronted to a range of uncertainties associated to the nature and the scale of the impacts (e.g. impacts of climate change). In addition, finding a unique monetary measure for ecosystem services is not possible as aggregation of preferences across individuals and across different types of services makes little sense. This section does however look into the main relevant society level externalities and estimates of reference values is given from the literature, so as to give an order of magnitude of these externalities in the costs benefit analysis of the farm. The different environmental impacts analysed is those presented in Chapter 4.

5. 2. 1. BIODIVERSITY

Rotations can be ordered according to their respective impact on biodiversity, with monoculture being the most damaging cropping system and diversified crop rotations the most virtuous, as presented in Chapter 4.

Potential win-win rotations

There is an economic rationale underpinning the choice of rotations with less negative impacts on biodiversity. Diversified rotations usually help preserve soil quality and structure, on which crop yields depend upon to a large extent. In addition to the positive impact on yields, choosing diversified rotations might also help reduce the exposure of the farm to both price and yield variability.

Economy-environment trade-offs for rotations

On the other hand, some rotations favourable to biodiversity conservation can be characterised by comparatively lower average revenues. This is the case for rotations with temporary grasslands and grass leys, which weight on the average revenues from the rotation. This effect can be compensated, to some extent, by the fact that these rotations are less intensive in chemical inputs. This trade-off can be overcome, at least partially, by acknowledging that biodiversity conservation provides benefits to the society as a whole and that farmers could be compensated for their role of preservation.

- **Giving a value to biodiversity and ecosystem services**

Valuating these positive externalities would help to increase the relative profitability of cropping systems and farming practices less harmful to biodiversity and ecosystems. For this to be possible, two essential questions have to be addressed:

- What is the economic value of biodiversity?
- What financial mechanisms would have to be implemented in order to reward farming practices that are more biodiversity-friendly?

The answer to the first question is not straightforward and unique as it varies across individuals, space and time. A variety of methods are used in order to approximate the concept of value of biodiversity. A broad consensus exists among researchers and policy-makers in forums such as the TEEB (The Economics of Ecosystems Services and Biodiversity) to value biodiversity indirectly through ecosystem-based services.

Table 5-7 provides an overview of existing estimations for ecosystem-based services that might be of relevance as regards the comparison between cropping systems. The values presented in table 5-6 as well as in tables 5-7 and 5-8 are directly related to the social value of the ecosystems and other environmental assets presented in this report. This social value[22] can be approximated by the maximum willingness-to-pay (WTP) of agents to obtain one additional unit of the service provided by the ecosystem[23]. In case the user has property rights over the area which is host to this specific ecosystem, then the value of the service provided can be approximated by the willingness-to-accept a compensation. The results provided in this section generally rely on these valuation techniques, which often combine WTP and willingness-to-accept a compensation. A comprehensive presentation of these and other methods can be found for example in Turner R. K. et al. (2003)[24].

Table 5-7: Estimated values for biodiversity services (non-wood products, in € or $ per ha)[25]

Country/region	Nature of the service/product	Value	Reference
Turkey	Non-wood products	18.4$ (~14€)	OECD, 2001
Canada	Non-wood products	2.4$ (~2€)	Anielski et Wilson, 2005
Scandinavia	Picking	10.15$ (~7.5€)	Turner et al., 2003
Switzerland	Picking	22€	Rauch, 1994
	Hunting	5-7€	Alfter, 1998
France	Vegetal products	7€	IFEN, 2005

22 Which is equal to the sum of the marginal utility for each users
23 An additional challenfge is to define a relevant measure for this service
24 « Valuing nature: lessons learned and future research directions », Ecological Economics, 46, 493-510
25 Source : Conseil d'Analyse Stratégique (CAS), Biodiversity group, 2009

Country/region	Nature of the service/product	Value	Reference
	Hunting	4-5.8€	Montagné et al., 2007
	Forest honey	1.3-2€	MAP, 2006
	Mushrooms	0.7-1.3€	MAP, 2006

5. 2. 2. Landscape

Crop rotations impact the landscape through the diversification of crops in space and through conservation of un-cropped areas and interconnections between them.

- **Potential win-win rotations**

The ecological function associated with landscapes such as the diversity and quantity of flora and fauna, is relevant from the farmer's standpoint: landscapes may affect important parameters impacting yields and production costs, such as pollination, water use or trafficability with agricultural machinery. Positive landscape externalities may be associated with temporary grasslands, extensively used areas or grass leys and combined with relatively higher yields (for break crops) and lower water use.

- **Economy-environment trade-offs for rotations**

However, as mentioned above, the average revenues from these rotations are brought down by grasslands or grass leys.

Table 5-8: Estimated values for landscape (recreation, aesthetic, cultural services in € or $ per ha)[26]

Nature of the landscape	Country	Value	Reference
Forest	Turkey	0.1$ (~0.1€)	OECD, 2001
Forest	Canada	15$ (~11€)	Anielski et Wilson, 2005
Forest	USA	35-88 (~26-65€)	Kriege, 2001
Forest	Scandinavia	15-20$ (~11-15€)	Turner et al., 2003
Forest	Italy	77-85$ (~57-63€)	CDB, 2001
Forest	France	90-126€	Lebreton, 2004 ; IFEN, 2005; MEEDDAT 2008
Forest	Ireland	250$ (~185€)	CDB, 2001
Forest	Germany	214$ (~159€)	CDB, 2001
Forest	Switzerland	216-777€	Rauch, 1994 ; Alfter, 1998
Forest	G-B	134£-2290$ (~149-2544€)	Turner et al., 2003 ; Willis et al., 2003
Permanent meadows (excursion/walk)	France	< than for forests	CAS, 2009
Permanent meadows (aesthetic amenities)	France	60€	CAS, 2009

- **Giving a value to aesthetic, cultural and recreative functions of landscapes**

The aesthetic, cultural and recreation functions associated with landscapes are linked to the diversity of landscape over space and the quantity and diversity of species, the two being closely

[26] Source : Conseil d'Analyse Stratégique (CAS), Biodiversity group, 2009

related. These functions have a social value, which could be incorporated to the overall economic analysis of the farm.

The general idea is that more diversified rotations are likely to generate a higher diversity in landscapes (for example by allowing temporary grasslands) and may be given a higher value from the society's viewpoint than monocultures. An illustration of these services can be given at least for specific features attached to landscapes, such as the presence of grasslands (Table 5-8).

- **Illustration for selected services provided by forests and permanent meadows**

An illustration of environmental amenities provided by forests and permanent meadows is given in Table 5-8 for different countries. These estimations are not directly usable for the comparison of rotations as regards their environmental impacts and their valorisation, because shifting from one rotation to another has no impact on forest area or permanent meadows. However, given that there is a link between temporary meadows and the type of rotation, using the results given for permanent meadows in the assessment of environmental amenities provided by rotations is possible, keeping in mind that this value is a possible upper bound.

5. 2. 3. Soil

- **Potential win-win rotations**

The issue of soil fertility (more specifically addressed in Chapter 4. through the examination of rotation effects on soil organic matter and soil structure) is extremely relevant for the farmer due to its great impact on the capacity of the soil to be productive. A soil that looses fertility (lower soil organic matter, degraded structure) is a soil that may need more inputs and/or may produce less compared to a fertile soil. Impact of rotations on soil structure is highly dependent on farming practices, such as tillage. Putting aside farming practices, it is possible to combine positive economic effects and positive (or less negative) effects on soil, compared to monoculture. This is the case for example of wheat-based rotations, which are characterized both by a higher profitability than wheat grown in monoculture and less negative impacts on soil organic matter.

- **Economy-environment trade-offs for rotations**

Rotations with temporary grasslands, permanent meadows and grass leys have particularly positive effects on soil structure and soil organic matter compared to monoculture. These rotations are however characterised by lower average profitability, due to lower average yields, and may therefore not be chosen by farmers.

- **Giving a value to the social function of soil fertility**

Soil fertility also has a value "per se" and can bring co-benefits at the society level: a fertile soil may allow the growth of spontaneous vegetation (for example of a forest, or of a recreational park), and regulate the water and nutrient cycles. Reference values associated with specific services provided by soils are given throughout this section, in particular in section 5. 2. 4 for services related to water quality and in section 5. 2. 5 for climate change.

Cropping systems which generate this kind of positive externalities are likely to be diversified rotations and rotations involving temporary grasslands and grass leys and extensively used areas, for example.

5. 2. 4. Water

The intensity of production, the amount of chemical inputs used and, to a lesser extent, the selection of crops in the rotation has an impact on the availability and the quality of water.

- **Potential win-win rotations**

A set of rotations combining less water use and increased profitability compared to monoculture can be identified. For example, oilseed-based rotations need less irrigation water because soil moisture is better preserved and evaporation is limited. They may also be more profitable than oilseed grown in monoculture because of lower needs in chemical inputs.

In addition, a number of rotations with roughly the same impacts on water use than monoculture but with higher performances regarding water quality (lower N-leaching and residues of pesticides) and potentially higher profitability ratios can be identified such as sugar-beet, oilseed and wheat based rotations.

- **Economy-environment trade-offs for rotations**

Rotations with temporary grasslands have significant positive co-benefits in terms of water quality, as fewer residues of pesticides are generally observed. However, the economic performance of these rotations is limited compared to others.

Maize based rotations also have comparatively less negative impacts than maize grown in monoculture, which is particularly intensive in water use and characterised by high rates of N-leaching. For example, rotations such as [maize/winter wheat] or [maize/w. wheat/w. wheat/] may have more limited rates of N-leaching, residues of pesticides and evaporation, as shown in Chapter 4. However, maize based rotations are not the most profitable and the compared economic impacts with maize in monoculture may range from negative to positive, crucially depending on crop selection and farming practices.

- **Giving a value to society-level services related to water quality**

Rotations that rely less on chemical inputs and that preserve soil structure contribute to the improvement of water quality (or to a lower degradation of it). This service has a value for the society as it would reduce the need of water treatment and the related cost of compliance with minimum standards in terms of water quality.

Cropping systems also have an impact on water quality through the way they structure the surrounding landscapes and ecosystems and the corresponding regulation services they can provide. These regulation services can be provided by ecosystems such as forests, wetlands or permanent meadows. A recent French study (Conseil d'Analyse Stratégique, 2009) proposed some estimates of reference values for services related to water quality provided by different ecosystems, such as forests or permanent meadows (90€/ha/year). Brander et al. (2006) found that the services provided by Wetlands regarding water quality could be valued at 28$/ha/year (median value, ~21€).

The set of rotations that is most likely to preserve ecosystem-based services related to water use are usually diversified rotations accompanied with adapted farming practices (as regards tillage for example). Rotations with temporary grasslands are likely to have positive effects on water quality compared to other rotations.

5. 2. 5. CLIMATE CHANGE

Cropping systems and farming practices affect the overall carbon balance of the soil (relevant for climate change mitigation) and the vulnerability of the land to climate change related risks (relevant for climate change adaptation).

- **Potential win-win rotations**

Several rotations that have a positive impact both on climate change mitigation, through higher capacity to sequestrate carbon and lower N_2O emissions, and on adaptation, thanks to a higher capacity to adapt to water shortages for example, can be identified: Oilseed rape, maize and sugar based rotations are likely to provide positive co-benefits in terms of GHG emissions and are characterized by a relatively high resilience to water shortages. As presented in Table 5-4, these rotations are profitable (more, in some case than the corresponding monoculture), provided adapted farming practices are implemented.

- **Economy-environment trade-offs for rotations**

On the other end, several potential high margin rotations, such as monoculture of maize and potato-based rotations have negative externalities as regards climate change. In particular, as these rotations are characterized by high evaporation rates, they require relatively important amounts of irrigation water, which makes them quite exposed to impacts of climate change on water availability and potential water shortages that may arise.

- **Giving a value to GHG emissions**

Giving a price to GHG emissions (especially CO_2) would increase the cost of energy and reduce the relative profitability of energy-intensive cropping systems. This would reduce the profitability gap between energy intensive rotations that often rely on high-yielding crops (e.g. maize) and less energy intensive rotations which, symmetrically, tend to be characterised by lower average yields. Giving a price to GHG emissions would also contribute to reduce non-energy GHG emissions such as N_2O for example.

Estimates of the social price of CO_2 vary widely, from 10$/t CO_2 up to several hundred Dollars, according to the different methodologies used and assumptions made. A recent study commissioned by the French government (Quinet, 2008), showed that the price of one ton of CO_2 consistent with European targets in terms of climate change mitigation most likely lies in the range of 32-45€, increasing gradually to 100€ in 2030.

The price of CO_2 that is given by the European Union Emissions Trading Scheme (EU-ETS) could also be used as a proxy of the social cost of CO_2 and used to value externalities related to GHG emissions. In 2009 and in the first part of 2010, the price of one ton of CO_2 has been in the range of 10-15€.

- **Giving a value to climate change adaptation**

Cropping systems and land management practices impact the structure of the landscapes, ecosystems and soils, which are decisive factors in the vulnerability and resilience of natural and human infrastructure to natural hazards (e.g. flooding, fires).

Estimations based on the costs of reparation or investment and maintenance costs are given in Table 5-9 for protection services provided by forests. These figures provide an illustration of the value of ecosystem services associated to the reduction of vulnerability and increasing resilience to natural hazards, which are set to increase in intensity and frequency as a result of climate change.

These services are relevant both at the farm level, as natural hazards result in direct economic costs for the farm (e.g. land loss, damages to crops), and at the broader society level, as economic activities and households are also exposed.

Table 5-9: Estimated values for protection services provided by forests (in € or $ per ha)[27]

Country/region	Service	Value	Reference
Turkey	Protection of catchment basin	7,4$ (~5.5€)	CCDE, 2001
France (south-east)	Fire and erosion	30€	MEEDDAT, 2008
Switzerland	Soil protection	1360€	Rauch, 1994; Alfter, 1998
Canada	Protection of catchment basin	0,06€	Willson, 2005

5. 2. 6. Conclusions

The findings from this section allow us to identify the rotations that combine positive economic impacts compared to monoculture and beneficial externalities from an environmental point of view, from the set of rotations that has been analysed all throughout this report.

- **Potential win /win rotations (positive economic and environmental impacts)**
  - [oilseed/wheat] or [oilseed/wheat/barley]: - to + (profitability)/ + (environment)
  - [maize/wheat] or [wheat/maize/wheat]: - to + (profitability) / ++ (environment)
  - [potatoes/spring barley/winter wheat/triticale]: = to + (profitability) / = to + (environment)

In the same way, rotations with positive environmental impacts but insufficient economic performances compared to monoculture can be identified. This profitability gap is to a high extent due to the lack of integration of negative externalities in the costs and benefits of the cropping systems. Identifying them and giving them a value (Table 5-10) is an essential step towards promoting rotations more respectful of the environment.

- **Potential win /loss rotations (positive environmental impacts combined with negative economic performances)**
  - [sugar beet/spring barley/oil-seed rape/winter wheat/winter wheat]: - (profitability) / = to + (environment)
  - [sugar beet/cereal (1 or 2 years)/potatoes/cereal (1 or 2 years)]: - (profitability) / = to + (environment)
  - Temporary grasslands (2 years)/ Barley/ Winter Wheat/ Maize silage/ Barley]: - (profitability) / ++ (environment)

[27] Source : Conseil d'Analyse Stratégique (CAS), Biodiversity group, 2009

Table 5-10: Environmental externalities and their relevance regarding their integration in the cost-benefit analysis of crop rotations

Type of environmental externality	Impact of the externality at the:		Existence of reference values and degree of preciseness (-- to ++)
	Farm level	Society level	
Biodiversity/ecosystems – aesthetic, recreative and cultural services (including landscapes)	NO	YES	YES (--)
Biodiversity/ecosystems – provision of marketable products ex. wood (e.g. picking, hunting, non-wood products)	NO	YES	YES (-)
Water availability	YES	YES	YES (-)
Water quality	NO. However, if water is polluted agriculture may be damaged as well (e.g. with pesticides).	YES	YES (+)
GHG emissions	NO	YES	YES (++)
Biodiversity/ecosystems – resilience to pests, natural hazards and climate change impacts	YES	YES	YES (-)

This page is left blank intentionally

6. EU POLICY INSTRUMENTS AND COMMERCIAL CONTRACTS WITH REGARDS TO CROP ROTATIONS

In the choice of the crops and type of rotation, or even monoculture, policies provide a major framework and driving orientations to farmers. The following policy tools are analysed with regards to their links with crop rotations:

- CAP 1st pillar: income support and decoupling, including cross-compliance and set-aside requirements (see section 6. 1. 1)
- CAP 2nd pillar: Rural Development Policy with Agri-Environmental Measures (see sections 6. 1. 2 and 6. 1. 3)
- Policies related to organic farming (see section 6.2)
- Nitrates Directive and pesticides framework Directive (see section 0)

Commercial contracts, concluded between farmers and local trade partners, also have an influence on the choices made related to the rotation practice (see section 6.5).

6.1. COMMON AGRICULTURAL POLICY (CAP)

The Common Agricultural Policy (CAP) aims to support farmers agricultural activity and to ensure food security at the EU level. With the Agenda 2000 CAP reform implemented in 1999, the CAP was divided into two pillars, dedicated respectively to income support and rural development.The analysis of CAP measures presented in this section are grouped under these two pillars.

6. 1. 1. CAP FIRST PILLAR: INCOME SUPPORT AND DECOUPLING

Area-based payments had consistent effects on cropping patterns and on rotations that have favoured high-input crops or those that are more harmful to the environment. The proportion of aid in the gross margin was very high: 30-40% for cereals and up to 60% in soya or irrigated maize growing regions. At the level of agrarian regions more than at farm level, payments per hectare favourised a specialisation of rotations towards more cereals, oilseeds and protein crops (Oréade-Brèche, 2007).

Many models have tried to evaluate the effects of decoupling subsidies for specific productions on crop allocations and thus indirectly on crop rotations. The review of some CAP economic simulation models conceived between 1999 and 2007, and covering the period between 2004 and 2013, show results of the 2003 reform compared to the Agenda 2000 baseline scenario on crop allocations, which impacts directly crop rotations, e.g. CAPSIM, CAPRI, FAPRI, ESIM, GOAL and AGLINK, (Balkhausen et al., 2007). These models predict a reduction in the land surface allocated to arable crops (i.e. cereals, oilseeds, protein crops and root crops reduction between 0.1 and 9%), and a decrease in sheep and beef production. Other models show that decoupling has led to a global movement to livestock farming extensification, mainly due to the removal of silage maize aids and payments per livestock head (Barkaoui and Bulteau, 2004). Farmers actually extend their productions rather than abandon or set lands aside. In terms of crop rotations, this would result in higher rates of fodder crops and lower rates of silage maize in the crop rotations, which are typical features of dairy farming systems (see section 3. 4. 2). Meanwhile, a decrease in sheep and beef production also means a decrease of the feed needs for this livestock, including feed crops produced on farm. In turn, crop rotations dominating in cattle farming systems, which include specific crops like silage maize could evolve and tend to adopt crop rotations typical of arable farming systems, with higher rates of cereals, and reduced rates of legumes on average.

In general, a reduction of land surface dedicated to a given arable crop may come in favour of a diversification of crop rotations in arable crop farming systems. Crop rotation forecasts actually vary strongly according to model assumptions. In 2006, policy researchers using the CAPRI (Common Agricultural Policy Regionalised Impact) model indicated that the effects on crop rotations resulting from decoupling are limited in the EU (Britz et al., 2008). This can be explained by the fact that for farms growing a little number of species (e.g. only cereals or proteins crops), the aids received under Agenda 2000 were already comparable to a single farm payment, therefore the reform of 2003 did not influence crop rotations in a significant maneer.

An analysis of the sugar beet reform (see Annex V - section 1. 1. 2 for details) shows that sugar beets were mostly replaced by winter cereals, potatoes and peas, which actually diversified the rotations, resulting in overall environment benefits (Renwick, 2005).

The reform on the protein crops sector (see Annex V - section 1. 3 for details) with an aid introduced for protein crops, in addition to SPS and subject to the Maximum Guaranteed Areas (MGAs) for payments, had a limited impact on crop rotations. Field peas areas have actually decreased by 24% after the reform, whereas field beans areas and sweet lupines areas rose by 8% and 18% respectively. This difference is explained by higher risks in production (mainly yields volatility) resulting from the cultivation of field peas compared to other crops.

The impact of the reform on energy crops (see Annex V - section 1. 4 for details) shows that in 2004, an aid for energy crops was introduced, in addition to SPS and coexisting with the non-food set-aside scheme, and aimed mainly to produce biofuels and electric or thermal energy from biomass. This reform led to an increase in the areas to 2.84 million ha in 2007 (Eurostat, 2008), and rape seed production increased of about +50% between 2000 and 2008. This resulted in the integration of energy crops in crop rotations.

The reform on tobacco (see Annex V - section 1. 5 for details) resuted in a strong reduction of 30% in tobacco cultivation areas between 2000 and 2006, as a consequence of the decoupled payments for tobacco production, and in a reduction of rotations including tobacco (European Commission, UNITAB, 2006).

6. 1. 2. Cross-compliance under the 2003 CAP Reform and 2008 Health Check

Two major reviews of the EU CAP on cross compliance are the 2003 CAP reform and the 2008 CAP Health Check. Mandatory cross-compliance was one of the major changes introduced in the 2003 CAP reform. This mechanism specifies that the full granting of decoupled direct aids and of certain rural development and wine payments depend on the respect of requirements regarding the environment, animal welfare, animal, plant and public health, as well as standards of Good Agricultural and Environmental Condition (GAEC). In 2008, cross-compliance was revised during the Health Check (see Annex V – section 2. for more details). In order to assure that farmers are kept informed about cross compliance requirements, Member States must set up a system of advising farmers on land and farm management, which advisory activity must cover at least the SMRs and GAECs (see section 7.).

Good Agricultural and Environmental Condition standards (GAECs) for crop rotation "where applicable" are to be defined by Member States according to local conditions and have as objective to improve soil organic matter levels (Annex III to Regulation 73/2009). Many MS implement this GAEC standard on crop rotation, which became optional for Member States as from 2009.

Various approaches are being taken by MS in respect of the objective soil organic matter and in view of controllability problems for the crop rotation standard. Under the decoupling introduced by the CAP reforms of recent years, farmers are no longer obliged to register their crops in their aid application forms. This makes it difficult to follow up the various crops cultivated over the years on a given parcel in application data.

France and Luxemburg promote crop diversification by requiring the growing of "at least 3 crops on arable lands" in the same year. Finland and Austria have defined standards limiting monoculture. Some MS have designed specific measures in order to implement the objective of the GAEC standard (e.g. England, Germany, Ireland, Italy, Luxemburg, Belgium, and Sweden). For instance, in Germany, farmers must analyse soil organic matter or calculate humus balance. The incorporation of organic materials into the ground, or other similar measures, supplement crop rotation in view of maintaining soil organic matter levels, and provide for a better soil structure while reducing erosion risks and enhancing water retention. In Sweden, cultivating cover crops is encouraged. In Ireland, farmers must establish the soil organic matter level through soil sampling, at least for their arable land. Where the level is below 3.4% the farmer must engage an advisor of a Farm Advisory Service to stipulate the appropriate remedial action(s) to be taken e.g. reincorporation of straw, crop rotation etc. Also in order to improve or stabilise soil organic matter levels, many related GAEC measures have been set in UK, e.g. including a specific measure on arable crop rotation standards[28]. This latter measure encourages farmers:

- to use a suitable break crop in rotations
- to try and optimise the use of organic materials by considering the rate of application on soil and crop needs. Where there are no break crops used, a record should be kept for 5 years of organic materials and the quantities applied to arable land.

Box 6-1: Impacts of cross-compliance under the 2003 CAP Reform and 2008 Health Check

The 2003 CAP Reform was particularly studied from the decoupling and cross-compliance perspective. It aimed to more freedom in the agricultural market and improvement of farmers' income, and was based on Single Farm Payment and cross-compliance (GAECs and SMRs). Crop rotations were impacted in a limited extent by the changes in crop allocations, however a direct link with crop rotations is hard to establish.

[28] The Scottisch Government, 2005, Cross Compliance Guidance Note, Part 1

6. 1. 3. THE SET-ASIDE OBLIGATIONS

The “set-aside” fields can be of different types:

- Fields used for non food purposes
- Fields left fallow[29] (with the possibility of rotation)
- Afforested fields
- Fields used for non-agricultural purposes (e.g. conversion to grassland)

Set-aside became obligatory with the MacSharry reform in 1992 and Regulation 1765/92, with three main objectives of the set-aside scheme as per Regulation 1765/92 (Oréade-Brèche, 2002):

- Market balance by controlling surpluses
- Development of non-food crops
- Environmental benefits

As part of the Agenda 2000 Reform (1999), Regulation 2316/1999 established a support system for producers of certain arable crops. Eligibility for area payments became linked to obligation to set-aside areas on farms. Small producers (less than 92 tonnes of cereals production) were exempted from this obligation.

Set-aside entitlements were maintained in 2003, and continued providing benefits to the environment as a side-effect of the obligatory market set-aside. In 2006-2007, more than 3.7 million ha of land were registered as “set-aside” in EU-15, i.e. 2.65% of EU-15 UAA. France, Germany, Spain, the UK and Italy had the most important set-aside areas (EUROSTAT, 2006), but with shares similar to the other MS, i.e. between 0.6 and 5.6% of national UAA (see Annex V - section 3).

A study estimated that roughly 48% of set-aside areas were part of crop rotation plans of farmers and the remaining 52% non-rotational set-aside fields being non-cultivated (Oréade-Brèche, 2002). Under the terms of the 2003 reforms, all agricultural land, including set-aside, must be maintained in “good agricultural and environmental condition”, which is implemented through specific standards for each Member State. This requirement intended to avoid the abandonment of agricultural land and its negative environmental consequences following the introduction of decoupling in 2003.

Between 1995 and 2006, non-food set-aside accounted for an average of 20%. As a response to high cereal prices and market shortages in 2007, the European Commission abolished the set-aside obligation and allowed farmers to bring this land to agricultural production. No quantitative data on the effects of the abolition of set-aside on crop rotation plans are available. But, as 52% of set-aside areas did not participate in any crop rotation, it is possible that some share of these lands are now cultivated and part of crop rotations. In fact, the European Commission estimated an increase of 2.9 million ha in cultivated cereals, i.e. around +5.2% for

[29] “Arable land not under rotation that is set at rest for a period of time ranging from one to five years before it is cultivated again, or land usually under permanent crops, meadows or pastures, which is not being used for that purpose for a period of at least one year. Arable land which is normally used for the cultivation of temporary crops but which is temporarily used for grazing is included.” [definition source: EEA multilingual environmental glossary]

2008 (EUROSTAT, 2008), balancing the decrease in the same crops due to CAP decoupling measure. This evaluation of Eurostat also estimated that plantings of rapeseed were expected to decrease by 400,000 ha, i.e. 6.4% of the total surface. The identified environmental benefits of set-asides are developed in the next section (see Annex V - section 3.1.1).

In Belgium and France for example, transposition of the EU set-aside programme into national legislation had a double beneficial impact on the regional soil erosion risk in agricultural regions. First, the area vulnerable to soil erosion decreased and second, fields with a high erosion rate were preferably taken out of production, resulting in a decrease of the average erosion risk. Rompaey et al. (2001) identified a negative correlation between the set-aside percentage and the regional soil erosion risk. In Belgium, set-aside fields contributed to effectively re-introduce the fallow lands into continuous arable rotations, and it was found that they could potentially deliver a range of biodiversity, resource protection, and other environmental benefits.

Box 6-2: Impacts of the set-aside obligation

Set-aside became obligatory with Regulation 1765/92 in 1992, with three main objectives:

- Market balance by controlling surpluses
- Development of non-food crops
- Environmental benefits

As a consequence of Regulation 2316/1999, as part of the Agenda 2000 Reform (1999), some small farmers were exempted from this obligation. However, set-aside entitlements were maintained in 2003, and in 2006-2007, more than 3.7 million ha of land were registered as “set-aside” in EU-15, i.e. 2.65% of EU-15 UAA. Half of the set-aside fields were included in a rotation, and 20% in non-food set-aside. In 2007, as a response to high cereal prices and market shortages, the European Commission abolished the set-aside obligation and this is estimated to have resulted in increased cereal surface areas and in decreased rape surface areas. However in Spain, the increase of fallowland management after 1992 increased the areas subject to soil erosion risk. The response of unseeded fallow, in terms of total runoff and sediment accumulation, is actually considerably higher than for the other management types. With the introduction of mandatory cross-compliance under Regulation 1782/2003 in 2003, MS had to establish standards of Good Agricultural and Environmental Condition such as the requirement to maintain an adequate cover of lands in winter for set-asides. The already mentioned beneficial effects on soil quality and preservation were observed.

However, some Spanish regions faced negative environmental impacts of set-aside. According to a study carried out by Boellstorff and Benito in 2005, the increase in the fallow land management, as a result of the 1992 EU policy, led to an increase in the areas of land under high erosion risk categories. Indeed, the implementation of unseeded fallow set-asides in agricultural regions of Spain has been found - in models - to intensify the rainfall erosivity at a higher rate than other land use scenarios (1. Traditional land use, mainly cereals and 2. Best management practices, i.e. if all set-aside were seeded). The response of unseeded fallow, in terms of total runoff and sediment accumulation, is in fact considerably higher than for the other management types. And seeded land management is found to limit erosion risks, as there is a 50% lower soil loss rate in the seeded fallow than compared with unseeded fallow. With the introduction of mandatory cross-compliance under Regulation 1782/2003 in 2003, MS had to establish standards of Good Agricultural and Environmental Condition such as the requirement to maintain an adequate cover of lands in winter for set-asides. The already mentioned beneficial effects on soil quality and preservation were observed.

6. 1. 4. CAP second pillar: Agri-Environmental Measures as part of the Rural Development Policy

Since the 2003 Reform, Rural Development policy clearly recognises the multifunctionality of agriculture. Regulation 1698/2005 details the Rural Development policy (RD) objectives for the period 2007-2013. The Rural Development policy is based on 3 main axes and a specific programme:

- Axis 1: improving the competitiveness of the agricultural and forestry sector.
- Axis 2: improving the environment and the countryside.
- Axis 3: improving the quality of life in rural areas and encouraging diversification of the rural economy.
- LEADER programme: this bottom-up approach encourages local actions related to development of territorial cooperation projects on at least one of RD axes.

Argi-Environmental Measures (AEM) focus on reducing environmental risks and negative pressure of farming practices and protecting the environment through sustainable farming practices. AEM provide a policy tool particularly adapted to fit locally specific problems and to experiment ands adapt alternative practices.

With agri-environmental measures, farmers commit on a voluntary basis for five years and can select the measures of their choice from the list of measures included in the rural development programme of their region or Member State, on condition that they are eligible, and they are paid in return for the environmental services provided. A range of actions are proposed by Member States (see the list of examples in Annex V – Introduction). The environmental issues mainly concern biodiversity, landscape and natural resources (see Annex V – section 4.). Austria's crop rotation scheme within the Agri-Environmental Programme (ÖPUL), implemented in 1995, has been a success with over 84% of farmers participating in 1997. A study showed that the yields of participants to the crop rotation scheme are significantly higher than those of non-participants. The conditions to be respected are a maximum of 75% of arable land to be used to produce cereals and maize; a winter cover crop covering at least 15% of arable land must be planted before November 1st and may not be ploughed under before December 1st (Salhofer et al., 2002)[30].

[30] Salhofer, K. And Scheifer, G., 2007, Self-selection as a problem in evaluating agri- environmental programs, EAAE-Seminar. Assessing rural development of the CAP

In Greece, the Regulation 2078/92 came into effect in 1995 with the first relevant programme concerning the "reduction of nitrate pollution" in the plain of Thessaly. This required all eligible farmers to restrict the use of fertilisers and follow crop rotations (Beopoulos, 1997).

In Portugal, the Castro Verde Zonal scheme promotes low intensive agriculture to protect cereal steppe birds in the Castro Verde Special Protection Area. Also this scheme pays farmers to maintain traditional crop rotations and low grazing intensities, reduce pesticide inputs and to keep stubble or crop coverage over the winter[31]. Traditional crop rotations include one of these schemes:

- base cereal / coarse grain / fallow (2 years);
- base cereal / coarse grain / hay pasture / yellow lupine / subterranean clover (5 years).

Conversion to organic farming, extensification, input reduction and crop rotation, that were the most selected AEM by farmers in all EU-15 Member States in 2002 (see Figure 6-1) seem likely to lead to a greater diversification in the crop mixes. Links between low-input crop systems and greater diversity in arable rotations are detailed and demonstrated in the section about organic farming and EU pesticides Regulation.

However, the specific measure on crop rotations involved less than 3% of EU-15 areas for the AEM in 2002 (Figure 6-1), and was only implemented in France, Spain and Germany at the time.

The measure on "Crop Rotations" represented about 10% of the total AEM in Spain and Germany and 3% in France in 2002 (Figure 6-1). A low number of subscriptions to this measure could be explained by the observed difficulty of its implementation. In France, farmers mostly had difficulties due to the technical complexity of the measure, and due to the difficulties to comply with all the crop-specific requirements of the contract, agronomical limited possibilities, land management (management of the rotation of parcels) and increased labour/investment needs (CETIOM, 2005). Therefore, a part of the involved farmers gave up before the end of the 5-years programme (CETIOM, 2005).

In France, the impacts of crop rotation AEM on farming systems, cultural successions and agricultural practices were assessed in 2006 (CETIOM, 2007), and farming systems showed the following results (see Annex V – section 4.1 for more details on these impacts of crop rotation AEM):

- More diversity in rotations
- Farmers engaged a high share of their land under the crop rotation AEM
- Lengthening of rotations, but shorter rotations were noticed in smaller farms, notably due to the difficulty to have all surfaces eligible (see Annex V – Introduction)
- Changes in practices notably reduced fertilisers' inputs and improved weed management.

[31] www.birdlife.org

Figure 6-1: Breakdown of area under AEM by type of action in EU-15 in 2002: (DG Agri, 2005)

i.e. Organic Farming, Input reduction, Crop Rotation, Extensification, Landscape, Erosion, Other

The promotion of High Natural Value (HNV) farming is also an aspect in line with AEM, providing arable rotations with a number of sequences of fallowand reduced fertilisers use.Higher mixed cropping systems are aspects correlated with crop rotationsso arefarming. (see Annex V – section 4.2 for more details on High Natural Value farming).

Box 6-3: Impacts of Agri-Environmental Measures

Agri-Environmental Measures (AEM) of the Rural Development Policy aimed to tackle environmental issues, promote rural development and a multifunctional agriculture and was based on a wide range of AEM possible environmental “contracts/services” (on a voluntary basis, 5 years commitment) going beyond the baseline of cross-compliance rules. This impacted crop rotations through the rotational measure, and the promotion and support for environmentally sound farming practices.

6.2. POLICIES RELATED TO ORGANIC FARMING

The organic area in the EU has increased by 21% between 2005 and 2008 and is still developing. However, organic shares of total agricultural areas remain limited: it represented 4.1% of the EU-27 total Utilised Agricultural Area and about 2% of the farms in 2008 (EUROSTAT, 2009).

Regulation on organic production and labelling of organic products (Regulation 834/2007) aims to strengthen sustainable cultivation systems and to widen the range of organic high-quality products. It also aims to promote a more consistent control system on production methods and end-product standards.

The Regulation sets general rules and principles on how agricultural products and food labelled as organic products must be cultivated and processed. Recommendations insist on better soil management and maintenance of fertility, with a strong emphasis on crop rotations and green manure. As stated, pest and weed management should rely on biological and mechanical production processes and crop rotations can help achieve that. The use of synthetic fertilisers and pesticides, as well as the use of GMOs and products including GMOs, are prohibited.

General principles of organic farming are the following:

- Preference of closed cycles and reduced use of external resources for plant and animal production
- Respect of natural ecosystems and recognition of local or regional ecological balances

Regulation 834/2007 Preamble 13 explicitly highlights the need for diversification and lengthening of crop rotations*:* "essential elements of the organic plant production management system are soil fertility management, choice of species and varieties, multiannual crop rotation, recycling organic materials and cultivation techniques"*.*

Article 5 of the same Regulation also states that crop rotations should rely on "legumes and other green manure crops". Linking livestock management and cropping systems is actually an inherent approach of organic farming. Procedures of some certification bodies may set even higher standards and mention clearly to organic farmers the varieties and crop families to grow. For instance, the CERES (CERtification of Environmental Standards GmbH) policy on crop rotations includes minimum requirements for the rotation of annual field crops, legumes, cover crops, etc.

In France, recent inventories actually identified that diversified and long crop rotations were characteristic of organic farming systems, rotations extending up to an average of 6 to 8 years (ITAB, 2008). Also, organic cropping systems actually included a frequent use of legumes in the rotations, such as alfalfa, clovers and horse beans, up to 15% of crop productions[32], i.e. 3 times more than in conventional agriculture.

Box 6-4: Impacts of organic farming policy framework

Policies on organic farming aimed to attain sustainable farming practices and were based on certification requirements, which include very restricted use of pesticides/fertilisers, and requirements for a holistic sustainable farming management (crops, production methods). As a result, crop rotations were held a keystone of organic farming, leading to more diversity and longer rotations, and better crop/weed/pest management. Technical constraints remain, and cover the poor availability of seeds and difficulties in managing weeds and pests.

[32] Gerber, M., Fontaine, L., et al. , 2008, RotAB, Les grandes cultures biologiques en France : état des lieux des rotations pratiquées par régions

6.3. POLICIES ON THE USE OF AGRICULTURAL CHEMICALS

The Nitrates Directive[33] was adopted in 1991 to protect water quality across Europe, by preventing the nitrates of agricultural sources from polluting ground and surface waters. All Member States have now transposed the obligations by drawing up a Code of Good Agricultural Practices (GAP) and by implementing required Actions Programmes for identified vulnerable zones, as set out in Annexes II and III of the Directive. Nitrate Vulnerable Zones (NVZs) are defined as areas contributing to pollution and comprise also waters that are affected or likely to be affected by exceeding nitrates concentrations, if action is not taken.

The recently adopted EU Framework Directive on the sustainable use of pesticides (Directive 2009/128)[34] aims to achieve the sustainable use of pesticides, particularly by controlling agricultural pesticides pollution and by ensuring high levels of protection for the environment and human health. Member States are in charge of defining National Action Plans and ensuring the safety and effectiveness of the active substances and products, as well as reducing their associated risks and inappropriate use, notably by promoting crop rotations, but also by introducing set up quantitative objectives, targets, measures and timetables for pesticide use. The general principles for Integrated Pest Management are described in the Directive and proposed as options to be implemented at national level. Directive 2009/128 completes the policy framework on pesticides covered for many years by a legislation on the placing of plant protection products on the market and on pesticide residues in food.

6.3.1.1 Impact of nitrates Directive on crop rotations

The Nitrates Directive clearly encourages farmers to better manage nutrient supply by limiting nitrogen spreading and synchronising plant and soil cycles. It also guides farmers regarding land use for production crops, grasslands, and set-asides. To better manage nitrogen fertilisation, farmers in some countries (e.g. in France) are required to develop a yearly nitrate management plan for crops. In addition, regional legislations define different modalities of intercropping, patterns of fertilisation use (e.g. fractionation, closed periods) and rotations with market or cover crops. Cover crops are indeed one of the most efficient ways of limiting nitrate losses from arable lands. For that reason, crop rotations and a minimum land cover during winter and rainfall periods have been implemented in MS. France for instance sets an objective of 100% of soil winter cover by 2012. A wide range of cover crops are already authorised in MS, under specific conditions: e.g. permanent meadows, “nitrate trap” crops, milled and incorporated grain crop residues and new growths of preceding crops.

In a French case study, the effects of policies and policy options were assessed on 65 crop rotations including 11 different crops, with regards to a set of information, including agro-management (average yield, water/soil/nutrient management, etc.) and economic data (producer prices, variable cost), as well as data concerning bio-physical conditions of the agro-

[33] Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources

[34] 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

environmental zones (climate, soil types) and farm resources and structures. The case studies showed a partial adoption of the Directive requirements only, with reduced soil erosion (22% erosion at regional level and on average farm) resulting from the Nitrates Directive adoption (see Annex V – section 6. for more details on this case study).

6.3.1.2 Impacts of EU pesticide legislation on crop rotations

Framework Directive 2009/128, establishing a framework for Community action to achieve the sustainable use of pesticides, encourages looking at new sustainable alternatives for the crop production, such as biological control, mating disruption-confusion, and mass trapping, and promotes the use of Integrated Pest Management (IPM) which may be compulsory in EU MS by 2014. Choice for optimal crop rotations is mentioned in Annex III of the same Directive which lists the mandatory minimum requirements for IPM that farmers may have to meet as from 2014.

Other legislations on pesticides include crop specific guidelines, developed mainly by the IOBC (International Organisation for Biological and Integrated Control of Noxious Animals and Plants), such as guidelines for pome fruits[35], stone fruits[36], grapes[37], olives[38] or field grown vegetables[39], have been used in MS at the national level and take into account the general principles of IPM. In order to examine the significance of the existing crop-specific IPM elements, the most representative crops at EU level have been selected, because of their large cultivated areas, market share, volumes of harvested production and high input of plant protection products for their cultivation. Wheat, maize and oilseed rapes have been selected to represent a typical rotation system for arable crops and were therefore evaluated. Similarly wine, tomatoes, potatoes and apples have also been selected, all in different other categories, to be of major significance.

Results show that details on crop rotations (and on all other IPM principles and under principles) are mentioned in the crop-specific guidelines of IOBC and only in some MS programmes- e.g. in Germany, Netherlands and Austria (Table 6-1). Crop rotations are explicitly mentioned as a “measure for the prevention and/or suppression of harmful organisms”. Consequent environmental benefits are implicit.

Table 6-1: Evaluation of crop-specific guidelines concerning crop rotations[40]

Selected Crops	Specifications mentioned on crop rotations in guidelines	Elements are mentioned in:
Wheat-Maize-Oilseed Rape	Number of fields in a crop rotation, cultivation rates, cultivation breaks, weed management by the	IOBC* and MS (DE, NL)

[35] Guidelines for Integrated Production of Pome Fruits. Technical Guideline III. 4th edition 2008. Edited by C. Malavolta & J.V. Cross, IOBC WPRS Bull. Vol. 47, 2009. ISBN 978-92-9067-221-0 21 pp.
[36] Guidelines for Integrated Production of Stone Fruits. Technical Guideline III. 2nd edition 2003. Edited by C. Malavolta, J.V. Cross, P. Cravedi & E. Jörg. IOBC WPRS Bull. 26 (7) 2003. ISBN 92-9067-155-4. 52 pp.
[37] Guidelines for Integrated Production of Grapes. Technical Guideline III. 3rd edition 2007. Edited by C. Malavolta & E.F.Boller, IOBC WPRS Bull. Vol. 46, 2009. ISBN 978-92-9067-220-3 21 pp.
[38] Guidelines for Integrated Production of Olives. Technical Guideline III. 1st edition 2002. Edited by C. Malavolta, G. Delrio & E.F. Boller. IOBC WPRS Bull. Vol. 25 (4),2002. ISBN - 92-9067-141-4 67 pp.
[39] Guideline for Integrated Production of Field Grown Vegetables. Technical Guideline III. 1st edition 2004. Edited by C. Malavolta, E.F. Boller & F.G. Wijnands. IOBC WPRS Bull. Vol 28 (5) 2005. ISBN 92-9067-177-5. 24 pp.
[40] adapted from “Development of guidance for establishing IPM principles” - final report, EU Commission, 2008

(arable crop)	use of crop rotation	
Tomatoes (vegetable)	Crop rotation is mandatory in IOBS. Systems must be chosen to avoid problems with soil-borne pathogens and pests.	IOBC and MS (DE)
Potatoes	Number of fields in a crop rotation to limit disease and nematode infestation, cultivation rates, cultivation breaks, weed management by the use of crop rotation	IOBC and MS (DE, AT)
Apples	No specifications (perennial crop)	PAN Europe (Pesticide Action Network-Europe)
Vines	No specifications (perennial crop)	IOBC and MS (DE)

**IOBC: International Organisation for Biological and Integrated Control of Noxious Animals and Plants*

Box 6-5: Impacts of the Nitrates Directive and legislation on pesticides

The Nitrates Directive and legislation on pesticides aimed to limit nitrogen/chemical risks to the environment, and was based on nitrogen spreading management and synchronising plant and soil cycles, and gave the principles for Integrated Pest and Crop Management (IPM, ICM). Crop rotations were impacted through better crop management (intercropping, soil covers) and crop-specific guidelines.

6.4. SUMMARY

Table 6-2 summarises the findings with regards to the impacts of EU policy framework on crop rotations.

Table 6-2: Impacts of EU policies on crop rotations

	Nitrates Directive/ Pesticides legislation	2003 CAP Reform: Decoupling and Cross-compliance	Rural Development Policy (Agri-Environmental Measures- AEM)	Organic farming
Aim	Limit nitrogen/chemical risks to the environment	More freedom in the agricultural market and improvement of farmers income	Tackle environmental issues, promote rural development and a multifunctional agriculture	Attain sustainable farming practices
Main legal requirements/ features	- Managing nitrogen spreading and synchronising plant and soil cycles -Principles for Integrated Pest Management (IPM,)	-Single Farm Payment -Cross-compliance (GAECs and SMRs)	A wide range of AEM (5 years commitment on a voluntary basis) going beyond the baseline of inter alia cross-compliance rules	Certification requirements: - Restricted use of pesticides/fertilisers - A holistic sustainable farming management
Observed Environmental benefits	Less pollution in waters and soils, reduction in soil erosion, landscape (and biodiversity in the case of IPM) enhancement	Landscape and wildlife enhancement, soil protection, less pollution	Improvements in biodiversity, landscape, natural resources (soil, water, lands, plants, etc.), climate change	Improvements in biodiversity, landscape, natural resources (healthy soils, waters), climate change
Impacts on Crop Rotations	-Better crop management (intercropping, soil covers) -Some crop-specific guidelines	- Changes in crop allocations (Balkhausen et al., 2007) - A direct link with crop rotations is hard to establish. According to Britz et al. (2008), the impacts on CR are limited -In the case of cross-compliance, specifications to encourage the spread of crop rotations exist, but no data were found to assess their impacts	- Crop rotation measure is clearly positively impacting crop rotations - Promotion and support for environmentally sound farming practices	-Crop rotation is a keystone of organic farming: more diversity and longer rotations -Crop rotations can help weed and pest management
Main issues	-In some specific conditions, farmers may pay fines rather than complying with Nitrates Directive -Specifications about crop rotations could be detailed more precisely - Integrated pest management practices (IPM) development could be supported by training		- More effective and simple environmental indicators would help rising understanding - Technical/administrative complexity make the implementation hard for farmers (e.g. crop rotation measure)	Technical constraints: poor availability of seeds, difficulties in managing weeds and pests

6.5. IMPACT OF COMMERCIAL CONTRACTS ON CROP ROTATIONS

6. 5. 1. FARMERS PERCEPTION ON CONTRACTS

In the survey performed during this study, 45 interviews were conducted with farmers and farm advisors (belonging to FAS) in 7 Member States (i.e. Hungary, France, United Kingdom, Sweden, Italy, Poland, and Ireland). Results suggest that getting a contract was evaluated "easy to relatively easy" by all pooled farmers. This could simply be explained by the fact that contractors themselves proposed contracts options to farmers and therefore were already willing to offer the contracts. About 60% of the farmers who answered the questions concerning subscribed contracts were actually committed by contract (see Annex V – section 7.) and confirmed the place of cooperatives and processors as their main economic partners, before traders. 15 out of 28 farmers under a contract were actually working with cooperatives (Figure 6-2).

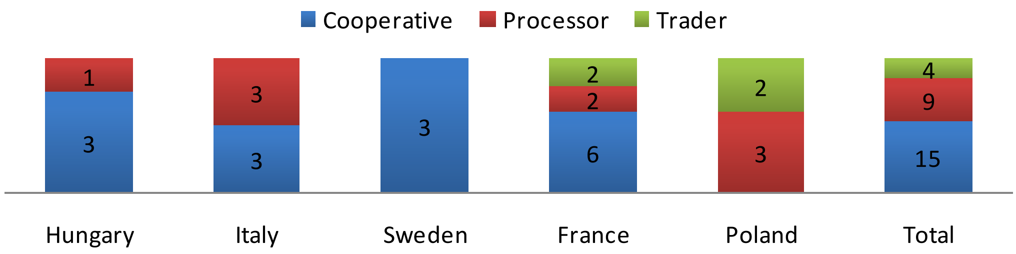


Figure 6-2: Type of commercial partners of interviewed farmers under contract

The rate of involvement in farming contracts appeared positively correlated to the size of farms; nevertheless farms with more than 150 ha subscribed less to contracts. No trend appeared regarding the commitment time of contracts (see Annex V – section 7. for more details).

6. 5. 2. TYPES OF CONTRACTS

6.5.2.1 Contracts in conventional agriculture

Various types of agricultural contracts for production between growers and economical partners exist, depending on the types of productions, economic, social and physical environment, regions, etc. In this section we are interested in the relationships existing between farmers and the cooperatives and/or traders that concern crop production.

Two main types of "crop" contracts can generally be distinguished, as defined by Ricome et al. (2008):

- Contracts for production: the production can be better coordinated and delivered with qualitative specifities. It concerns industries with precise needs for quality of the raw agricultural material (e.g. hobs for breweries, high oleic sunflower oil for biodiesel).
- Contracts for commercialisation: farmers are offered for their productions a panel of modalities and practices for the market launch. This implies most of the time no restrictions concerning the methods of production or varieties cultivated.

An analysis, conducted by Ricome et al. (2008) in the South-Pyrenees region (largest agricultural region in France) studied the types of contracts offered by two large cooperatives to their members. Cooperatives A and B are representative of the region, as they respectively account for about 4,000 and 5,000 members, whereas there were 13,565 farm holdings in the region in 2005 (Agreste, 2006). Authors identified a major contract that has long been implemented: farmers receive an "average price" calculated on the basis of the overall supply from all members. Currently however, new forms of contracts are emerging, as a response to more instable prices. Farmers have a tendency to stock up a larger part of their products and organise their marketing themselves. This corresponds to a more individualised system of contractualisation, with higher financial risks nevertheless (Ricome et al., 2008). On the other hand, a new other form of contract, which is more integrated (i.e. a "commitment contract"), entails that farmers deliver their entire production to cooperatives, whilst receiving privileges like reinforced technical help, priority for production contracts, as well as incentive payments. Finally these farmers can commit to deliver a defined percentage of their productions, and not a predetermined quantity, which limits the yield risk.

In this current context of price volatility and in order to minimise the risks linked to production, tendencies show that farmers are progressively trying to minimise their costs of production, rather than maximising the selling prices (personal comm., A. Petit). Ricome is more reserved, but asserts that farmers are relatively opportunistic and would all the same try to maximise yields if changes in prices (input and agricultural prices, etc.) were promising. These "new" behaviours would entail more cautious choices of sowing, productions and use of fertilisers. This also explains partly the substitution of cereal areas by oilseed crops, e.g. 18.1 million tonnes of rape seed were produced in 2007, which is a 13% increase on 2006 figures (Eurostat, 2009). Energy crops cost less to cultivate (fewer requirements in fertilisers and water), but farmers also take account of the associated lower costs of lands and of risks.

6.5.2.2 Contracts in organic agriculture

Organic farming acts on a similar mode as farming contracts, given that organic practices are designed to comply with a set of different binding requirements. Because most of the seeds and inputs such as fertilisers, soil amendments, plant protection products and other substances have to be organic, close relationships between sellers and manufacturers are often encountered. Also, since organic products are high value products and there is a greater insistence on traceability, stricter certification and control requirements have been implemented.

However, the integration of organic farmers with their cooperatives is often reduced compared to conventional agriculture for that same reason. The relationships are therefore less distorted. The main explanation is that organic farming often relies on short production branches. Producers often sell their products directly to the customers and avoid multiplying intermediaries. Even more than for conventional agriculture, the main challenge is to find suitable and sustainable outlet perspectives, as organic systems are usually characterised by a great crop diversity, more uncertain yields and limited market volumes. Priorities for European organic farming development, as set out in the Organic action plan (2004), concern the matching of consumer demand and the provision of optimal conditions for trade and functioning of the market mechanisms, by better organising the sector. The development of farmers' markets, producer and marketing associations, different forms of co-operation between customers and farmers, such as the French AMAPs [41] (Associations for the promotion of small farmers and organic agriculture) and specialised retailing chains (e.g. Biocoop in France or Bio Austria in Austria) ensure farmers sell off their products at a sustainable price. Growing interest from supermarkets and big retailers explain the increased share of organic products in the conventional market network, but it is still difficult to find a full organic product range (FiBL, 2009). In order to encourage a viable production of alfalfa e.g., initiatives led by industrial partners have developed many applications for the crop and its by-products, which come along with new quality requirements. Alfalfa is primarily used for animal feeding, given its high content in proteins and minerals (various nutritional demands are usually coming from customers). Alfalfa can also be processed and used by the textile or pharmaceutical industry for numerous applications.

6. 5. 3. Crops and crop rotations under contract

6.5.3.1 Productions and crop rotations under contract

Survey results show that farming contracts concern productions of superior quality and specialised production. The most contractualised productions are milk and milk products, high-quality cereals (for seeds and grains as a majority), oilseeds crops, sugar beets, tobacco. Interviews showed some contracts for tomatoes in Italy, but they would not affect crop rotations as tomatoes are usually grown in the EU in glasshouses.

Increased supply segmentation, due to new needs of industry and new possibilities of non-food utilisations, led to new forms of contracts but also to a variety of crops (see Table 6-3) and livestock.

Oilseed and protein crops, as well as quality cereals are the main crops under contracts. Recommendations do not directly concern crop rotations but principally the choice of varieties and the respect of criteria on quality. Therefore it is difficult to conclude on crop rotations.

Even if there is a multiplicity of productions under contracts and new forms of agreements, areas under contracts for production are in fact modest. Energy crops are an exception, as all cultivated surfaces are under contracts. Energy crops areas totalised up to 2.8 million ha in 2007, largely exceeding the 2 million ha set as Maximum Guaranteed Area (i.e. areas that are effectively supported by subsidies). Therefore these crops can be judged advantageous and may likely be maintained over the years. Given that the EU reduced the aid by about 30% in 2008, areas under energy crops must not have been increasing. No further impacts on crop rotation can be expected if the proportion of each specific crop remains the same.

6.5.3.1 New possible crops under contract

Contracts have direct impacts on longer and more diversified crop rotations (i.e. choice of crops and time between each) when they encourage the implementation of new crops. The EU

[41] www.reseau-amap.org/amap.php, consulted: 30.04.2010

Directive on Biofuels 2003/30/EC led to major increase in the contractual surfaces under energy crops, which were indeed replacing other crops and being integrated in crop rotation plans. Perennial switch-grass and Miscanthus are two interesting examples of new contractual crops that have been introduced to produce biomass for energy and that offer clear environmental benefits. Switch grass and Miscanthus require less water and nutrients and limit soil erosion while improving soil fertility. Sugar beet (Northern Europe), hemp and flax are other typical crops, partly cultivated for energy purposes.

Table 6-3: Crops under production contracts in large cooperatives in South-Pyrenees, France[42]

Cooperative A	Cooperative B
11 standard contracts* on:	**8 standard contracts*** on:
Oilseeds crops: sunflower oil high oleic food grade, sunflower oil high linoleic **Legumes:** GM-free soybeans, **Cereals:** high-protein varieties of common wheat (e.g. *Greina, Quality*, *Galibier, Esperi,*), selected variety of barley for brewery (*Prestige)*, durum wheat *Joyau*, Maïze Popcorn	**Oilseeds crops**: sunflower oil high oleic food grade, sunflower seeds for bird shops **Legumes**: GM-free soybeans, **Cereals**: high-protein varieties of common wheat (e.g. *Galibier, Esperi*), regional bread wheat (*Apache, Arlequin* with high tolerance *to fusariose*)

******Standard contracts base on similar levels of requirements and agreements*

However, it is important to assess the economical efficiency and profitability of the crops for farmers prior to introduction of these new crops, as market perspectives are identified to be the main driver in the cultivation and long term adoption of crops. Using a discounted-utility model, Bocqueho et al. (2010) calculated that Switch-grass and Miscanthus are competitive with traditional crops, but only because they are sold on the energy market (which is a strong advantage compared to the food market) and that energy prices are reasonably volatile. Indeed, results from a standard Net Present Value model stated that these crops should not be cultivated. Authors confirm that financing and risk sharing from the contractualisation of the production are likely to reduce the volatility of the prices.

6.5.3.2 Conclusions

Crops under contracts for production represent a small percentage of the European UAA but related areas are difficult to assess; no detailed and trade statistics are available. Nevertheless, they should not have major impacts on crop rotations, as contracts of currently cultivated crops mostly concern improvements of varieties (technical performance, quality, adaptation to climate change, etc.). Contracts for commercialisation seem to be of even less importance, as they only refer to the selling conditions of the products and do not involve any link to crop rotations. The possibility to implement new contracts to promote crop rotations seems limited.

[42] adapted from Ricome et al., 2008

6. 5. 4. Summary

Table 6-4: Pros and cons of agricultural contracts

Types of contracts / Features	Contracts of commercialisation (all farming systems)	Contracts for production (all farming systems)	Contracts for production (organic farming)
Main identified productions under contract	All kind of productions	Mainly specialised or high value added productions; e.g. High quality cereals, vegetables, oilseeds crops for specific industrial processing, protein crops	All kinds of productions but with a higher share of legumes
Agreements/ requirements on:	- Purchase prices (different modalities and risks/benefits) - Quality of delivered products	- Methods of production - Number of treatments - Quality of delivered products	Mainly, respect of certification agreements (traceability, products free of synthetic chemicals, etc.)
General Advantages	- Control over quality and quantity - Specialisation and concentration of the productions - Liberalisation of market:; in some contracts, farmers can try to get the best prices at any moment - A technical support for information/advices	- Guarantee of markets for farmers and generally more visibility of outlet perspectives - A better sharing of the risks and benefits between farmers and traders/cooperatives - Specialisation and concentration of the productions (increase the net income on a short term) - Control over quality and quantity - Better traceability - A technical support for information/advices	- Retailing market and guaranteed prices for the productions - Greater acknowledgement of the quality of work in organic farming and contacts with customers more frequent (direct sales, associations, etc.)
General Constraints	- Farmers a priori more vulnerable to financial risks (associated with yield uncertainty, market prices, ...) - Some restrictions from downstream retailers (supermarkets outlets)	-Farmers must agree to sell the product to the coop/traders -Some binding contracts (e.g. traceability, technical limitations, frequency of technical visits ...) - Potential risks that firms call off the contracts for any reason or for low prices	- Generally low productions volumes are under contracts Or/and - contracts are too binding
Impacts on crop rotations	- Limited impacts on crop rotations as farmers usually remain free to decide on their farming practices -Possible positive influence on crop specificities and environmental requirements from retailers and consumers	-Farmers are restricted on some elements of their farming practices (but usually to meet the standards, which can lead to both intensive or more integrated agriculture) - Crop-specific requirements	

7. ROLE OF FARM ADVISORY SYSTEM AND OTHER SOURCES OF INFORMATION IN CROP ROTATION PRACTICES

Farm decision-making is a complex issue, in general and applied to crop rotations particularly. Farmers rely on a range of actors and information sources. The information communicated to farmers varies highly according to the position, activity and level of commercial interests of the information sources, and therefore three major aspects to be taken into account when assessing the information sources are:

- the role of the information source in farmers' decisions,
- its level of influence on farmers' decisions, and
- its impact on crop rotations as a result of the two prior aspects.

Farmers can request information from specialised agricultural institutes, farm advisors, cooperatives where they deliver their products or traders providing them with seeds or materials of production. These sources shape the knowledge of farmers and play an important role in their choices of farm management, crops to grow, farming techniques and eventually crop rotations.

These sources with different initial purposes support farmers' decision-making, however farm advisory services stand apart from the other sources as their primary and only role is to provide information and communicate with farmers. A separate section is therefore dedicated to the role of farm advisory services.

7.1. THE SPECIFIC ROLE OF FARM ADVISORY SYSTEMS

The rapid development of agricultural innovation requires efficient systems of information flow to reach farmers. The continuous access to relevant advice and information is necessary to make decisions within the framework established by both EU and national laws and regulations. Several different typologies of information and advice can be distinguished, relating to a broad range of actions. These typologies range from the most general reporting of facts and research results (information) to guidance tailored to the need of an individual farmer (advice). Farm advisory services are constructed as demand-driven information and advice systems which are more suitable to respond to farmers' needs than a supply-driven extension service (Povellato, 2006).

7. 1. 1. THE EVOLVING OBJECTIVES OF FARM ADVISORY SERVICES

Focus of advisory services have been changing through time according to their given socio-economic and policy context faced by societies and therefore by farmers. For example in the period following World War II, an increase of productivity was the most important issue throughout all Europe as a response to the general food shortage on the continent (Dyson, 1998), which eventually led to a production level superior to needs. Once the overproduction problem emerged in Europe in the 1970s, the main areas of advice were linked to limiting this overproduction, co-operation among holdings (machinery rings) and combination of different income types. The socio-economic advice (i.e. advice on farm efficiency, financial management, social support services, etc.) had been developed as a new field of activities. The reduction of costs (low input) soon becomes a key area of advice. In the 1980's and 1990's European society more and more often called for multifunctional services to be rendered by the agricultural sector. Environmental standards, extensive production, organic farming and animal welfare have become major issues (agroextension.net, 2010).

7. 1. 2. Setting up the Farm Advisory Systems

Since 2003 the implementation of cross-compliance requires EU Member States to define **statutory management requirements (SMRs)** and minimum standards for **good agricultural and environmental condition (GAECs)** [43] This requirement is set out in Council Regulation (EC) No 1782/2003[44], which also obliged Member States to set up, by the 1st January 2007, a Farm Advisory System (FAS) to provide advice to farmers at least on SMRs and GAECs (Prazan et. al, 2006) (Box 7-1).

Box 7-1: Farm Advisory Systems and Farm advisory services

The Farm Advisory System (FAS) includes the overall organisation of the system of advising farmers on land and farm management, including the various operators (private and/or public bodies) contributing to the delivery of the various farm advisory services to farmers required within a MS (Article 12 of Council Regulation (EC) No 73/2009)(ADE, 2009).

Farm advisory services include the advisory activities, called services, to be provided to farmers covering "*at least SMR and GAEC*". "Farm advisory services" should assess the specific situation of the farmer who uses the advisory service and not only present general information. As such one-to-one advice is particularly effective, due to the very individualised way of giving advice. If European Agricultural Fund for Rural Development (EAFRD) is mobilised by the MS, advisory activities for farmers have also to include occupational safety standards based on Community legislation (ADE, 2009).

The Farm Advisory System of the EU does not replace the different existing advisory systems in the MSs but officialises a system where farmers must respect the conditions specified in SMRs and GAECs (see Chapter 6.). If farmers fail to comply with these specified conditions, their direct payments and some rural development and wine payments can be reduced or cancelled. The mechanism of the system is presented in Figure 7-1.

The regulation of 2003 left four years for MS to set up an appropriate advisory system or to adjust existing systems to the requirements. Belgium, Denmark and certain regions of Italy (IT-CA, IT-SA, IT-VA) had already had an advisory system organised well enough to launch the Farm Advisory System before 2004. Most Member States (12) however only set up their Farm Advisory System in 2007.

---

[43] See Chapter 0on policy aspects

As for the type of operating bodies of Farm Advisory Systems, the share of public and private bodies is approximately equal (23 vs. 24) with a tendency to more private consulting organisations that has been chosen by 18 Ms and regions.

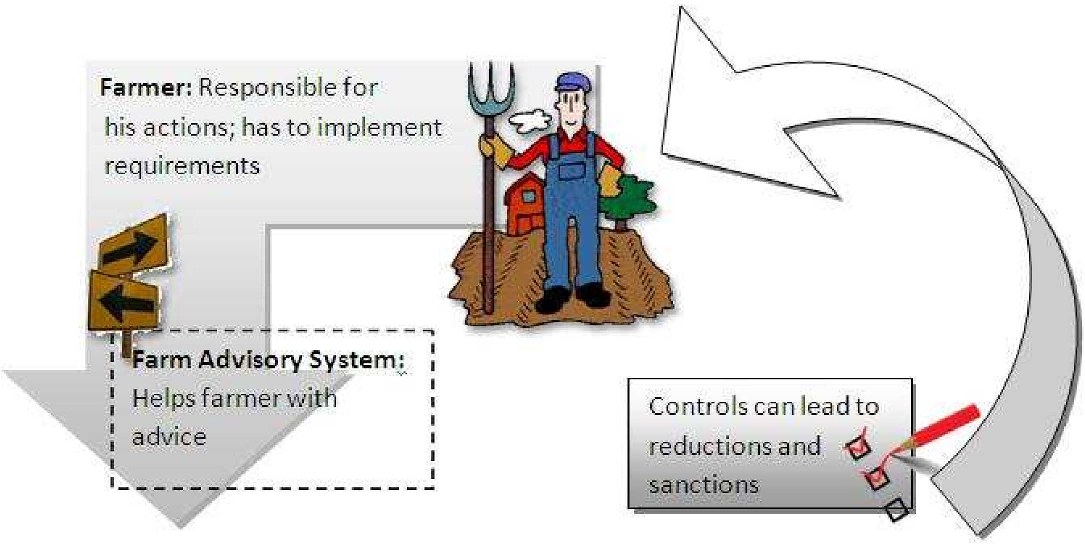


Figure 7-1: The EU concept of the role of the Farm Advisory System[45]

7. 1. 3. Actions and limits of action

Member States have developed two major approaches regarding advice delivered by Farm Advisory Systems:

- the on-farm one-to-one advice and
- the on-farm small groups.

Concerning the former, farmers get advice mainly through the direct visits on farm, supported by requirement lists (checklists). Checklists include details regarding the performance assessment and are either checked systematically or used as a guide by the advisor.

The activities implemented by the Farm Advisory System must cover at least SMRs and GAECs, but Member States may broaden this scope. Almost half of the MS already designed their FAS going beyond the scope of cross compliance. All farmers may benefit from the Farm Advisory System on a voluntary basis. Priority may be given to certain categories of farmers or specific actions, in case the available budget is not sufficient for all. Further, the frequency of advice, the qualification of advisers, and the choice to provide advice for free or to let the farmer pay are not specified in the Regulation: Member States rather are given the flexibility to organise it in the most appropriate way. Figure 7-2 presents the priorities in terms of farmers and actions chosen by MS for their Farm Advisory Systems in 2008, before the Health Check deleted the priority for farms >15000 €.

[44] now repealed and replaced by Council Regulation (EC) No 73/2009
[45] adapted from DG AGRI, 2009

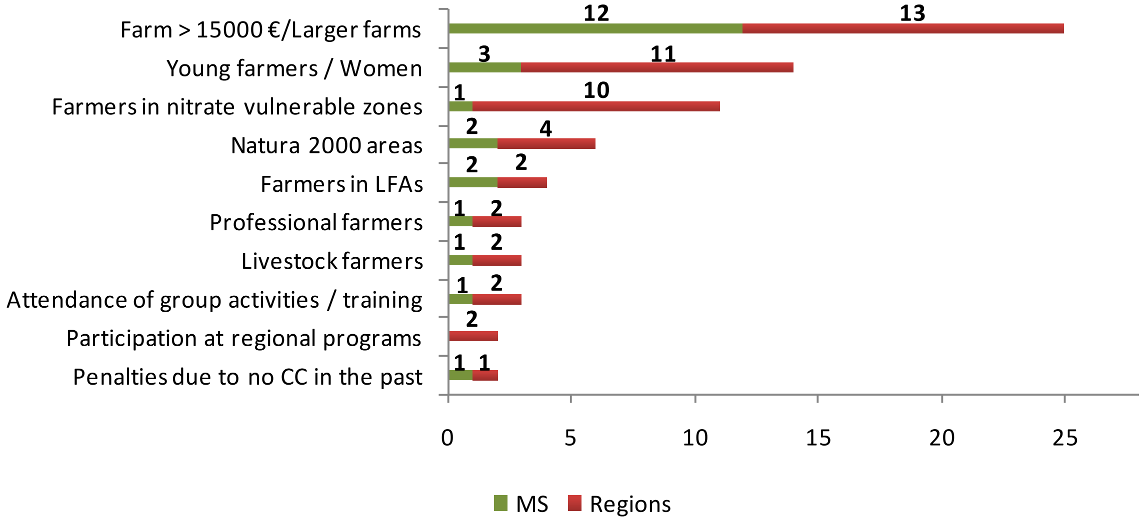


Figure 7-2: Priority of actions in Farm Advisory Systems (DG AGRI, situation 2008, before the Health Check deleted the priority for farms >15000 €)

During the BIO survey most farmers confessed missing explanation and understanding regarding existing EU CAP regulations, and the conditions, restrictions and requirements related to these regulations. Farm advisors indicated that their advice mainly remained limited to cross compliance issues, and to questions of farmers' random topics. They also confessed not to have spare means and time for additional activities, indirectly linked to cross compliance, such as information on EU agricultural policy and the promotion of crop rotations (BIO, 2010 - France, Hungary).

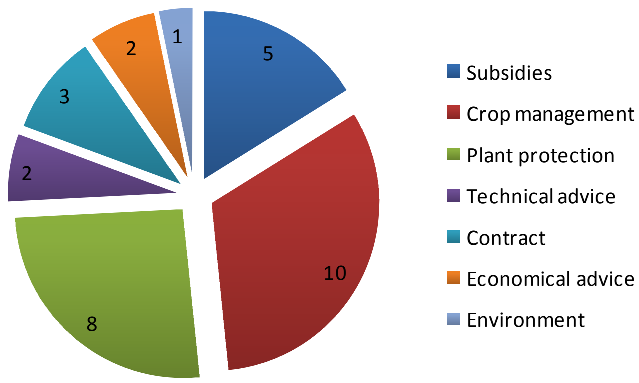


Figure 7-3: Main reason of requesting Farm advisory services (BIO survey, 2010)

According to the results of the survey, farmers contact farm advisors with various frequencies, Swedish farmers mentioned the most frequent contacts with farm advisors, followed by Italians. French and Hungarian farmers declared the smallest number of contacts to farm advisors, with less than ten consultations a year on average (BIO, 2010).

Different reasons for contacting farm advisors were mentioned by farmers (see Figure 7-3): they said to mostly contact farm advisors for questions of crop management and fieldwork (dates for sewing, treating and harvesting, techniques and quantities for sowing, water and fertilisation needs, crop choice...) and plant protection, and the majority of them declared to follow the recommendations on the choice of crops. The financial and accounting issues were least often mentioned as a reason to contact farm advisors compared to agronomical questions. Farm advisors on the other hand indicated that farmers asked support on a broad range of subjects, from interpreting administrative correspondence to basic agronomical decisions (BIO, 2010).

7. 1. 4. ADVICE ON CROP ROTATIONS

According to the survey performed in 6 different Member States, communication approaches of farm advisors vary, comprising one or more of the following approaches:

- One-to-one or one-to-group communication
- On-farm or out of the farm
- Telephone or Internet helpdesk
- Publications (paper or electronic)

In the survey, approximately half of the farmers interviewed recalled hearing their farm advisor talk about crop rotations, mostly during meetings. They said that crop rotations were mostly discussed in relation to soilborne diseases and nutrient management. In some cases, farmers indicated that the farm advisor promoted crop rotations specifically (Ireland), and encouraged farmers to implement rotations, by highlighting their beneficial effects on yields and the destructive effects of monoculture (Poland, Sweden). Several Swedish respondents said that "crop rotation is not a hot topic" as they are commonly used in Sweden. On the other hand, half of the respondents said they never had heard of crop rotations from their farm advisor.

7.2. SOURCES OF INFORMATION ON CROP ROTATIONS TO FARMERS

European farmers consult numerous sources of information before making a decision at the farm level. Major actors and information sources playing a role in farmer's decisions can be divided in three types: the commercial partners, the experts, and the other farmers

7. 2. 1. COMMERCIAL PARTNERS

Farmers are in continuous contact with dealers of inputs, such as seeds, fertilisers and plant protection products, and buyers of agricultural productions. These commercial partners provide technical advice while selling inputs and buying products. Commercial partners may be of different types: in the survey performed by BIO 45 interviews were conducted with farmers and farm advisors (belonging to FAS) in 7 Member States (i.e. Hungary, France, United Kingdom, Sweden, Italy, Poland and Ireland). 50% of the farmers interviewed declared a recent contact with a cooperative, 30% with a processor and 20% with a trader (Figure 6-2 – BIO, 2010) which refers to an close interdependence between farmers and commercial partners, who play an important role in how crops are grown and harvested, and whether and how land is conserved (Rickson, 2003). Commercial partners represent significant economic drivers in farmers' decision-making as they link farmers to the market. Their type vary in Europe: for example, no interviewed Polish farmers had a recent contact with a cooperative, while all Swedish interviewees had. Also, farmers never mentioned a trader in Italy, Hungary and Sweden; while they are much mentioned in other countries (see section 6.5 on commercial contracts – BIO, 2010).

As for the trade issues related to production, farmers and companies form contractual partnerships and share power, notably on land use and crop choice. However, when it comes to soil conservation, including crop rotation issues, current environmental policies as well as concepts of “duty of care” allocate responsibility primarily to farmers (Rickson, 2003). Both aspects of this relationship between farmers and commercial partners may impact decision-making regarding crop rotations.

7.2.1.1 Traders of inputs

In France, the cumulated cost of herbicides, pesticides, fuel, and fertilisers, reaches close to 30% of farms’ turnover, therefore input providers influence significantly farmers’ practices and decision-making (Pers. Comm.: Lionel Vilain, 2010, after calculation on the basis of national statistics). During the survey, farmers confessed a tendency to entrust commercial partners for choosing their plant protection products and process of treatments (BIO, 2010).

Hence conventional farming systems appear input based and notably supported by traders of inputs, who have commercial interests (Rahman, 2007; Pers. Comm.: Lionel Villain, 2010). Therefore these commercial partners may not be interested in promoting crop rotations, which are expected to reduce the uses of inputs at the farm level. The French Fertiliser Industry Union (UNIFA) actually published information sheets on the calculation of nutrient balance, including references to rotations (UNIFA, 2010). However, the biggest and nitrogenous fertiliser production company of Hungary (Nitrogénművek Zrt) makes no reference to crop rotations on its website (Nitrogénművek Zrt, 2010), similarly to the Association of Fertiliser Manufacturers in Spain (ANFFE, 2010).

7.2.1.2 Contractors

Contractors execute works for farmers lacking machinery or labour force for certain works on their farm. For time management or resource efficiency issues, contractors can encourage farm management simplification and the reduction of the farms’ operational complexity. Simplification of farm works requires the simplification of the farm organisation thus a loss of diversity of cultivated crops occurs, which is inconsistent with the principles of crop rotations (Pers.Comm.: Lionel Villain, 2010; Massey University, 2010). The work provided by contractors being essential to farmers, the pressures coming from the conditions of contracting has a major influencing force on farmers’ decisions (Rickson et. al., 1996, 2006, Burch et al., 1999).

7.2.1.3 Traders of products and Processors

As agricultural production requires strong involvement and preparation months before the harvest, farmers, being essentially ‘price takers’ rather than ‘price givers’, are highly dependent on guaranteed buyers and market opportunities, which means that their ability to negotiate the prices they receive for their products is considerably lower than the power enjoyed by food processors, distributors, fast food outlets and, of course, supermarkets (Burch et al. 1999, Rickson et al.2006). Hence, most participants in the survey had a production contract (see section 6.5 on commercial contracts - BIO, 2010), except in Hungary and Ireland where farmers tend to organise their production without contracts.

Being committed to a production contract makes farmers more likely to adapt their choices to demand and requirements of the commercial partners on the downstream side of production, such as processors. However, such agri-food processing companies, which contract with farmers for supply respond more to pressures from competing on international markets and, therefore, are less focused on local land and water degradation issues (Rickson and Burch, 1996, Burch et al., 1999). Processors buy the raw crop, e.g. sugar beets, and transform it into a value added product, e.g. sugar. Due to difficulties of storage of perishable agricultural products, farmers seek a trustful business relationship with the processor company (their client) and thus show high willingness to adapt their practices to processors preferences (BIO, 2010). Since the incidence of soil degradation varies across farms according to agronomic conditions of soil type, land slope, rainfall and socioeconomic factors such as farmer income and knowledge of conservation measures, for instance, standardized relationships between companies and farmers at the regional level can be detrimental to farmers needing special assistance. Product traders or processors are generally specialised in certain (types of) crops, the main groups being cereal or oil crop producers and therefore are logically want the farmers they contract with to maximise production of these crops, which is a directive for adopting crop rotation as a soil conservation technique.

Decisions about farm land use and its conservation has largely moved upwards from the owner/producer (farm and farm family) to decisions by corporations concerned with guaranteeing supply and standardising the production useful for processing (Rickson, 2003; Pers. Comm.: Rickson, 2010). Locally these actors have a most determining influence on farmers' crop choices as they represent the customers for farmers' products. A crop variety imposed by processors, e.g. potatoes species Russet Burbank, might disrupt rotations and make them harder to manage. Such a new imposed crop might impose the use of increased amounts of fertilisers and plant protection chemicals (Rickson, 2003).

7.2.1.4 Cooperatives

Cooperatives' role is to concentrate and organise the agricultural productions and trade with agri-food industries downstream. Cooperatives organise the market (vertically and horizontally) and lead up the farmers towards some specific choices to match supply and demand. Surveys show that technicians from cooperatives can, as a majority, provide advice on the methods of productions and chemical treatments.

The General Confederation of Agricultural Cooperatives COGECA in the EU is the officially recognised representative body of all European agricultural cooperatives. According to the organisation's estimates, cooperatives provide about 50% of European agricultural inputs and undertake more than 60% of the collecting, processing and commercialisation of agricultural productions. The 2005 top-30 cooperatives in terms of turnover are all in Northern or Western Europe but none in Southern Europe. Trends show that cooperatives in Europe are specialised (dairy products, meat, wine, horticulture, etc.), with a high turnover in Northern countries, while they are of smaller dimension and more numerous in Southern countries (COGECA, 2005).

Cooperatives are a determining limiting factor for farmers without another market opportunity, and farmers often adapt their crop choices to the local cooperatives preferences and specialities, which may disrupt crop rotation systems on farms (Rickson, working document). Cooperatives are likely to play an important role in farmers' preferences in their crop choices, i.e. limit their crop choices which is a factor playing against the diversification of the cultivated plants and as such crop rotations.

Cooperatives influence farmers highly, in particular because often they provide the only market opportunity locally. In France for instance, it has been observed that cooperatives became even more independent from farms, as a result of the "liberalisation" of their activities (Filippi, 2002).

7. 2. 2. Experts

To manage the complex and technical issues related to their activity, farmers refer to expert knowledge, and to the expert knowledge providers who can be addressed by farmers. In this study we treat within this category the professors of agricultural schools, specialised press, agricultural websites, agricultural institutes and also providers of Farm advisory services.

7.2.2.1 Education

The association of Agricultural Education in Europe (EUROPEA) connects about 600 agricultural educational institutions throughout Europe (EUROPEA, 2010). In 2005 about 20% of farmers in the EU27 had basic or full agricultural training (Boisselier, 2009) Classes within agricultural training aim to provide a global overview on agronomy and agriculture which makes of them impartial sources, disconnected from commercial interests.

Agricultural schools aim to give an overview on the whole of the food and agricultural system including the topic of crop rotations as an agronomic solution for pest and soil nutrient management. The basic orientation of the school however is determining regarding the final idea students may have about crop rotations, i.e. alternative agricultural training or organic agricultural training where the use of crop rotations is an unquestionable part of farm management (Defra, 2010).

The level of influence of agriculture teachers may be the most significant in the first years, education being the primary source of knowledge besides family factors (Pers. Comm.: Lionel Vilain, 2010). However, this influence may fade over time, and agriculture teachers do not appear in the preferred sources of information by beef cattle producers (Vergot et al., 2005).

7.2.2.2 Specialised agricultural press

Specialised agricultural press and websites provide information on a wide range of aspects of agriculture supported by expert sources. Generally each country has their leader agricultural magazine (e. g. in France: La France Agricole, in the UK: Farmers Weekly). Their intense presence in farmers' life can be illustrated by the number of copies sold. For example "La France Agricole" sold 150,500 copies in 2002-2003, i.e. 22% of the number of farmers in France at the time.

According to a survey carried out among cattle farmers in Florida, US, specialised farm magazines are listed as the second most preferred channels of information (Vergot et al., 2005) and in a survey covering the whole USA, crop or livestock specific publications are listed as the most useful information sources by farmers (Gloy et al., 2000).

In 2009 and 2010, 9 updates out of 32,000 on the website of La France Agricole mentioned crop rotations, and on the website of Farmers Weekly 83 updates mentioned crop rotations out of a total of over 25,000 in 2009-2010 (www.lafranceagricole.fr; www.fwi.co.uk) which suggests that the topic of crop rotation is marginally discussed in mainstream agricultural magazines. The explanation might lie in the fact that advertisers actually convey commercial messages to their target audiences through media, and the survival of farming magazines and websites depends highly on advertisers, which are mostly agricultural companies of farm input products, machinery and equipment (Li, 2010; see section 7. 2. 1 on commercial partners). Activities of these agricultural companies might be difficult to conciliate with crop rotations and the implied low input farming (Rickson, 2003; Pers. Comm.: Lionel Vilain, 2010).

7.2.2.3 Agricultural institutes

A number of agricultural institutes specialised in specific fields of agricultural production (e.g. CETIOM[46], ITAB[47]) exist in Member States. Their role is similar to that of Farm Advisory Services with more focus on certain particular issues of their interest.

The most influential institutes of France (Arvalis, CETIOM) being specialised mostly in mainstream market crop production promote the input based agricultural approach and are thus not particularly likely to encourage the practice of crop rotations.

Agricultural institutes tend to be the number one bodies farmers contact in case they have production related questions. In France farmers are most likely to rely on advice from these institutes (Pers. Comm.: Lionel Vilain, 2010). In Ireland Teagasc-The Agriculture and Food Development Authority groups research and development, training and advisory services in one institute that is highly entrusted by farmers (BIO, 2010).

Agricultural institutes have a very important role in shaping the perception of the economic conditions of farmers. Parameters of accounting tools or optimisation tools that help farmers in their calculations and cost and income projections are distributed by these institutes. According to expert opinion (Jeuffroy, 2010) the fact that these tools' time scale is usually limited to one year is an obstacle to the dispersion of the long term planning required in the application of crop rotations. Besides the short term perspective individually used accounting tools such as accounting centres calculate margins per culture and not per rotation (CETIOM, 2010).

7.2.2.4 Farm Advisory System (FAS)

Farm Advisory Systems are required providing farmers with advice on at least cross compliance requirements, to help them to comply with those obligations, and as such can deliver impartial

[46] Technical centre for research and development of oilseed production procedures in France.
[47] Technical Institute of Organic Agriculture

advice applied to the specific farm situation, disconnected from any commercial interest (see section 7.1).

7. 2. 3. Other farmers

A non negligible role is attributed to the local habits and pressures on farmers' decisions. Farmers often refer to their peers for technical issues. They discuss much with neighbours and observe neighbours fields, which they keep as a continuous reference, given the similarity of their soils, local climate, input providers, crops etc.

7.2.3.1 Associations of farmers

Farmers' associations represent farmers to promote their products or enhance their position on the market. There are farmers' associations based on geographical proximity between the members (e.g. Irish Farmers' Association) or similar production profile (e.g. Irish Organic Farmers and Growers Association, Royal Association of British Dairy Farmers (RABDF).

Promotion of crop rotations by farmers' associations Farmers' associations' position on crop rotations can vary according to their specific profile such as in the case of agricultural institutes. Farmers associations have significant influence on farmer's decisions and they provide forum to the circulation of experience amongst farmers.

7.2.3.2 Neighbours

First interlocutor and first reference to farmers are their neighbours, who face the same soil and weather conditions, and who are involved in the same commercial context and often crop the same crops.

Local pressures, neighbours' opinion (Sachs, 1972) and the fear of adopting practices different from the local standards appear to be a very important factor of influence to farmers and significant drivers in farmers' behaviour (Pers. Comm.: Vilain, Pouzet, 2010). At the same time, it can be used as a motivating factor. Seeing what the neighbour has achieved, how it was achieved, and how they can achieve similar benefits is one of the strongest forces for motivating farmers to make desirable changes (Seevers, Graham, Gamon, & Conklin, 1997 in Vergot et al., 2005).

The general perception of crop rotations in a given region can therefore be a highly influencing factor for a farmer.

7.2.3.3 Power of influence of the sources

Farmers' personal perception of utility of different information sources does not vary significantly according to farm type, education or other factors (Vergot et al., 2005; Gloy et al., 2000). From a general perspective, farmers entrust and consult more likely other farmers and extension agents (i.e. the equivalent of farm advisors in the EU) and supply dealers. They entrust less likely regional and manufacturer sales representatives, and agricultural teachers (Figure 7-4 and Figure 7-5). However a significant level of economic interest present in the relation between the source and the farmer, such as in the case of supply dealers makes the source is less likely to give impartial advice to the farmer (Rickson, 2003).

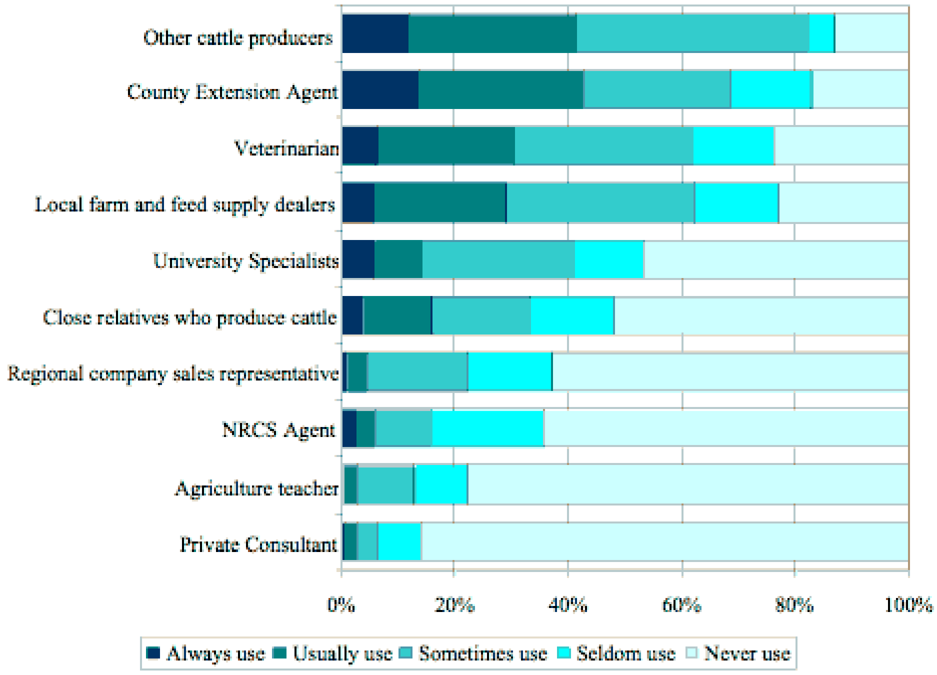


Figure 7-4: Preferred Sources of Information by Beef Cattle Producers (Vergot et al., 2005)

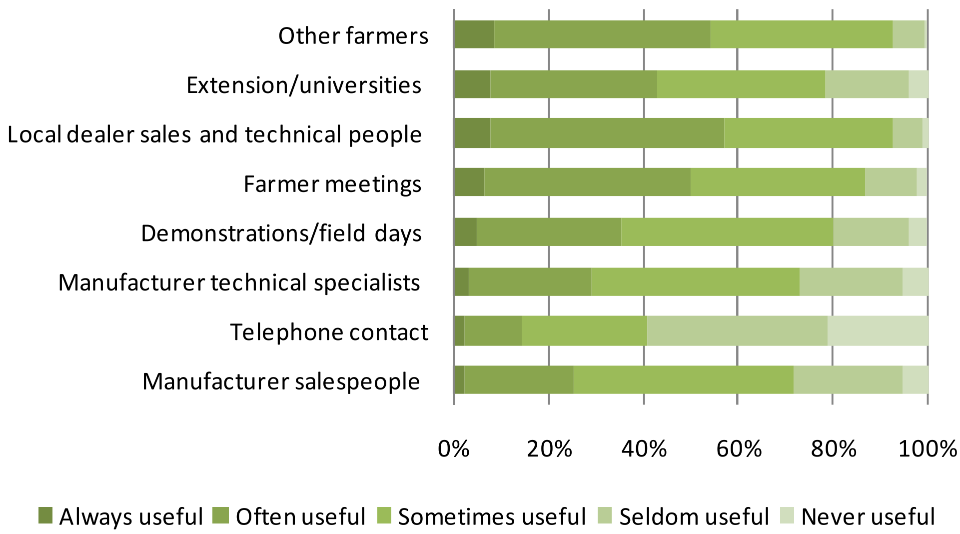


Figure 7-5: Distribution of the rankings of each information source (Gloy et al., 2000)

Figure 7-6 presents the approximate rank of the assessed sources as for their level of independence, the top side representing the most independent source. Input traders have been estimated as the most partial and most driven by economic interest followed by the rest of the commercial partners. Cooperatives seem to be less influenced by economic interests and are located in the middle of the scale along with farmers' associations and agricultural institutes. Neighbours and educational institutions appear on the top of the figure with Farm Advisory Services as the sources considered to be least influenced by economic interests when giving information or advice to farmers. According to the qualitative results of the survey, Farm Advisory Services present the best scores as for the independence from economic drivers and real importance in farmer's decisions amongst the different sources of information that farmers rely on (BIO, 2010).

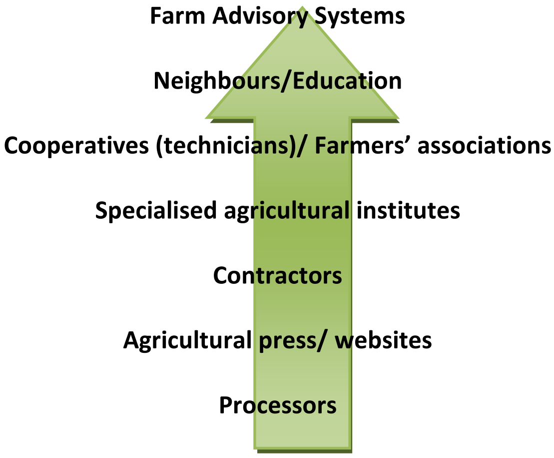


Figure 7-6: Level of independence of the information sources (Pers. Comm.: Rickson, Villain)

In order to assess the specific role of actors and information sources an estimation of ranking according to their importance from the farmer's point of view; i.e. how much the farmer is likely to rely on the information gathered from the given actor/source, to what extent it influences the farmer's decisions compared to the others is presented in Figure 7-7, based on the scientific sources findings. During the survey performed in the frame of this project, Hungarian and French farmers said that commercial partners had the most influence on their choices followed by agricultural institutes and Farm Advisors (BIO, 2010). The concept of crop rotations is generally present in schools' thematic range, but the impact of classes on the benefits of crop rotations does not seem to last and farmers generally do not highly rely on their studies in their real life farm management (BIO, 2010). The majority of farmers are subscribed to certain agricultural magazines but they do not seem to have a significant influence on farmers' decisions (BIO, 2010).

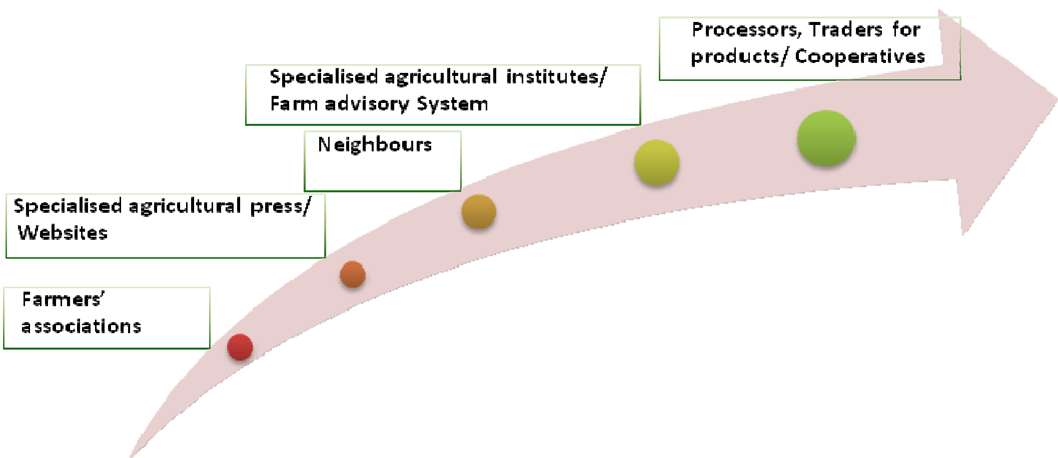


Figure 7-7: Weight of information sources in farmers' decision-making (based on BIO, 2010)

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. BENEFITS OF DIVERSIFIED AND LONG CROP ROTATIONS

Crop rotations have benefits on the environment and from an agronomical perspective. These two aspects are described below.

8. 1. 1. ENVIRONMENTAL BENEFITS

Crop rotations, depending on the crops chosen, prove to have many environmental benefits e.g. on biodiversity, landscape, soil quality, climate change and water (see Figure 8-1 and chapter 4.). More widely, crop rotations appear to be a key to the achievement of the sustainable management of agriculture and natural resources.

8. 1. 2. AGRONOMICAL BENEFITS

A higher diversity in crop rotations primarily allows breaking pest/weed cycles, especially when the successively cultivated crops are from different botanical families. Thus, crop rotations have the potential to lead to a reduction in chemical inputs in practice. Soil structure, quality and fertility are also largely improved, on the condition that sufficient lengths in rotations are respected (Figure 8-1 and chapter 4).

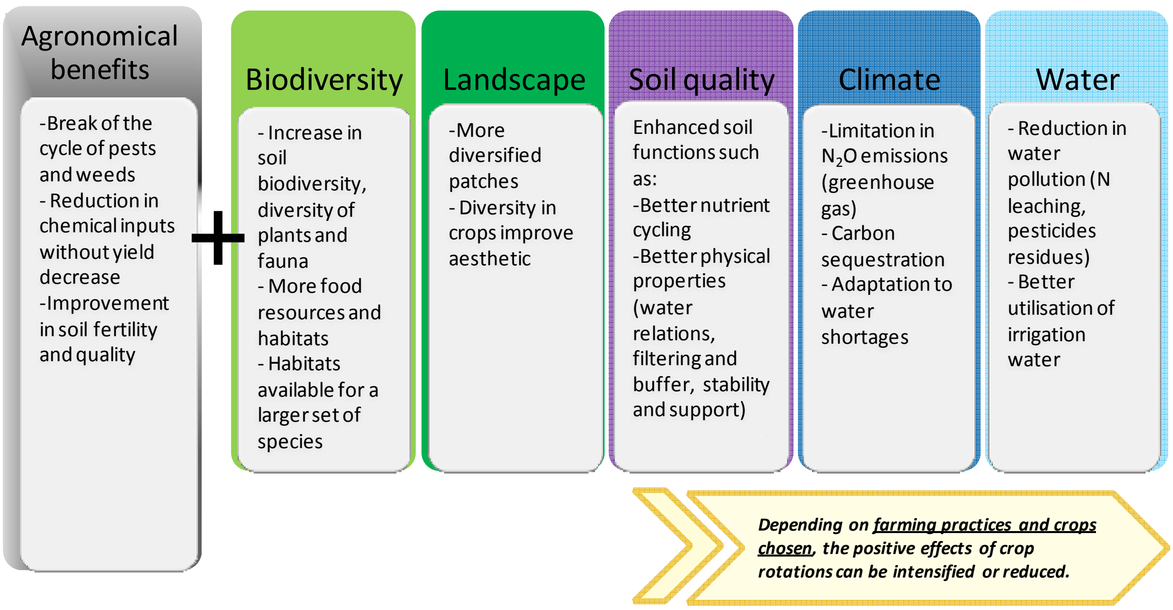


Figure 8-1: Environmental and agronomical benefits of diversified and long crop rotations

8.2. DECISION–MAKING AROUND A CROP ROTATION

The farmers' willingness and possibility to implement improved crop rotations as a farm management practice may be influenced by a range of factors. Thus it is essential to take account of the different context and restricted choices before initiating actions for the promotion of crop rotations.

The following main drivers/constraints can be distinguished (Figure 8-2):

- **Socio-Economic context:** a favourable market is a key driver to farm production. Even though alfalfa inserted in a crop rotation has proved to enhance the levels of SOM, the decision to grow the crop largely depends on the presence of industries to transform it.
- **Agronomical and bioclimatic conditions**: European regions offer different types of soil and climatic conditions that limit the choices of farmers in their farm practices and in the crops they grow.
- **Types of farming system**: typical rotations are usually associated with the types of farming systems. E.g. livestock farming systems may usually be dependent on the use of land for grazing and forage crops.
- **Agricultural and environmental policies**: At the European and national levels, policy tools exist that can promote efficient managements of crop rotations.
- **Technological advances**: farmers choose to simplify their work. Typically, working monoculture is technically easier to implement than having to change and manage diverse parcels and crops.

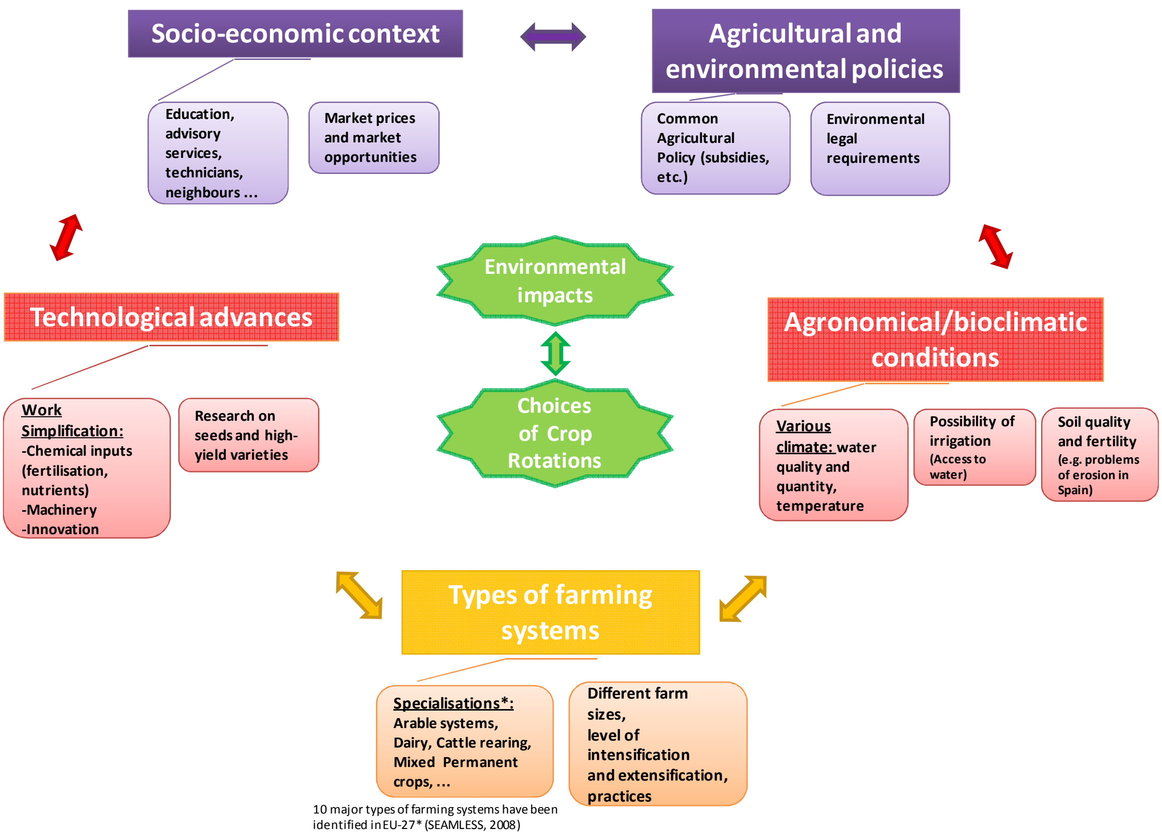


Figure 8-2: Influencing factors on decision making around crop rotations

8.3. RECOMMENDATIONS

8. 3. 1. AT THE EU AND MS LEVELS

Diversified and long crop rotations, i.e. with different botanical family and usually more than 3-4 years (which is the observed current average in conventional agriculture) can bring several benefits to the environment. Initiatives to promote diversified crop rotations can be encouraged by:

- **Promoting low-input farming systems**, such as organic farming, conservation agriculture etc., including soft management practices, more respectful of the environment, and promoting the use of crop rotations in line with these practices and provide training on how to do it.
- **Communicating the detrimental impacts** of usual management practices of intensive agriculture on the environment, particularly tillage, chemical treatments and fertilisation, tractor and agricultural machinery traffic,

Promoting the beneficial impacts on the environment of diverse crop rotations, and other farming practices such as soil cover, no-tillage, maintenance of soil organic matter and reduction of erosion.

Actions specific to different environmental dimensions are mentioned below:

- **Soil functions**
  - **Taking account of the quality of soils for crop choices and crop rotations choices** in order to avoid depletion of resources (e.g. deep soils accept better a secondary crop during the year)
  - **Promoting the insertion of catch or cover crops in the rotations**, which may return more carbon into the soil than rotations without, built up soil health and prevent soil erosion.
  - Finding a good balance between crops with lower and higher nutrient needs in the rotation, as the latter have a tendency to deplete the soil.
  - Integrating legumes in the rotation that enrich soil fertility where appropriate, preferably not in zones with manure surplus (NVZs).

- **Climate change**
  - **Encouraging the insertion of legumes** and grasslands in crop rotations in order to prevent N_2O emissions (by reducing requirements for fertilisation).
  - **Encouraging the insertion of grasslands**, which are also participate to increase the soil carbon content and thus limit net C emissions.

- **Water**
  - **Encouraging the insertion of drought-resistant varieties** and appropriated sequences of crops in the rotations (e.g. crops with deep roots systems or catch crops in regions with high risks of erosion), in order to reduce water pollution and uses for agricultural production.

- **Biodiversity**
    - **Encouraging the insertion of crops as much dissimilar as possible**, with various sewing/harvest dates, various treatments needs, various pests and weeds sensibilities.
    - **Discouraging large areas of single crop** (monoculture) or rotations of similar crops.

- **Landscape**
    - Organising cropping systems geographically and in time,
    - Encouraging the insertion of crops with various sewing/harvest dates.

The agronomical benefits of crop rotations can also be enhanced by:

- **Providing training** to support crop rotations adoption by farmers, especially from the technical aspect. This should be adapted to conventional farmers aiming to change their usual crop rotations, and especially focus on information on the benefits and technical feasibility, and perception of risks and risk management. Trainings should aim to reassuring adopters on the economically safety and agronomically efficiency of crop rotations.
- **Promoting the favourable impacts** such as the global improvement of soil productivity (see Figure 8-1).
- **Encouraging the dissemination of information** to farmers, e.g. through participatory methods.

8. 3. 2. AT THE LOCAL LEVEL (FAS AND LOCAL INSTITUTES AND SERVICES)

- **Promoting "good" farming practices simultaneously to crop rotations**
    - Promoting the promotion of good farming practices, simultaneously with crop rotations promotion, which includes encouraging and providing training and advice on:
    - Integrated weeds/pest/diseases management
    - Crop residues management
    - Minimal tillage
    - Providing training on how to reason practices in order to maximise the benefits of an environmentally-interesting crop sequence.
    - Linking the practices to the farming systems and provide information and training on typical crop rotations of farming systems.

- **Farm Advisory Services/Agriculture chambers should guide farmers by providing training and information**
    - Making use of FAS in order to provide relevant training and information to farmers on crop rotations
    - Bringing into focus that some crop rotations are better than the others
    - **Providing generic information on crop rotations**, so that farmers remain flexible and can adapt the knowledge to their local conditions.

- **Accompanying farmers <u>constantly</u>**, given their high need of support to implement new technical options. This includes adapting the advice on crop rotations to local conditions, and reassuring farmers on the risks to fail with the growth of a new crop (e.g. producing a little harvest).

- **Reassuring farmers on the economic benefits to implement crop rotations**
  - **Reassuring farmers on the aspects** linked to the implementation of (new) crop rotations, by providing training as well as information on best practices, in order to help alleviate the reluctance farmers are showing to implement new crops.
  - **Encouraging crop rotation** as a tool to prevent farm from economic risks and providing information on long term production costs characteristics for crop rotations and profits compared to monoculture.
  - Informing farmers about the expected short-term technical and economical difficulties occurring after the shift from monoculture to crop rotations.
  - Providing training and support on efficient management of labour and energy consumption to produce diversified crops.

- **Financing further research on crop rotations at European level**
  - **Scientific data are missing** on the multiple technical aspects linked to crop rotations (technical as well as economic aspects). Consistent statistics and databases are currently needed to help inventory crop rotations.

8.4. NEEDS FOR FUTURE WORK

8. 4. 1. TARGETING GUARANTEED MARKET OPPORTUNITIES FOR CROPS

Outlet perspectives are the key driver for farmers, who may produce a crop only if it is likely to be sold: the presence of a market gives farmers the insurance and the economic guarantees to produce.

- **Create local markets opportunities:**
  - **Specialisation in local areas leads to reduced market opportunities**: cooperatives and traders, along with industries, focus on a few crops/productions, which offer limited links to value chains of alternative crops. Regional specialisation appears like a break to diversification of crop rotations and crops, and should not be encouraged, in view to promote crop rotations having a beneficial impact on the environment.
  - **Diversify systems towards more mixed farming** (associating livestock and cropping systems) should be encouraged.
  - **Commercial contracts**, which are signed between farmers and their economic partners before harvesting period, can be a mean to promote crops diversification.

- **Establish links between farmers and markets:**
  - **ntervene at the market level** in order to ask markets organisations to leave a place to alternative crops and enhance their (industrial) valorisation.

8. 4. 2. Compensating the economic loss due to the market opportunity

- **The economic loss** due to switching from a market crop to an alternative crop should be **compensated**, e.g. by valorising the beneficial services delivered to the environment
- **A reserve fund** could be created in order **to support farmers who grow environmentally-interesting crops** and do not find a market opportunity. In other words, the money would serve structuring markets.

9. REFERENCES

Adler, P.A., Del Grosso, S.J., and Parton, W.J., 2007. Life-cycle assessment of net greenhouse-gas flux for bioenergy cropping systems. Ecol. Appl. 17, 675–691.

ADVIENTO-BORBE, M. A. A., HADDIX, M. L., BINDER, D. L., ALTERS, D.T., DOBERMANN, A., 2007, Soil greenhouse gas fluxes and global warming potential in four high-yielding maize systems, Global Change Biology, Volume 13, Issue 9, pages 1972–1988, September 2007.

Agra CEAS Consulting, 2002. Integrated crop management systems in the EU. Final report for European Commission DG Environment

Al Kaisi M., 2008. Impact of tillage and crop rotation systems on soil carbon sequestration. Iowa State University, 6p.

Alfter, P. 1998, Recherche sur les biens et services non-bois de la forêt suisse. Quantification et essai de valorisation dans le cadre d'un projet de l'OFEFP. Schweiz. Z. Forstwes., 149, pp. 87-104.

Ambrosius, G., Hubbard, W. H., 1989, A social and economic history of twentieth-century Europe, Harvard University Press

Amigues J.P., P. Debaeke, B. Itier, G. Lemaire, B. Seguin, F. Tardieu, A. Thomas, 2006. Sécheresse et agriculture. Adapter l'agriculture à un risque accru de manque d'eau. Synthèse de l'expertise scientifique collective, INRA (France), 72 p.

Analysis of agriculture advisor's system in the partnering country in the frame of the AAC project – Summary, Austria Advisory system summary.doc, Author unknown, Available at: http://www.agroextension.net/attachments/Austria_advisory_system_summary_en.doc Date accessed: 05/05/2010

Anderson and Domsch, 1990, Application of eco-physiological quotients (qCO2 and qD) on microbial biomasses from soils of different cropping histories, Soil Biology and Biochemistry, Volume 22, Issue 2, 1990, Pages 251-255.

Anielski et Wilson, 2005, Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems

Archer, C., 2000, The European Union: structure and process, Continuum International Publishing Group

Armstrong G. , 2000, Earthworms in an organic rotation, Organic farming – towards a benign environment, Poster presentation, 5-6 April 2000.

Armstrong G. , 2000, Earthworms in an organic rotation, Organic farming – towards a benign environment, Poster presentation, 5-6 April 2000.

Arrouays D., Balesdent J., Germon J.C., Jayet P.A., Soussana J.F. and Stengel P., 2002. Increasing carbon stocks in French agricultural soils? B. Seguin et al. (Eds) Moderating the impact of agriculture on climate. INRA (Paris)

Artis,M. J., Nixson, F., 2007, The economics of the European Union: policy and analysis, Oxford University Press

Arvalis, Coinus, L., Emonet, E., Jouy, L., Granger, S., Caractérisation des itinéraires techniques en fonction de la rotation et de l'effet du précédent.

Asociación Nacional de Fabricantes de Fertilizantes website, 2010, http://www.anffe.com/, Association of Agricultural Education in Europe, http://www.europea.org/index.php?page=HomepageGB Date accessed: 05/05/2010

Aubert, F., Piveteau, V., Schmitt, B., 2009, Politiques agricoles et territoires, Editions Quae, pp 123-128

Backer, 2005, Technology in the Middle Ages History of Technology, Department of Aviation and Technology at San Jose State University in San Jose, CA, http://www.engr.sjsu.edu/pabacker/history/middle.htm.

Balkhausen, O., Banse, M., Grethe, H., 2007, Modelling CAP decoupling in the EU: a comparison of selected simulation models and results, Journal of Agricultural Economics, 59, 1, 57-71

Ball, B. C., Bingham, I., Rees, R. M., Watson, C. A., & Litterick, A., 2005. The role of crop rotations in determining soil structure and crop growth conditions. Canadian Journal of Soil Science 85, 557–577.

Barkaoui, A., Butault, J.-P., 2004. Impacts sur l'offre des régions françaises des différentes options de la réforme de la PAC de 2003. INRA Sciences Sociales. n° 4-5/03.

Barron M, Wratten SD, BJD, A four year investigation into efficacy of domiciles for enhancement of bumblebee populations, Agricultural and Forest Entomology, 2 , 2000) 141–146.

Bennett, Et Al., "Truman's Scientific Guide to Pest Management Operations", 6th edition, page 10, Purdue University/Questex Press, 2005.

Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends in Ecology and Evolution 18, 182–188.

BIOIS Survey, Survey eprformed for this project need, among farmers and Farm Advisors of 7 Member States, 2010

BirdLife International, 2010, www.birdlife.org

Birkas, M., 2009. Findings of long term experiments aimed to help improve tillage practices. Agriculturae Conspectus Scientificus.

Bittner, B., Kérékgyarto, A.M., Orosz, T., 2009, Difficulties of diversification and alternatives crop to tobacco in the European Union, 4th Aspects and Visions of Applied Econmics and Informatics, Debrecen

Bocqueho, G., Jacquet, F., 2010. The adoption of switchgrass and miscanthus by farmers: Impact of liquidity constraints and risk preferences. Energy Policy 38: 2598-2607

Boellstorff, D., Benito, G., 2005, Impacts of set-aside policy on the risk of soil erosion in central Spain, Agriculture, Ecosystems & Environment, Volume 107, Issues 2-3, 20 May 2005, Pages 231-243.

Boiffin, J., Kéli Zagbahi, J., & Sebillotte, M., 1986. Systèmes de culture et statut organique des sols dans le Noyonnais: application du modèle de Hénin-Dupuis. Agronomie 6, 437–446

Boisselier, Y., 2010, Training and Education in agriculture in Europe at NUTS 3 level Available at: http://www.agro-net.eu/index.php?option=com_content&view=article&id=128:training-and-education-in-agriculture-in-europe-at-nuts-3-level&catid=43:europe&Itemid=56 Date accessed: 08/08/2010

Bolinder, M., Janzen, H., Gregorich, E., Angers, D., & VandenBygaart, A., 2007. An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada. Agriculture, Ecosystems & Environment 118, 29-42.

Bowler, I. A., 2005, Agriculture under the Common Agricultural Policy: a geography,Manchester University Press ND, 1985

Bracken, F., Bolger, T., 2006, Effects of set-aside management on birds breeding in lowland Ireland, Agriculture, Ecosystems & Environment, Vol 117, Issues 2-3.

Brander, 2006, The empirics of wetland valuation: A comprehensive summary and a meta-analysis of the literature. Environmental & Resource Economics. 33(2): 223-250.

Bretagnolle and Houte , 2005, Enjeux de biodiversité en céréaliculture intensive : diagnostic, action et prospectives pour les oiseaux de plaine, Académie d'Agriculture de France. Séance du 23 mars 2005.

Britz, W., Heckelei, T., 2008, Recent developments in EU policies - challenges for equilibrium models, Paper prepared for presentation at the 107th EAAE Seminar "Modeling of Agricultural and Rural Development Policies". Sevilla, Spain, January 29th -February 1st, 2008.

Brown, James H., and Astrid Kodric-Brown. 1977. Turnover Rates in Insular Biogeography: Effect of Immigration on Extinction. Ecology 58:445–449.

Bruun, S., Hansen, T.L., Christensen, T. H., Magid, J., Jensen, L. S., 2006, Application of processed organic municipal solid waste on agricultural land: a scenario analysis, Environmental Modeling and Assessment (2006), 11, 251 - 265.

Burch, D., Goss, J., Lawrence, G. and Rickson, R. 1999. 'The Global Restructuring of Food and Agriculture: Contingencies and Parallels in Australia and New Zealand', Introduction to 'Antipodean Visions: The Dynamics of Agri-food Restructuring in Australia and New Zealand', special edition of Rural Sociology, 64:179-186

Butault J.P., Dedryver C.A., Gary C., Guichard L., Jacquet F., Meynard J.M., Nicot P., Pitrat M., Reau R., Sauphanor B., Savini I., Volay T., 2010. Ecophyto R&D. Quelles voies pour réduire l'usage des pesticides ? (90 p.)

Cabelguenne, M., Marty, J.R., Hilaire, A., 1982. Comparaison technico-économique de la valorisation de l'irrigation par 4 cultures d'été (maïs, soja, sorgho, tournesol). Agronomie 2, 567-576

Campbell, C. A., Zentner, R. P., Janzen, H. H., and Bowren, K. E., 1990. Crop Rotation Studies on the Canadian Prairies, Publ. 1841/E. Res. Br., Agric. Canada. Can. Govt. Publ. Ctr. Ottawa, p.133.

Castellazzi, M.S., Perry, J.N., Colbach, N., Monod, H., Adamczyk, K., Viaud, V., Conrad, K.F., 2007. New measures and tests of temporal and spatial pattern of crops in agricultural landscapes. Agriculture Ecosystems & Environment 118, 339–349.

Centre Technique Interprofessionel des Oleagineux Metropolitains

Ceotto and Spallacci, 1996, "Lucerne as a "nitrate scavenger" for silty soil manured with pig slurry", Book of abstracts 4th ESA Congr., 492-493.

CETIOM, 2007, Evaluation of the Rotational Measure, Working Document, unpublished

CETIOM, 2010, Démarche de progress du biodiesel, Available at: http://www.cetiom.fr/fileadmin/cetiom/kiosque/PDF_fiches_TK/fiche_demarche_biodiesel2010.pdf

Chaplin, H., Matthews, A., 2005, Reform of the EU Sugar Regime: Impacts on Sugar Production in Ireland, IIIS Discussion Paper N°90

Charles Townshend, 2nd Viscount Townshend - Wikipedia, the free encyclopedia. Available at: en.wikipedia.org/wiki/Charles_Townshend,_2nd_Viscount_Townshend Date accessed: 10/12/2009

Chevassus-au-Louis, 2009, L'approche économique de la biodiversité et des services liés aux éco systèmes, conseil d'Analyse Stratégique

Chmielewski F.M., Müller A., and Bruns E., 2004 Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000. Agr. Forest Meteorol. 121, 69–78.

CIV, Centre d'Information des Viandes, 2009, www.civ-viande.org/uk/ebn.ebn?pid=57&page=1&item=1&rubrik=1#209, Animal husbandry and environment

Clapp, C.E, Allmaras R.R, Layese M.F., Linden D.R. and Dowdy R.H., 2000. Soil organic carbon and C-13 abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil Tillage Res. 55, 127–142.

Clergue, B., Amiaud, B., Pervanchon, F., Laserre-Joulin, F. and Plantureux, S. , 2005, Biodiversity: Function and Assessment in Agricultural Areas: A Review, in E. Lichtfouse et al. (eds.), Sustainable Agriculture, DOI 10.1007/978-90-481-2666-8_21.

COGECA, 2005, Agricultural Co-operatives in the European Union, presented in Madrid (Spain), 22 November 2005

Convention on Biological Diversity (CBD), 2001, Assessment, Conservation and sustainable Use of Forest biodiversity

Convention on Biological Diversity , 1992.

Crop rotation - Wikipedia, the free encyclopedia. Available at: en.wikipedia.org/wiki/Crop_rotation Date accessed: 10/12/2010

Curry J P, 1986, Above-ground arthropod fauna of four swedish cropping systems and its role in carbon and nitrogen cycling, Journal of Applied Zcology 23: 853-870.

Cyson, T., 1998. World food trends and prospects to 2025, Proc. Natl. Acad. Sci. USA Vol. 96, pp. 5929–5936, May 1999 Colloquium Paper

Data available from : www.meuse.chambagri.fr/

Debaeke, P., Cabelguenne ,M., 1994. Influence of previous crop on available water for a subsequent winter wheat on a deep silty clay soil. Proc. 3rd ESA Congress, Padova (Italy), pp. 682-683.

Defra, UK - Farming - Organic Food and Farming - Organic Farming Methods, Available at:http://www.defra.gov.uk/foodfarm/growing/organic/systems/method.htm Date accessed: 08/08/2010

den Belder, E., Elderson, J., van den Brink, W. J. and Schelling, G., 2002, Effect of woodlots on thrips density in leek fields: a landscape analysis, Agriculture, Ecosystems & Environment, Volume 91, Issues 1-3, September 2002, Pages 139-145.

Desjardins R. L., Sivakumarb, M.V.K., de Kimpe, C., 2007, The contribution of agriculture to the state of climate: Workshop summary and recommendations, Agricultural and Forest Meteorology, Volume 142, Issues 2-4, 12 February 2007, Pages 314-324.

Desjardins R. L., Smith W., Grant B., Campbell C. and Riznek R., 2005. Management strategies to sequester carbon in agricultural soils ans to mitigate greenhouse gas emissions. Climatic Change 70, 283–297.

Dick, Richard, 1992, A review: long-term effects of agricultural systems on soil biochemical and microbial parameters, Agriculture, Ecosystems & Environment, Volume 40, Issues 1-4, May 1992, Pages 25-36, Biotic Diversity in Agroecosystems.

Diffley, A. , 2007, Soil Health and Biodiversity in Practice: Harnessing biology, ecology and resiliency on the farm, The Organic Broadcaster, published by the Midwest Organic and Sustainable Education Service

Dimopoulos, D., Fermantzis, I., Vlahos, G., 2006, The Responsiveness of Cross Compliance Standards to Environmental Pressures, Cross Compliance Network, 6th Framework Programme

Doorenbos, J., Kassam, A.H., Bentvelsen, C.L.M., Branscheid, V., Plusje, J.M.G.A., 1979. Yield response to water. In: FAO Irrigation and Drainage Paper (FAO), no. 33 / FAO, Rome (Italy). Land and Water Development Div., 200 p.

Duiker, S.W., and Lal, R., 1999. Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. Soil Tillage Res. 52, 73–81.

EC -DG Agriculture and Rural development, 2005, Agri-Environment Measure: Overview on general principles, types of measures and applications

EC, DG Agriculture & Alliance Environnement, 2007, Evaluation des impacts sur l'environnement des mesures de la PAC relatives au coton, Available at: http://ec.europa.eu/agriculture/eval/reports/coton/index_fr.htm

ECAF, 2005 in European Conservation Agriculture Federation (ECAF) website: http://www.ecaf.org/index.php?option=com_content&task=view&id=53&Itemid=52

Ecological Agriculture Projects Faculty of Agricultural and Environmental Sciences, McGill University, 2008, Choosing Crops for a Crop Rotation Available at: eap.mcgill.ca/MagRack/COG/COGHandbook/COGHandbook_2_2.htm, Date accessed: 11/08/2010

Edwards CA, Bohlen PJ (1996) Biology and Ecology of Earthworms, 3rd edn., Chapman and Hall, London, 426 pp.

Edwards P (1977) Studies of mineral cycling in a montane rain forest in New Guinea II. The production and disappearance of litter. J Ecol 65:971-992

EEA Report No 2/2009 Water resources across Europe — confronting water scarcity and drought.

EEA, 2003. EEA Indicator Fact Sheet: Sectoral water use. Available at: themes.eea.eu.int/Specific_media/water/indicators/WQ02,2003.1003/ Date accessed: 10/10/2009

El Titi, A., 1991. The Lautenbach Project 1978-89: Integrated wheat production on a commercial arable farm, south-west Germany. P 399-411. In L. G. Firbank, N., Carter, Darbyshire J.F. and Potts, G.R. (ed). The Ecology of Temperate Cereal Fields. Blackwell Scientific Publications, Oxford, England.

Energy and economic analysis of comparative sustainability in low-input and conventional farming systems, unpublished M.Sc. Thesis, Departement of Crop and Soil Sciences, Michigan State University

EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION, 2001, Report of the 6th Meeting of the EPPO ad hoc Panel on Diabrotica virgifera virgifera held jointly with the 8th International IWGO Workshop on Diabrotica virgifera virgifera, Venezia, IT, 2001-10-29/30

EUROSTAT, 2009, EUROPE IN FIGURES — Eurostat yearbook 2009.

Eurostat-AGR, 2007, “Agriculture Main statistics 2005-06”, Eurostat-European Comission

Fahrig, L. & Jonsen, I., 1998, Effect of habitat patch characteristics on abundance and diversity of insects in an agricultural landscape. Ecosystems, 1, 197–205.

FAO, 2003, Projections of tobacco production, consumption and trade to the year 2010

FAOSTAT, online database, data from 1961 to 2002.

Farahani, H.J., Peterson, G.A., Westfall, D.G., Sherrod, L.A., Ahuja, L.R., 1998. Soil water storage in dryland cropping systems: the significance of cropping intensification. Soil Sci.Soc. Am. J. 62, 984–991.

Farina A. , 2006, Principles and Methods in Landscape Ecology – Towards a Science of Landscape, Springer Landscape Series, The Netherlands

Farm Accountancy Data Network: ec.europa.eu/agriculture/rica/

Farmer M., Silcock P., Cooper T., Swales V.

Field R.H., Benke S., Badonyi K. & Bradbury R.B. (2007) Influence of conservation tillage on winter bird use of arable fields in Hungary. Agriculture Ecosystems & Environment, 120, 399-404

Filippi, M., 2002 Les sociétés coopératives agricoles entre ancrage territorial et intégration, économique Etud. Rech. Syst. Agraires Dév. 33 pp. 79-94.

Filser J., Fromm H., Nagel R.F. & Winter K. (1995) Effects of Previous Intensive Agricultural Management on Microorganisms and the Biodiversity of Soil Fauna. Plant and Soil, 170, 123-129

Filser, Juliane, Fromm, Henning, Nagel, Roland F. and Winter, Karin, 1995, Effects of previous intensive agricultural management on microorganisms and the biodiversity of soil fauna, Journal Plant and Soil, Volume 170, Number 1, 123-12.

Firbank,L. G., Smart, S. M. , Crabb,J., Critchley,C. N. R. , Fowbert,J. W. , Fuller, R. J. ,Gladders,P. , Green,D. B. ,Henderson, I. , Hill,M. O.,2003,Agronomic and ecological costs and benefits of set-aside in England, Agriculture, Ecosystems & Environment, Volume 95, Issue 1, April 2003,Pages 73-85

Flynn H., Smith P., Bindi M., Trombi G., Oudendag D. and Rousseva S., 2007. Practices description and analysis. Policy Incentives for Climate Change Mitigation Agricultural Techniques (PICCMAT). Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006).

Flynn, H. C., 2009, Agriculture and Climate Change: An Agenda for Negotiation in Copenhagen, The Role of Nutrient Management in Mitigation, International Food Policy Research Institute, Focus 16, Brief 7, May 2009.

Forristal, 2005, Rotations: A New Role in a New Era?

Fox, 1991, Comparative Economics of Alternative Agricultural Production Systems: A Review. Northern Journal of Agricultural and Resource Economics 20(1)(1991):124-142.

Freibauer A., Rounsevell M.D.A., Smith P. and Verhagen J., 2004. Carbon sequestration in the agricultural soils of Europe. Geoderma 122, 1-23.

Frieben, B. & Kopke, U. , 1996,. Effects of farming systems on biodiversity. In: Biodiversity and Land Use: The Role of Organic Farming (edited by J. Isart, J. & J.J. Llerena), pp 11-21. Proceedings of the First ENOF (The European Network for Scientific Research Co-ordination in Organic Farming) Workshop, Bonn.

G. Bocquého, F. Jacquet, 2010, Perennial herbaceous energy crop adoption by farmers: impact of risk preferences and liquidity constraints, Energy Policy, 38, 5, pp 2598-2607

Gaiser T., Abdel-Razek M., and Bakara H., 2009. Modeling carbon sequestration under zero-tillage at the regional scale. II.The influence of crop rotation and soil type. Ecological Modelling 220, 3372–3379

Gardner, Sarah M., and Brown, R.W., 1998, final report review of the comparative effects of organic farming on biodiversity, MAFF Contract OF0149, ADAS Wolverhampton and R & D Associates, Kirbymoorside.

Gardner, Sarah M.; Brown, R. W. and R & D Associates, , 1998, Comparative review of the effects of organic farming on biodiversity (OF0149,

Gaucherel, C., Giboire, N., Viaud, V., Houet, T., Baudry, J., Burel, F., 2006. A domain-specific language for patchy landscape modelling: the Brittany agricultural mosaic as a case study. Ecological Modelling 194, 233–243.

Gebremedhin, 1998, The economic importance of crop rotation systems: evidence from the literature

Giardini, 2004, Productivity and sustainability of different cropping systems

Giardini, L., & Morari, F., 2004. Soil fertility parameters. In Productivity and Sustainability of Different Cropping Systems. 40 years of Experiments in Veneto region (Italy). Pàtron Editore, Bologna (Italy), pp. 239-256.

Giardini, L., 2004. Productivity and Sustainability of Different Cropping Systems. 40 years of Experiments in Veneto region (Italy). Pàtron Editore, Bologna (Italy).

Gleyses G., Rieu T., 2004. L'irrigation en France : état des lieux 2000 et évolution. Ed Cemagref, 60 p.

Gloy, B. A., Akridge, J. T., Whipker, L. D., 2000. Sources of information for commercial farms: usefulness of media and personal sources, International Food and Agribusiness Management Review 3, 245–260

Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K. D., Dixon, J., Dendooven, L., 2009, Conservation Agriculture and Soil Carbon Sequestration: Between Myth and Farmer Reality, Critical Reviews in Plant Sciences, Publisher: Taylor and Francis Ltd, Volume 28, Number 3, May 2009 , pp. 97-122(26).

Green, B.H., E.A. Simmons, and I. Woltjer. 1996. Landscape Conservation: Some Steps Towards Developing a New Conservation Dimension. A draft report of the IUCN-CESP Landscape Conservation Working Group. Dept. Agriculture, Horticulture and Environment, Wye College, Ashford, Kent, UK.

Grignani, C., Zavattaro, L., Sacco, D., & Monaco, S., 2007. Production, nitrogen and carbon balance of maize-based forage systems. European Journal of Agronomy 26, 442-453.

Groot, S.P.C.; Jalink, H.; Hospers-Brands, M.; Köhl, J.; Veerman, A.; Wenneker, M.; van der Wolf, J.M. and van den Bulk, R.W, 2006, Improvement of the quality of propagation material for organic farming system, Joint Organic Congress, Odense, Denmark

Gyuricza, CS., Tóth Z. 2006. Vetésforgó és vetésváltás. In: Földművelés és földhasználat (szerk. Birkás M.), Mezőgazda Kiadó, Budapest, pp. 316-355.

Haber, W., 2004, Landscape ecology as a bridge from ecosystems to human ecology, Ecological Research, 19:99-106.

Halvorson, A.D., Del Grosso, S.J. and Reule, C.A., 2008. Nitrogen, tillage, and crop rotation effects on nitrous oxide emissions from irrigated cropping systems. J. Environ. Qual. 37, 1337–1344.

Hamza, M., & Anderson, W., 2005. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. Soil and Tillage Research 82, 121-145.

Hassink, J., Lebbink, G., Van Veen, J. A., 1991, Microbial biomass and activity of a reclaimed-polder soil under a conventional or a reduced-input farming system, Soil Biology and Biochemistry, Volume 23, Issue 6, 1991, Pages 507-513.

Hattendorf, M. J., Redelfs, M. S., Amos, B., Stone, L. R., Gwin, R. E., Jr., 1988. Comparative water use characteristics of six row crops. Agron. J. 80, 80-85.

Heard, J., Ablett, C. R., Michaels, T. E., O'Toote, J.T., Forrest, R.E., 1990, Production of Narrow-Row Direct Harvest White Beans in Ontario, Factsheet, number 142/50. Available at: http://www.omafra.gov.on.ca/english/crops/facts/90-058.htm Date accessed: 04/03/2010

Heimann-Detlefsen D., 1991, Auswirkungen eines unterschiedlich intensiven Pflanzenschutz-und Düngemitteleinsatzes auf die Collembolenfauna des Ackerbodens. PhD thesis, Technical University of Braunschweig.

Helenius, J., 1997. Spatial scales in ecological pest management (EPM): importance of regional crop rotations. Biological Agriculture & Horticulture 15, 163–170.

Hendrickx et al, 2007 Hendrickx F, Maelfait JP, Wingerden Wv, et al. How landscape structure, land-use intensity and habitat diversity affect components of total arthropod diversity in agricultural landscapes. J Appl Ecol 2007 ; 44 : 340-51

Hendrix, P.F., Chun-Ru Han, Groffman, P.M., 1987, Soil respiration in conventional and no-tillage agroecosystems under different winter cover crop rotations, Soil and Tillage Research, Volume 12, Issue 2, August 1988, Pages 135-148.

Hermans, I., Crop rotation and the use of cover crops: How do they contribute to good agricultural practice, Soil Service of Belgium, 6-8 October 2010, Roma, GAEC Workshop 2010.

Hopkins A. and Del Prado A., 2007. Implications of climate change for grassland in Europe: impacts, adaptations and mitigation options: a review. Grass and Forage Science 62, 118–126

Hoskin, 1981, An Economic Analysis of Alternative Saginaw Valley Crop Rotations- An Application of Stochastic Dominance Theory. Unpublished Ph.D. dissertation, Michigan State University

House of Lord - UK Parliament, 2005, Too much or too little? Changes to the EU sugar regime, 18th Report of session, Vol. 2 Evidence, pp 50-56 http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes

Huang M., Shao M., Zhang L., Li Y., 2003. Water use efficiency and sustainability of different long-term crop rotation systems in the Loess Plateau of China. Soil & Tillage Research 72, 95–104

Hunter, M. D., 2002, landscape structure, habitat fragmentation, and the ecology of insects, Agricultural and Forest Entomology, 4, 159-166.

Hutchinson, J.J., Campbell, C.A., and Desjardins, R.L., 2007. Some perspectives on carbon sequestration in agriculture. Agric. Forest Meteorol. 142, 288-302

Hüther W., 1961, Ökologische Untersuchungen über die Fauna pfälzischer Weinbergsböden mit besonderer Berücksichtigung der Collembolen und Milben. Zool Jahrb Syst 89:243-368.

Huyghe C. , 2009, Multi-function grasslands in France. II. Combining production and environment preservation, Cahiers Agricultures, Volume 18, Number 1, pp. 7-16

IEEP, 2005. Cross-compliance in the CAP: Conclusions of a Pan-European Project 2002-2005. Available from: http://www.ieep.eu/publications/pdfs/crosscompliance/conclusionsenglish.pdf

IFORE, MEEDDM, 2008, Conférence "Relever le défi de la biodiversité : l'agriculture durable", Paris – 17/10/2008.

Iglesias A., Avis K, Magnus B., Fisher P., Harley M., Hodgson N., Horrocks L., Moneo M., and Webb J., 2007. Adaptation to Climate Change in the Agricultural Sector. Report to European Commission Directorate-General for Agriculture and Rural Development, ED05334, Issue Number 1, December 2007, AEA Energy & Environment and Universidad de Politécnica de Madrid, 137 p.

Ikerd, J.A, 1991, Decision support system for sustainable farming, Northeastern Journal of agricultural Economics N°20, pp 109-113

Impacts of fertilisers and legumes on N2O and CO2 emissions from soils in subtropical agricultural systems: A simulation study, Agriculture, Ecosystems & Environment, In Press, Corrected Proof, N.I. Huth, P.J. Thorburn, B.J. Radford, C.M. Thornton

Ingersent, K. A.,Rayner, A. J. ,2000,Agricultural policy in Western Europe and the United States,Edward Elgar Publishing

INSEE - Comptes de l’agriculture, calculs SCEES

Institut Français de l'Environnement (IFEN), 2005, Les multiples valeurs de la forêt française, Ministère de l'Écologie et du Développement Durable

IPCC, 2001a. Climate Change 2001, The Scientific Basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

ITAB, 2008, Les grandes cultures biologiques en France : état des lieux des rotations pratiquées par régions

Jacquet, F. ; Butault, J.P. ; Guichard, L. SFER, Société Française d'Economie Rurale (FRA) ; CEMAGREF, Centre National du Machinisme Agricole, du Génie Rural, des Eaux et des Forêts (FRA), La réduction des pesticides en grandes cultures par l’adoption de systèmes de production économes en intrants : une modélisation au niveau de la France; [Communication orale]. La réduction des pesticides agricoles enjeux, modalités et conséquences ; 2010/03/11-12 ; Lyon (FRA), 22p.

Jaison J. Jerome, 2006, Organic Farming & Biodynamic Agriculture Training resource book.

Jarvis, S. C., Stockdale, E. A., Shepherd, M. A., & Powlson, D. S., 1996. Nitrogen Mineralization in Temperate Agricultural Soils: Processes and Measurement. Advances in Agronomy 57, 187-235.

Jayet P.A., Labonne J., 2005. Impact d’une réforme de la Politique Agricole Commune par le découplage in : Economie et Prévision, 2005, n° 167. pp. 101–116.

Jeanneret P, Schupbach B, Luka H, Quantifying the impact of landscape and habitat features on biodiversity in cultivated landscapes, Agriculture, Ecosystems and Environment, 98 , 2003, 311–320.

Jeanneret P, Schüpbach B, Pfiffner L, Walter T, Arthropod reaction to landscape and habitat features in agricultural landscapes, Landscape Ecology, 18 , 2003, 253–263.

Jeuffroy, M. H., 2010, Réduire les intrants pour concilier performances économiques et environnementales at SIA 2010 : Agriculture et environnement : le défi agricole, Paris, 22/02/2010

Johnson and Ali , 1982, Economics ofWheat-Fallow Cropping Systems in Western North Dakota. Western Journal of Agricultural Economics 7(1)(July 1982):67-77"

Johnson P. 2005 The environmental policy of the European communities. Eds International Environmental Law and Policy Series

Jones, 1996, Enhancing Yield, Profitability and Nitrogen Mineralization in Corn-Based Integrated Cropping Systems.” Unpublished Ph.D. dissertation, Department of Crop and Soil Sciences, Michigan State University"

Jones, R. A., 2001,The politics and economics of the European Union: an introductory text, Edward Elgar Publishing

JRC - Soil Organic Carbon Content Available at: eusoils.jrc.ec.europa.eu/esdb_archive/octop/octop_download.html Date accessed: 16/12/2009

JRC, Vogt, J., Soille, P., de Jager, A., Rimaviciute, E., Mehl, W., Foisneau, S., Bodis, K., Dusart, J., Paracchini, M.L., Haastrup, P., Bamps, C., 2007, A pan-European River and Catchment Database,

Justes E., Dorsainvil F., Thiébeau P., Alexandre M., 2002. Effect of catch crops on the water budget of the fallow period and the succeeding main crop. Proc 7th ESA Congress, Cordoba, 503-504.

Karlen, D.L. , Varvel,G. E., BullockD. G. and Cruse, R. M. , 1994, Crop rotations for the 21st century, Advances in agronomy, vol 53, Pages 1-45

Katsvairo and Cox, 2000, Economics of cropping systems featuring different tillage, rotation, and management systems. Agron. J. 92: 485-493

Kay, B. D., 1990. Rates of change of soil structure under different cropping systems. Advances in Soil Science 12, 1-52.

Kirkegaard, J., Christen, O., Krupinsky, J., & Layzell, D., 2008. Break crop benefits in temperate wheat production. Field Crops Research 107, 185-195.

Kjeldsen-Kragh, S., 2007, The role of agriculture in economic development: the lessons of history, Copenhagen Business School Press DK

Kolbe, H., 2007, Designing crop rotations in organic and low-input agriculture: Evaluation of pre-crop effects.

Kriege, 2001, Economic Value of Forest Ecosystem Services: a Review. The Wilderness Society, Washington, DC.

Kumar, K., & Goh, K., 1999. Crop Residues and Management Practices: Effects on Soil Quality, Soil Nitrogen Dynamics, Crop Yield, and Nitrogen Recovery. Advances in Agronomy 68, 197-319.

Lagerlof, J. & U. Scheller. 1987. Abundance and activity of Pauropoda and Symphyla (Myriapoda) under four arable crops. In J. Lagerlof (ed.) Ecology of soil fauna in arable land. Dynamic and activity of microarthropods and enchytraeids in four cropping systems. Uppsala, 357 pp.

Lains,P., Pinilla, V., 2008, Agriculture and Economic Development in Europe Since 1870, Taylor & Francis

LARBANEIX G., 2008. Etude comparative de la gestion des adventices sur 3 systèmes de culture céréaliers du Bassin parisien. Mémoire de fin d'étude AgroParisTech.

Lavalle C., Micale F., Houston T. D., Camia A., Hiederer R., Lazar C., Conte C., Amatulli G. and Genovese G., 2009. Climate change in Europe. 3. Impact on agriculture and forestry. A review. Agron. Sustain. Dev. 29, 433–446.

Lavoie, 1991, Soil compaction machinery selection and optimum crop planning, Trans. ASAE 34, 1-8

Lazányi, J., 2006. Soil compaction in the Westsik crop rotation experiment. In Natural resources and sustainable development: University of Oradea Publishing House, Oradea, pp. 279-288.

Lazányi, J., 2009. Carbon sequestration of land-use in Nyírség region under the Kyoto protocol. In 4th Aspects and Visions of Applied Economics and Informatics. Debrecen, Hungary, pp. 1191-1202.

Lebreton, 2004, Changes in population structure of the soilborne fungus Gaeumannomyces graminis var. tritici during continuous wheat cropping Environ. Microbiol 6 1174–1185.

Leroy, P., Jacquin, C., 1994. Un logiciel pour le choix d'assolement sur le périmètre irrigable d'une exploitation. 17ème Conf. Rég. Europ. Irrigation Drainage ICID/CIID, Varna (Bulgarie), 16-22 mai 1994. Vol 2, pp 61-72.

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.

Li, H., 2010, Newspaper advertising and Magazine Advertising Information, Available at: http://www.newspaperadvertising.com/articles/art5.html,Date accessed: 08/08/2010

Liu, Jianguo, Cubbage, Fred W. and Pulliam, H. Ronald, 1994, Ecological and economic effects of forest landscapenext term structure and previous termrotationnext term length: simulation studies using ECOLECON , Ecological Economics, Volume 10, Issue 3, August 1994, Pages 249-263.

Lopez Cedron, F.X., Ruiz-Nogueira, B., Pineiro, J., Sau, Y.F., 2009. Productividad de la rotación anual raigrás-maíz en Galicia: Evaluación durante cinco años en regadío y secano y bajo dos sistemas de siembra. Pastos e Forraxes, Cultivos COP,Pastos. Vol. XXXVI (2), pp. 193-216

López-Bellido, L., López-Garrido, F. J., Fuentes, M., Castillo, J. E., & Fernández, E. J., 1997. Influence of tillage, crop rotation and nitrogen fertilization on soil organic matter and nitrogen under rain-fed Mediterranean conditions. Soil and Tillage Research 43, 277-293.

Louhichi, K., Belhouchette, H., Wery, J., Therond, O., Flichman, G., 2008, Impact Assessment of the 2003 CAP Reform and the Nitrates Directive on the Arable Farming system in the Midi-Pyrénées region: bio-economic modelling at field, frams and regional levels, 109th EAAE Seminar, Viterbo, Italy

Lupwayi, N. Z., Rice, W. A., and Clayton, G. W. , 1998, Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation, Soil Biology and Biochemistry, vol 30, issue 13, pp. 1733-1741

Lys, J. A., Zimmerman, M. & Nentwig, W. , 1994,. Increase in activity density and species number of a carabid beetles in cereals as a result of strip-management. Entomologia Experimentalis et Applicata 73, 1-9.

M.S Carter, Albert K., and Ambus P., 2009. Is organic farming a mitigation option? – A study on N2O emission from winter wheat. In : Climate Change: Global Risks, Challenges and Decisions, IOP Conf. Series: Earth and Environmental Science 6 (2009)

Majewski, E., 2009, Dr. Hab Faculty of Agricultural Economics, Warsaw University of Life Sciences

Majewski, E., Radecki, A., Was, A., Straszewski, S., 2009, Crop rotations in Poland, unpublished paper, Faculty of Agricultural Economics, Warsaw University of Life Sciences.

Maracchi G., Sirotenko O. and Bindi M., 2005. Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. Climatic Change 70, 117–135.

Mazoyer and Roudard, 2002, Histoire des agricultures du monde : du néolithique à la crise contemporaine, Editions du Seuil, Volume 307 de Points.

McDonald, F., Dearden, S., 2005, European economic integration, Pearson Education

McLaughlin, Alison, and Mineau, Pierre, 2000, The impact of agricultural practices on biodiversity, Agriculture, Ecosystems & Environment, Volume 55, Issue 3, October 1995, Pages 201-212.

MEEDDAT, 2008, La valeur économique de la forêt méditerranéenne en France

Meyer-Aurich A, Weersink A, Janovicek K, and Deen B, 2006. Cost efficient rotation and tillage options to sequester carbon and mitigate GHG emissions from agriculture in Eastern Canada. Agric. Ecosyst. Environ. 117, 119-127

Milan Macàk, 2009, Department of Sustainable Agriculture and Herbology, Faculty of Agrobiology and Food Resources, Slovak Agricultural University in Nitra

Miralles-Bruneau, M. M. 2008. Evaluation multicritère de systèmes de culture : cas des effets des cultures de légumineuses à graines et des cultures intermédiaires en système bas intrants du Sud-Ouest de la France. MASTER PROFESSIONNEL Sciences Technologie Santé mention Biologie Agronomie Santé, INRA Toulouse – UMR AGIR.

Mokyr, J., Strotz, R. H., 1998, The Second Industrial Revolution, 1870-1914.

Montagné, 2005, « La Valeur Economique Totale de la Forêt Méditerranéenne Française ». Forêt Méditerranéenne Tome XXVI, Numéro 4

Morari, F., Lugato, E., Berti, A., & Giardini, L., 2006. Long-term effects of recommended management practices on soil carbon changes and sequestration in north-eastern Italy. Soil Use and Management 22, 71-81.

Mosier, A.R., Halvorson, A.D., Reule, C.A., and Liu, X.J., 2006. Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. J. Environ. Qual. 35, 1584–1598.

Musick, J.T., Jones, O.R., Stewart, B.A., Dusek, D.A., 1994. Water–yield relationships for irrigated and dryland wheat in the U.S. Southern Plains. Agron. J. 86, 980–986.

Nations Encyclopedia, 2009, Data on climate for European countries, http://www.nationsencyclopedia.com/Europe/index.html.

Nemecek T., von Richthofen J.S., Dubois G., Casta P., Charles R. and Pahl H., 2008. Environmental impacts of introducing grain legumes into European crop rotations. Eur. J. Agron. 28, 380–393.

"Nick van Eekeren, Lydia Bommele, Jan Bokhorst, Ton Schouten, Dirk Reheul and Lijbert Brussaard, 2010, Anecic earthworms and associated ecosystem services in a ley-arable crop

rotation, 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010, Brisbane, Australia. Published on DVD."

Nitrogénművek Zrt, http://www.nitrogen.hu/ Date accessed: 05/04/2010

Norman Borlaug, The Nobel Peace Prize 1970, nobelprize.org/nobel_prizes/peace/laureates/1970/borlaug-bio.html

Norwood, C.A., 1994. Profile water distribution and grain yield as affected by cropping system and tillage. Agron. J. 86, 558–563.

Nykaenen, 2009, Legumes, presentation, Conference COST, november 2009.

Obst, A., Diercks, R., 1971, Crop Rotation and Soil Pathogens, Trends in Germany, EPPO Bulletin, Volume 1, Issue 3 , Pages 77 – 83, 1971 Blackwell Scientific Publications.

OECD, 2001, Valuation of Biodiversity Benefits: Selected Studies

Ogle S, Breidt, F, and Paustian, K, 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry 72, 87-121.

Olesen J.E and Porter J.R, 2007. Mitigation and adaptation. Policy Incentives for Climate Change Mitigation Agricultural Techniques (PICCMAT). Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006).

Olesen J.E. and Bindi M., 2002. Consequences of climate change for European agricultural productivity, land use and policy. Eur. J. Agron. 16, 239–262.

Olesen J.E., Rubæk G.H., Heidmann T., Hansen S. and Borgensen C.D., 2004. Effect of climate change on greenhouse gas emissions from arable crop rotations. Nutr. Cycl. Agroecosys. 70, 147–160,

Ollier, C., Utz, H., 2008, Eurostat, Statistics in Focus, Agriculture and Fisheries, 59

Opdam, P., van Apeldoorn, R., Schotman, A., Kalkhoven, J., 1993. Population responses to landscape fragmentation. In: Vos, C.C., Opdam, P. (Eds.), Landscape Ecology of a Stressed Environment. Chapman and Hall, London, pp. 147-171.

Oréade-Brèche, 2002, Evaluation de l'impact des mesures communautaires concernant le gel des terres, Rapport final Janvier 2002, (for DG-Agriculture) http://ec.europa.eu/agriculture/eval/reports/gel/index_fr.htm

Orlovius, K. , 2003, Fertilizing for High Yield and Quality - Oilseed Rape, International Potash Institute, Bulletin No. 16

PAN Germany, 2009, Website, Principles, Crops, Pest, Crop rotations, http://www.oisat.org/control_methods/cultural__practices/crop_rotation.html

Pearce, J., 1981, The common agricultural policy, prospects for change, Routledge

PECBMS , 2009, The State of Europe's Common Birds 2008. CSO/RSPB, Prague, Czech Republic, available at http://www.ebcc.info/wpimages/video/SECB2008.pdf [last accessed 7 December 2009]

Persson, T., Bergkvist, G., and Katterer, T., 2008. Long-term effects of crop rotations with and without perennial leys on soil carbon stocks and grain yields of winter wheat. Nutr. Cycl. Agroecosys. 81, 193–202.

Piorr, H.-P., 2003. Environmental policy, agri-environmental indicators and landscape indicators. Agriculture, Ecosystems and Environment 98, 17–33.

Poirier, V., Angers, D. A., Rochette, P., Chantigny, M. H., Ziadi, N., Tremblay, G., & Fortin, J., 2009. Interactive Effects of Tillage and Mineral Fertilization on Soil Carbon Profiles. Soil Sci Soc Am J 73, 255-261.

Porter J.R. and Semenov M.A. 2005. Crop responses to climatic variation. Phil. Trans. Roy. Soc.London B 360, 2021-2035.

Povellato,A., Scorzelli,D., 2006, A Research Paper of the Cross Compliance Network The Farm Advisory System: A Challenge for the Implementation of Cross Compliance, INEA (Istituto Nazionale di Economia Agraria)

Prazan, J. and Petersen, J.E.,2006, Review of existing farm advisory tools and farm level indicators-CIFAS study report, European Environment Agency

printable-maps, 2009, printable-maps.blogspot.com/2008/09/map-of-climate-zones-in-europe.html.

Quinet, 2008, Rapport de la mission "La valeur tutélaire du carbone", conseil d'Analyse Stratégique

Rahman,M.H., Yamao, M. , 2007, Community Based Organic Farming and Social Capital in Different Network Structures: Studies in Two Farming Communities in Bangladesh, American Journal of Agricultural and Biological Science 2(2): 62-68,

Reddersen, J. , 1997,. The Arthropod Fauna of Organic versus Conventional Cereal Fields in Denmark. Entomological Research in Organic Agriculture 15, 61-71.

Redman, Mark, 2010, High Nature Value Farming: Examples and Ways Forward, Land use and Biodiversity Session, Green Week, 3rd of June 2010.

Reeves, D. W., 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil and Tillage Research 43, 131-167.

Renwick, A.W., Revoredo Giha, C.L., 2005. Crop Substitution on UK Sugar Beet Farms and its Effects on the Environment: A Multi-Product Cost Function Approach. Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Providence, Rhode Island, July 24-27, 2005

Rickson, R.,2003, Globalization, Environmental Sustainability and Local Peace, Griffith University Public Lecture Series

Rickson, R.E. and D. Burch. 1996. “Contract farming in organizational agriculture: its effects upon farmers and the environment." Pp. 173-203 in Globalization and Agri-Food Restructuring: Perspectives from the Australasia Region London: Avebury Press edited by D. Burch, R.E. Rickson and G. Lawrence.

Rickson, Sarah T., R.E. Rickson, and D. Burch. 2006. ‘Responses of Farm Women to Globalizing Agriculture.’ Pp. 119-136 in Bock, Bettina and Sally Shortall (eds) Rural Gender Relations: Issues and Case Studies, London: CABI Publishers

Ricome, A., Képhaliacos, C., Carpy-Goulard, F., 2008, L’analyse de la gestion des incertitudes dans les relations contractuelles entre exploitations agricoles et coopératives : le cas de deux grandes coopératives du sud-ouest de la France, 2èmes journées de recherches en sciences sociales, INRA SFER CIRAD, Lille

Robertson, G.P., Paul, E.A., and Harwood, R.R., 2000. Greenhouse gases in intensive agriculture: contributions of individual gases to the radiative forcing of the atmosphere. Science 289, 1922–1925.

Robinson, C.A., Ghaffarzadeh, M., and Cruse, R.M., 1996. Vegetative filter strip effects on sediment concentration in cropland runoff. J. Soil Water Cons.50, 227-230.

Roth, G. W., 1996, Crop Rotations and Conservation Tillage, Conservation tillage series Number One, Pennstate, College of Agricultural Sciences, Cooperative Extension.

Rovillé, M. and Aufray, R. (date unknown) Modes de gestion agricole et influences sur la biodiversité du sol, CNRS website, available at http://www.cnrs.fr/cw/dossiers/dosbiodiv/index.php?pid=decouv_chapC_p5_d1&zoom_id=zoom_d1_2

Rovillé, M., and Aufray, R., 2010, Modes de gestion agricole et influences sur la biodiversité du sol, CNRS website, Available at:http://www.cnrs.fr/cw/dossiers/dosbiodiv/index.php?pid=decouv_chapC_p5_d&zoom_id=zoom_d1_2. Date accessed: 07/07/2010

Sachs, E. G. ,1972, The farmer an entrepreneur personality?, Paper presented at the Seminar 16 on "Information and Communication Problems in Development" at the Third World Congress for Rural Sociology, August 22–27, 1972, Baton Rouge, Louisiana, USA

Saffih-Hdadi, K., & Mary, B., 2008. Modeling consequences of straw residues export on soil organic carbon. Soil Biology and Biochemistry 40, 594-607.

Schmid O., Dabbert S., Eichert C., Gonzálvez V., Lampkin N., Michelsen J.,Slabe A., Stokkers R., Stolze M., Stopes C., Wollmuthová P., Vairo D. and Zanoli R. (2008), Organic Action Plans: Development, implementation and evaluation. A resource manual for the organic food and farming sector. Edited by Schmid O., Stopes C., Lampkin N. and Gonzálvez V. Research Institute of Organic Agriculture FiBL, CH-5070 Frick, Switzerland and IFOAM-EU Group, BE-1000 Brussels, Belgium

Schmidt et von Fragstein, 1999 in David C., Viaux, P., Meynard, J.-M., 2004, Les enjeux de la production de blé tendre biologique en France, Le Courrier de l’environnement de l’INRA n°51, février 2004.

"Schoney, R. and T. Thorson. “The Economic Impact of Extended Crop Rotations on Saskatchewan

Grain Farms.” Canadian Farm Economics 20(2)(1986):21-26."

Schroter D., Cramer W., Leemans R., Prentice C., Araujo M.B., Arnell N.W. and Bondau A., 2005. Ecosystem service supply and vulnerability to global change in Europe. Science 310, 1333–1337.

Seibutis and Deveikyte , 2006, The influence of short crop rotations on weed community composition, Agronomy Research, 4 (Special issue), pp. 353-357

Sheil, R., 1994, Rotational Farming—A system misrepresented?, Pesticides News, No. 25, September 1994, pages 10-11

Singer, M. J., & Munns, D. N., 1996. Soils. An introduction. Prentice Hall, Upper Saddle River, NJ.

Smeding, F.W. and Joenje, W. , 1999, Farm-Nature Plan: landscape ecology based farm planning, Landscape and Urban Planning 46 pp. 109-115

Smeding, F.W.and Joenje, W., 2009, Farm-Nature Plan: landscape ecology based farm planning, Landscape and Urban Planning 46, 109-115.

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. Agric. Ecosyst. Environ. 133, 247–266

Sombrero, A., de Benito, A., 2010, Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain, Soil and Tillage Research, Volume 107, Issue 2, April 2010, Pages 64-70.

Soulié, L., Roger-Estrade, J., Viaux, P., 2006, Le dispositif de La Motte: rotation et fertilité du milieu en agriculture biologique sasn élevage, étude de la dynamique de l'azote en conditions limitantes, proposition et test d'adaptation de la rotation, Mémoire pour l'obtention du DIPLÔME D'INGENIEUR AGRONOME de l'institut national agornomique Paris-Grignon, Soutenu le : 6 décembre 2006.

Spector, C., 2001, About Soil pH, Available at: soil.gsfc.nasa.gov/soil_pH/plant_pH.htm. Date accessed: 17/12/2009

Stanger, 2008, Long-Term Cropping Systems: The Profitability and Risk of Cropping Systems Featuring Different Rotations and Nitrogen Rates " Agronomy Journal 100

Stephen D. Murphy, David R. Clements, Svenja Belaoussoff, Peter G. Kevan, and Clarence J. Swanton, 2006, Promotion of weed species diversity and reduction of weed seedbanks with conservation tillage and crop rotation, WEED BIOLOGY AND ECOLOGY, Weed Science 54(1):69-77. 2006 .

STEVENSON F. C., VAN KESS., 1996, A landscape-scale assessment of the nitrogen and non-nitrogen rotation benefits of pea, Soil Science Society of America journal, Soil and sustainable forest productivity. Symposium, Seattle, WA , ETATS-UNIS (15/11/1994), Soil Science Society of America, Madison, WI, ETATS-UNIS (1976) (Revue), vol. 60, no 6, pp. 1613-1678 (46 ref.), pp. 1797-1805.

Stewart, B.A. & Koohafkan A.P. 2004. Dryland agriculture, Long neglected but of worldwide importance. In Challenges and Strategies for Dryland Agriculture. CSSA Special Publication no. 32, pp. 49-60. Madison, USA, American Society of Agronomy, Crop Science Society of America and Soil Science Society of America.

Stone LR, Schlegel AJ, Gwin RE, Khan AH., 1996. Response of corn, grain sorghum, and sunflower to irrigation in the High Plains of Kansas. Agric. Water Manag. 30, 251-259.

Sylvie Recous, Xavier Leroux, Eleonore Attard, Gilles Lemaire, François Laurent,Abad Chabbi, Bernard Nicolardot and Frank Poly, 2010, Impact of land use changes on soil carbon pools, gross nitrogen fluxes and nitrifying and denitrifying communities, 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Teyssier, F., 2006. Consommations d'eau pour l'irrigation sur 2001-2005 en Midi-Pyrénées. Agreste Midi-Pyrénées, Données n° 35.

Thenail, C., 2002. Relationships between farm characteristics and the variation of the density of hedgerows at the level of a micro-region of bocage landscape. Study case in Brittany, France. Agricultural System 71, 207–230.

Thenail, C., Joannon, A., Capitaine, M., Souchere, V., Mignolet, C., Schermann, N., Di Pietro, F., Pons, Y., Gaucherel, C., Viaud, V., Baudry, J., 2009, The contribution of crop-rotation organization in farms to crop-mosaic patterning at local landscape scales, Agriculture Ecosystems and Environment, 131, pp 207-219.

Theobald, 2004, Bayesian selection of fertilizer level when crop price depends on quality. Computational Statistics and Data Analysis 47, 867-880.

Thomas, R.J., 2008. Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. Agric. Ecosyst. Environ. 126, 36-45.

Thomsen, IK, and Christensen, B.T., 2004. Yields of wheat and soil carbon and nitrogen contents following long term incorporation of barley straw and ryegrass catch crops. Soil Use Manage. 20, 432-438.

Tietenberg, 1992, Environmental and Natural Resource Economics. Harper Collins, New York

"Torstensson, G, & Aronsson, H, 2000, Nitrogen leaching and crop availability in manured catch crop systems in Sweden, Nutrient Cycling in Agroecosystems 56: 139–152."

Tóth T., Németh T., Fábián T., Hermann T., Horváth E., Patocskai Z., Speiser F., Vinogrado Sz., Tóth G., 2006, Internet-based Land Valuation System Powered by a GIS of 1:10,000 Soil Maps 18th World Congress of Soil Science Abstracts (CD).

Turner, 2003, Modelling Community Response and Perception to Natural Hazards: Lessons Learnt from Hurricane Lenny 1999

U.S. Department of Agriculture, Natural Resources Conservation Service, Soil Survey Division, World Soil Resources, 2001, Washington, D.C.

Ulber L., Steinmann H.H., Klimek S. & Isselstein J. (2009) An on-farm approach to investigate the impact of diversified crop rotations on weed species richness and composition in winter wheat. Weed Research, 49, 534-543

UNCCD, 2009, Drought and forest fires increase vulnerability to desertification in Europe, available at http://www.unccd.int/media/pressrel/showpressrel.php?pr=press21_08_03a.

UNEP, UNEP/DEWA/GRID-Europe, 2009, website: Fresh water in europe, Fresh water consumption, Water: a public good?, http://www.grid.unep.ch/product/publication/freshwater_europe/consumption.php.

UNIFA website, http://www.unifa.fr/01_actu/fichiers/chap04.pdf+site:http://www.unifa.fr+rotation&hl=en&gl=fr&pid=bl&srcid=ADGEEShrx_E6jVU4_oIPfeXuAiTkU

UNITAB (2007): 2004-2007 The reform of the tobacco CMO, http://www.wmaker.net/unitab/docs/GB.pdf

Van Rompaey, A. J. J., Govers, G., Van Hecke,E., Jacobs, K., 2001, The impacts of land use policy on the soil erosion risk: a case study in central Belgium, Agriculture, Ecosystems & Environment, Volume 83, Issues 1-2, January 2001, Pages 83-94

Vepsalainen V. , 2007, Farmland Birds and Habitat Heterogeneity in Intensively Cultivated Boreal Agricultural Landscapes, Academic dissertation, 45 p.

Vereijken, P., Kloen, H., Visser, R., 1994. Innovatieproject Ecologische Akkerbouw en Groenteteelt, eerste voortgangsrapport. Rapport 28, AB-DLO, Wageningen. 95 pp.

Vergot,P., Israel,G., Mayo, D.E., 2005, Sources and Channels of Information Used by Beef Cattle Producers in 12 Counties of the orthwest Florida Extension District, Journal of extension, 43:2, Available at: http://www.joe.org/joe/2005april/rb6.php Date accessed: 14/12/2009

Victorian Government, 2008, Land and biodiversity at a time of climate change, Our Environment Our Future, Department of Sustainability and Environment Melbourne, April 2008.

Vilain, L. 2009. Personal communication

Virtual Academy for the Semi-Arid Tropics (VASAT), 2007, Crop Rotation Practices, Available at: http://www.icrisat.org/VASAT/learning_resources/crops/pm/pm_prod_practices/html/m8_8/resources/2143.html Date accessed: 11/08/2010

Warnken, P.F.,1999,The development and growth of the soybean industry in Brazil, Wiley-Blackwell

Weibull, A.C., Östman, Ö., Granqvist, Å. , 2003, Species richness in agroecosystems: the effect of landscape, habitat and farm management, Biodiversity and Conservation 12, pp. 1335–1355

West T.O. and Post W. M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Sci. Soc. Am. J. 66, 1930–1946.

Willis, 2003, Ordering effects in nested 'top-down' and 'bottom-up' contingent valuation designs, Ecological Economics, 45(2), 255-270

"Wilson, 2005, Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems. Published by the Canadian Boreal Initiative and The Pembina Institute. 78 pp."

Witek, T., 1993, Valorisation of the agricultural production space. IUNG Puławy

WWF, 2004, Sugar and the environment, Encouraging Better Management Practices in sugar production, global freshwater programme, Available at: assets.panda.org/downloads/sugarandtheenvironment_fidq.pdf Date accessed: 03/04/2010

Yang, X.M., and Kay, B.D., 2001. Rotation and tillage effects on soil organic carbon sequestration in a typic Hapludalf in Southern Ontario. Soil Tillage Res. 59, 107–114.

Young and Westcot, 1996, The 1996 U.S. Farm Act Increases Market Orientation," AIB-726. USDA, ERS,