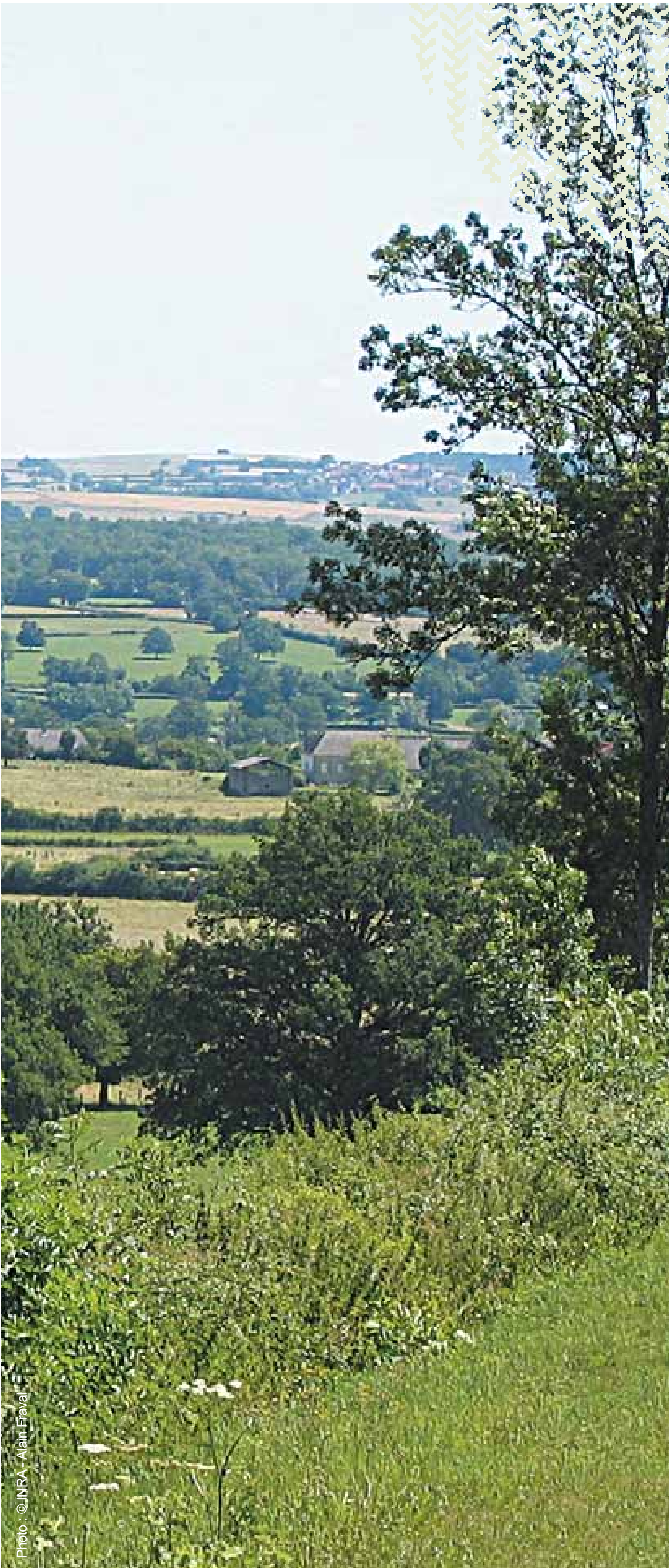

Agriculture and biodiversity

Benefiting from synergies

July 2008

Multidisciplinary Scientific Assessment

Synthesis of the assessment report written by INRA in response to a request from the Ministry of Agriculture and Fisheries and the Ministry of Ecology, Energy, Sustainable Development and Regional Development

FOOD & NUTRITION
AGRICULTURE
ENVIRONMENT

INRA

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The final report of the multidisciplinary scientific assessment, on which this synthesis document is based, was written by the group of scientific experts independently of their employers and / or funding bodies, or INRA. Responsibility for the contents of the report rests solely with the authors.
The list of scientific experts contributing to this assessment is listed at the end of the document.

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Ministère de l'Écologie, de l'Énergie, du Développement durable et de l'Aménagement du territoire

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MINISTÈRE DE L'AGRICULTURE ET DE LA PÊCHE

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Foreword

Context and scope of the ESCo

This Multidisciplinary Scientific Assessment, "Expertise Scientifique Collective (ESCo)" in French, carried out in response to a demand from the ministries of agriculture and ecology, takes place in a context of strong interest in biodiversity, and its consideration as an issue of major importance. This interest is due to the appreciation of current rates of biodiversity loss (linked to, amongst other factors, agricultural activity), of increasing understanding of the multiple roles of biodiversity (potential genetic resources, ecosystem services with a market value or not, capacity for the biotic regulation of agro-ecosystems…) and of the need to develop new agricultural production modes to respond to future challenges (reductions in pesticide use, adaptation of agricultural systems to climate change, reductions in fossil fuel use…). Biodiversity largely determines the capacity of agro-ecosystems to adapt to such challenges.

The issue of biodiversity in agriculture

More so than in any other sector of human activity, agriculture is indivisibly linked with biodiversity. It can benefit from biodiversity, modify biodiversity and can contribute to its maintenance. For agriculture, biodiversity is thus an object of vital and increasing importance at all levels of agricultural policy. Agricultural activity generally implies the management and control of ecosystems in the areas that it exploits. Questions of relationships between agriculture and biodiversity are thus often posed in terms of compromises or co-existence. However, agriculture can also have beneficial effects on biodiversity, at different scales and levels of organisation. In addition, the benefits of agriculture for the maintenance of biodiversity can be numerous, for agricultural production is due to, in its largest sense, "ecosystem services" provided within agricultural areas.

The current political situation and the need for the assessment

When the request was made for the ESCo, at the beginning of 2007, a number of political actions were being announced: at the European level, a renegotiation of the common agricultural policy based on the conditions for governmental aid for agriculture, and discussions as to the definition of objectives to halt biodiversity loss in the context of the international convention of biological diversity. In France, numerous initiatives were also underway with the establishment of a national strategy for biodiversity, and in particular the initial development of a sector strategy for agriculture, the mid-term revision of the French national rural development plan (PDRH) and re-negotiation of national agro-environmental measures after their establishment in 2007, as well as preparations for the 9th conference of parties (COP 9), in May 2008, which undertook a detailed examination of agriculture.

Since then, political interest in these questions has only grown, with consideration of the question of biodiversity in the context of the Grenelle summit for the environment, which resulted in the creation of a foundation for biodiversity research, and resulted in the establishment of various on-ground projects, such as the development of a network of "green veins", a national strategy for protected areas, and conservation plans for 131 endangered species, including pollinators. In addition, during the French presidency of the European Union, an international scientific meeting for policy makers on the topic of "Agriculture and biodiversity" was organised.

The questions addressed by the ESCo

In this context, and in response to these issues, the ministries in charge of agriculture and ecology requested INRA to carry out a review of the current state of multidisciplinary knowledge of relationships between agriculture and biodiversity, with an aim of providing all stakeholders with all of the necessary elements required to adequately inform policy measures and decisions.

The questions, formulated by the ministries in a letter outlining the terms of reference addressed to INRA, concerned the effects of agriculture on biodiversity, the roles and possible benefits of biodiversity for agriculture, the possible technical opportunities for the better integration of biodiversity into agriculture, and finally the economic, technical and social feasibility of this integration.

The scope of the ESCo

The multidisciplinary scientific assessment is focused on biodiversity overall, only considering the biodiversity of domesticated species as one of the components of production systems likely to impact on total biodiversity. Geographically, the ESCo is only concerned with continental France. Aquatic environments and forests are also not within the terms of reference of the ESCo.

The multidisciplinary scientific assessment (ESCo)

The ESCo is a support mechanism for government decision making. The exercise consists of responding to a complex question posed by a government body by establishing, on the basis of an extensive worldwide bibliographic review, the current state of multidisciplinary scientific knowledge surrounding the question including the known facts, uncertainties, gaps in knowledge and controversies. The ESCo does not carry out any research of its own to respond to the questions asked. Neither does it provide advice or recommendations, nor does it include a consideration of future trends or scenarios.

The assessment was carried out by a group of scientists, with specialists from different disciplines and working for a diverse range of research organisations. The assessment resulted in the production of a report summarising the contributions of each of the experts and of a synthesis destined for use by policy makers and managers.

Method and scope of the ESCo

Encompassing the necessary expertise to respond to the questions asked required that the assessment consist of experts from the areas of ecology and agronomy at all of the various relevant scales (field, farm, production system, landscape), economics, sociology and legal studies. This association of disciplines allowed integration across increasing levels of complexity, from biological organisms to the landscape, and ultimately to the structures of decision making.

The ESCo involved some twenty experts form various research organisations in France (INRA, CNRS, IRD, Agronomy teaching institutes) and overseas (Agroscope and Institute of environmental sciences from Zurich, Louvain-la-Neuve University).

The work of these experts was based on the analysis of some 2000 bibliographic references, comprising of scientific articles, international reports and technical documents, from which the experts extracted, analysed and summarised useful elements to respond to the questions.

The assessment is structured in five parts. It begins with a preliminary section outlining the definitions, concepts and issues for the theme "agriculture and biodiversity". The first chapter explores the modes of action of agriculture on biodiversity, via agricultural practices at the field level, and also at the landscape scale (chapter 1). Subsequently the assessment describes the services provided by biodiversity that can contribute to increasing the productivity and stability of agro-ecosystems, with a particular emphasis on factors external to agricultural fields and which constitute the landscape matrix (chapter 2). Next, the integration of the elements and services of biodiversity into agriculture is examined in the context of production systems and their constraints Chapter 4 analyses the legal foundations and legal instruments used by government for biodiversity management; in particular an examination is made of the results of agri-environmental measures (MAE) and possible models for their organisation and management. Finally, chapter 4 also analyses the conditions required for the successful implementation of policy measures.

Biodiversity and agriculture

This introduction aims to provide the contextual elements required to understand the origin of the question addressed by the scientific experts in this assessment, namely, the required conditions for a greater integration of biodiversity into agriculture. This question requires a meeting of two terms, biodiversity and agriculture. Though it may appear trivial, this link is complex due to its dual historical background: that of the concept of biodiversity and that of agricultural changes since the second half of the XXth century. A recent idea, biodiversity is a complex notion that is the end result of the combined influences of scientific knowledge, social concerns and politics. In the same manner, agriculture is a sector that has been profoundly modernised over the last 50 years, in particular through the replacement of ecosystem services provided by biodiversity by industrial inputs. Responding to the questions in this assessment by developing a summary of the current state of knowledge of relationships between agriculture and biodiversity and of the potential benefits to be gained by wider society from a better integration of the two is a new subject. Such a study is situated at the crossroads of ecology, agronomy, economics, law, sociology and political science.

1. Biodiversity: concepts and challenges

1.1. The emergence of the concept of biodiversity

Even though acknowledged since antiquity, studies of the diversity of living organisms have experienced a series of major successive developments since the XVIIIth century, marked in particular by the classifications of Linnaeus, the development of the theory of evolution followed by that of genetics, and during the 1950's the emergence of ecology as a discipline in its own right. More modern developments of this scientific story are the emergence of the concept of "biodiversity", during the 1980's, and later that of functional diversity and ecosystem services.

The term "biodiversity" was popularised by the Earth Summit in Rio in 1992, where the Convention for Biological Diversity was also signed (CBD). It encompasses three levels of the organisation of living organisms: ecological diversity (or the diversity of ecosystems), species richness (the diversity of species, or inter-species diversity), and genetic diversity (diversity within species). While considered by some as synonymous with biological diversity, the term biodiversity is distinguished by two epistemological differences. The first, within the field of natural sciences, corresponds to the interdependences between the three major components of the diversity of life, classically studied by specialists who in general ignore each other – ecologists, taxonomists and geneticists. The second difference, a more significant one, is situated in a much larger context: biodiversity does not belong only to biologists but places the diversity of living organisms within the wider challenges, preoccupations and conflicts of interest expressed at the Rio conference.

Changes in the concept of biodiversity from that of the concept of the conservation value of biodiversity to a utilitarian conception of biodiversity as a provider of ecosystem services have marked the last decade. This change has been accompanied by a transformation in the dominant values at the base of motivations to protect biodiversity: the emphasis has shifted from simple existence values to the value of the direct and indirect ecosystem services provided by biodiversity.

To the already complex scientific concept of biodiversity must be added the fact that the term has been used and modified in international debates from four distinct types of perspectives, which are not necessarily coherent amongst themselves. The institute of sustainable development and international relations (IDDRI) characterises these four viewpoints in the following manner:
- an environmentalist perspective with conservation as a primary objective;
- an agronomic perspective that aims to limit losses of genetic diversity with an ultimate goal of plant improvement;
- a commercial perspective that is expressed by the adoption of the principle of the patenting of intellectual property rights (patenting plants, animals or DNA parts) during the negotiations of the *Uruguay Round*;
- a cultural or indigenous perspective that has been integrated into the debate since the end of the 1980's.

Biodiversity has thus become a framework within which many of the questions posed by the relationships between mankind and other species and the natural environment have been framed and reformulated. "Biodiversity management" has largely replaced "nature protection". This multiplicity of conceptions and objectives (from its conservation value to its functional value) leads to great difficulties in the development of a legal framework for biodiversity conservation.

1.2. Biodiversity in the legal context

The convention on biological diversity (CBD) is the first international agreement defining biological diversity and recognising it as a value that states should protect. Biological diversity is defined as the "variability of living organisms of all origins, including terrestrial ecosystems, marine and other aquatic ecosystems and the ecological complexes of which they are components. This includes the diversity within species, between species and at the ecosystem level". Consequently, biodiversity is presented as an integrative concept allowing, in principle, reference to the entirety of life and its necessary relationships with abiotic elements. However, it is precisely because the objective of biodiversity protection leads to the re-thinking of the relationship mankind has with the natural environment that this definition is extremely difficult and ambitious to implement. With a lack of agreement on the nature of these new relationships, the legal framework in which such protection is supposed to occur remains fundamentally the same. Constructed on the basis of historical visions of nature, this framework is still profoundly marked by an essential division between things and humans, with only humans having rights. Numerous proposals, resulting from legal research, have attempted to build a definition of a legal entity for natural resources, which could take into account the interdependence and complexity of relationships between humans and the environment. However, these proposals, which would often lead to profound changes in current legal models, are in general politically and economically difficult to accept. The concept of a "communal human heritage" is such an example. This concept was not retained in the CBD.

Currently, the protection of biodiversity must thus remain within classical legal structures, which the CBD did not manage to reassess or change. The authors of the CBD commented that biodiversity remains an abstract concept that the law, and more generally government policy, has difficulty taking into account. Legal studies have drawn two primary conclusions. Firstly, in the case of a conflict of interest between biodiversity protection and other values recognised by law, such as land ownership, intellectual property or the principles of a free market, the current legal framework is in general more favourable to the latter. Secondly, the protection of biodiversity is contained within the category of measures for the protection of human health and the environment, and concrete protection measures most often concern only "elements" of biodiversity, such as given ecosystems, natural areas, wild animals or given genetic resources. As a consequence, measures for the protection of biodiversity are still to a large extent targeted, meaning that they target specific species or areas, whereas measures for the prevention of damages apply widely in the areas of human health or the physical environment, but not in the case of biodiversity (example: the procedures for the evaluation of plant based pharmaceuticals or fertilisers).

1.3. Biodiversity in the political context

The political foundations for the protection of biodiversity stem initially from the greater realisation of the threats to biodiversity, and of the interests for humanity to preserve it. It is thus based on a perspective of the conservation of natural resources and the environment. The fact that current species disappearances are occurring at a rate greater than that over previous geological time spans resulted in scientist's initially focussing on the numbers of species present in ecosystems, this corresponding to the quantitative dimension of biodiversity, which was implemented in the political sphere as measures for species preservation.

Today, a consensus among scientists seems to have formed around the assumption that the impact of species on ecosystem function depends more on the function that these species carry out in the ecosystem, than on the number of species itself. This convergence has resulted in the notion of "services" provided by biodiversity as defined by the *Millennium Ecosystem Assessment* (ONU, 2005): provisioning services such as food, fresh water…, regulating services such as climate regulation, water purification and water quality, cultural services such as recreation opportunities…

Policies of environmental protection are based on a double approach. Initially, the intrinsic value of some natural ecosystems / species, and then in 1992, of biodiversity was recognised. This implies that, in principle, they be protected independent of the utility that may exist for mankind, and that this intrinsic type of value coexists with any functional values, such as those provided by some ecosystems such as wetlands. However, the concept of services induced an important change, as it provides a new conceptual framework better able to reconcile these two approaches. In fact, the concept of services corresponds not only to those services that have utility to mankind, but also those useful to various elements of the environment and to biodiversity itself. Stated in another fashion, the functional approach as encompassed by the concept of services can provide a new basis for policies of environmental protection, through the recognition of the functional value of biodiversity, while at the same time not reducing this simply to human requirements. In addition, the concept of services facilitates the evaluation of biodiversity, in particular in the framework of the costs of biodiversity losses. However, the risk remains of adopting an overly restrictive vision of the services provided by ecosystems, by excluding, for example, protection measures for "cultural and spiritual" services, or through restricting protection only for those services for which replacement techniques do not exist.

Why protect biodiversity
(after Lévêque, 1997)

Economic motives

- It contributes to the provision of numerous food products, pharmaceuticals and materials for industry, construction and domestic uses.
- It is at the base of all agricultural production, both from the point of view of the number of species used and the number of varieties selected through human intervention. It is indispensable for the continued improvement of domesticated plants and animals.
- It provides important opportunities in the area of biotechnology, especially for micro-organisms, but equally in the area of genetic manipulation.
- It stimulates economic activity linked to tourism and the observation of species in their environment, or the attraction of a beautiful landscape.
- It plays a role in the regulation of major biological, physical and chemical cycles and equilibriums in the biosphere, in particular the production and recycling of carbon and oxygen.
- It contributes to soil fertility and soil protection, as well as to the regulation of the hydrological cycle.
- It absorbs and decomposes various organic pollutants and minerals. It participates, for example, in water purification.

Ethical and conservation motives

- It is indispensable for the maintenance of the process of evolution of the living world.
- Humans have a moral obligation to not eliminate other forms of life.
- According to the principle of equity between generations, we have an obligation to pass on to our children the living heritage that we have received.
- Natural ecosystems and the species that they contain are important laboratories for understanding the process of evolution.
- Biodiversity is subject to value judgements: it is what is natural, what is vulnerable, what is good for mankind and the survival of mankind, *etc.*

2. Agricultural modernisation over the XX^th^ century

The word agriculture refers to the range of activities that utilise or transform the natural environment for the production of plants and animals useful for mankind. It is thus a human activity applied to biological objects, with the goal being the provision of goods and services to mankind, these in general being food and fibre.

Agriculture defines itself as an economic activity with the goal of the satisfaction of human needs – these needs being considered essential not only due to their magnitude, but also their permanence. To satisfy these needs, agricultural activity uses techniques that modify factors of the complex natural and living environment, in a context of environmental variation, which requires constant adjustment and adaptation to environmental and climatic conditions.

Since the industrial revolution in the XIXth century, agriculture has had greater difficulty than other sectors in integrating into the market economy, with its efficiency and productivity remaining low. Until the middle of the XXth century, it was considered as a sector slow to develop and with low quality of life for the people involved. Many people wanted to leave the agricultural sector. Agriculture also seemed largely closed to scientific progress and to innovation, with the transfer of empirically based knowledge and techniques occurring within the family or community context. It is important to take into account this context to fully appreciate the degree of change that began at the beginning of the XXth century and reached its greatest development during the 1960's.

2.1. A social demand, a model of industrial development, and technical performance

The "modernisation" of agriculture was driven by a political choice, this being the desire to develop the productive capacities of France, such that it could emerge from the food shortages and dependences of the post war period. The result was achieved during the 1970's when France occupied the 2nd place in terms of world agriculture. This development was the result of a social movement as much as a technical one. Through changes in agricultural practices and economic modes of organisation, it allowed farmers to become integrated into the industrial world and gave them a degree of economic "parity". These changes profoundly modified the vision within the agricultural sector of its place in the world and society.

Such modernised agriculture is based on the availability and accessibility of inputs: water, fertilisers, phytosanitary products, machinery. Depending on the region, the production systems and the farms, modernisation has taken diverse paths combining in different ways production factors depending on the initial local situation. Such changes have resulted, however, in the generalised use of mineral fertilisers and pesticides, specialisation on a reduced number of crops at the farm level and the simplification of rotational systems.

The conjunction of mechanisation, the generalised use of chemical inputs and the retirement of large numbers of elderly farmers from small farms has allowed major increases in production and in the efficiency / productivity of agricultural labour.

An analysis of this "silent revolution", as defined by the stakeholders in this movement themselves, underlines the enormous social, institutional and political dimensions of the changes in the methods of agricultural production.

2.2. Impacts on agricultural practices, the environment and on landscapes

The "modernisation of agriculture" is central to a major change in the traditional relationship between cities and the country. The predominantly rural France of the pre-war period gave way to an urban France, with the cities becoming the motors of development. The proportion of the surface of the country dedicated to agriculture decreased with increasing urban areas and their infrastructure. This reversal of dominance resulted in major transformations in land uses, cropping and animal husbandry practices and thus effects on the natural world. These transformations corresponded to changes in production systems, and globally, a disassociation of cropping and animal husbandry and increases in farm specialisation

The search for ever more controlled conditions of production justified the development of large regional rural development projects such as irrigation, the drainage of wetlands (from 1970 to 2000, the surface areas irrigated and areas drained more than tripled), and reforestation (the area of forest has increased by more than 35% during the second half of the XXth century). Since 1945, 15 million hectares have been subject to land tenure reform. In one century, the linear length of hedgerows has been divided by three. Since the end of the Second World War, the productivity of temporary and sown grasslands, as well as that of cereal crops, has doubled.

Increases in the national cattle herd to 8 million heads has been made possible by a major increase in pasture productivity and by the increased use of cereals, sown grasslands, silage, and of increased imports of soya and other protein sources, while at the same time some 5 million hectares of grassland has disappeared. However, the general trends in the surface area of grasslands mask a great deal of variation between different regions. In mountainous areas, the maintenance of practices such as the use of summer grazing ranges, which historically have been linked with cheese production, has been reoriented to more extensive grazing systems with an emphasis on meat production.

Major modifications in rotational systems resulted, at the field scale, in shorter rotation times and increases in monoculture systems, primarily for corn, wheat and other grains.

In summary, agricultural modernisation over the second half of the XXth century has led to the establishment of an agriculture that is productive, integrated into the wider food industry and heavily dependent on government aid. If assessments of agricultural policies and of agricultural performance are today beginning to take into account its long ignored environmental costs, there still do not exist statistics or indicators of the environmental performance of agriculture or farms that would allow a complete economic audit of the process of agricultural modernisation.

3. Agriculture and biodiversity: benefiting from synergies

Research into the possible synergies between agriculture and biodiversity has experienced considerable recent interest, linked to the current global context and the emergence after the Rio conference during the 1990's, of new approaches to this relationship.

3.1. New challenges, new standards

Beyond the usual challenges, these being mostly the challenge of sufficient food production, agriculture has been recently confronted, as many other sectors, with questions of energy availability, environmental protection and also of the social, ethical and cultural concerns of citizens.

The food and energy challenge

The current context of tensions in world agricultural markets and food riots in some parts of the world are a symptom of current structural trends: increasing demand, stagnation in production due to the plateauing of technical performances, decreasing resource availability, and the low investment in agricultural development in developing countries. The challenge is therefore very important. It refocuses the debate squarely on the current models of food production and consumption (in particular the increasing global demand for animal products).

Modern agriculture consumes a large quantity of fossil fuels, both for the production of its main inputs, such as nitrogen fertilisers, and the mechanical work that it requires. The decreasing reserves and increasing prices of these energies logically suggest, from a simple economic point of view, the development and use of substitute inputs based less on non-renewable resources. Such replacement inputs may be available from agriculture itself, which by nature consists of transforming solar energy into biomass *via* photosynthesis. These questions should be addressed in terms of an audit of the energy passing through the food industry in its entirety.

The environmental challenge

Today, a major environmental issue for the equilibrium of the planet is the reduction of greenhouse gas emissions. In this context, the role of agriculture can be important, through the stabilisation, or even the improvement, of carbon balances and reductions in the dependence on fossil fuels. At more local scales, there are also problems linked to the introduction of pollutants into the environment. While a part of such effects is exported outside of agro-ecosystems and affects other parts of the environment, farmers are often the first affected by the consequences of such pollution, either at the level of their own health, the functioning of their farm or in their environment.

The ecological challenge and regional development

In France, the high diversity of landscapes has a high heritage, conservation and identity value. It is an economic resource that should be preserved. Coupled with a remarkable communication network, it is the base of an economic sector of major importance as well as a means of adding value to local products. Landscapes and biodiversity are also a living environment worth preserving for human populations. These landscapes and biodiversity are closely linked through habitats and ecosystems. The role of agriculture in their dynamics, while not exclusive, is highly important. This point will be further analysed in chapter 1.

Demographic and regional development challenges stem from population growth and changes in its geographical distributions as well as from the structural modifications induced by increases in life expectancy. High population concentrations in urban areas induce new demands in terms of the consumption of food and services, in particular recreational. This is reinforced by structural modifications: with life expectancy beyond the retirement age of some twenty years, demand for leisure activities, recreational areas, travel and tourist activities is increasing. Correlatively, the demand for high quality landscapes will also increase.

The societal challenge: what is the role of collective action?

The societal challenge can be described at two levels, the organisation of agricultural production and the relationships between agriculture and citizens.

Future production systems will need to integrate the dynamics of resources outside of a particular farm with on-farm activities. A hypothesis can be proposed, that collective organisation and other forms of coordination (primarily non-commercial) amongst farmers will be more prevalent in the future than in a system based solely on the use of manufactured inputs.

The multiplication of products with indications of their geographical areas of origin is without doubt a strategy that derives from farmers, but one which also responds to obvious needs for identification and product confidence from consumers.

3.2. Agriculture, biodiversity and sustainable development

The Rio earth summit (1992) marked a new phase in the consideration of agriculture and its place in relation to sustainable development and biodiversity. Two main themes emerged from these reflexions, one concerning the links between agriculture and biodiversity, which resulted in the creation of the concept of agro-biodiversity, and the other concerning the multi-functionality of agriculture. The first concept is tightly associated with the details developed in the convention on biological diversity (CBD), in the context of the conference of parties and its various working groups. The second is directly linked to the negotiations of the world trade organisation (WTO), where the challenge was to identify functions of agriculture other than purely productive ones (landscape management), which could justify the provision of public monies for agriculture.

Developed from a global initiative and a communal process, the two themes of agro-biodiversity and of the multifunctionality of agriculture were developed essentially by groups of experts and in the context of international negotiations.

Agro-biodiversity refers to the variety and variability of living organisms that contribute to food production, agriculture and associated activities in their largest sense. The fifth conference of parties to the convention on biological diversity decided on the following definition: "the term agricultural biological diversity refers to, in a general fashion, all of the elements constituting biological diversity which relate to food production and agriculture, as well as all of the components of biological diversity which constitute the agro-ecosystem : the variety and variability of animals, plants, micro-organisms, at the genetic, specific and ecosystem levels, necessary for the maintenance of the key functions of the agro-ecosystem, its structures and its processes".

In its widest interpretation, it is possible to include within agro-biodiversity cropped areas and fields as well as habitats and species outside of the farm boundaries, but which are beneficial for agriculture and which play a role in the regulation of ecosystem functions. We therefore can distinguish between the planned, or controlled, biodiversity and the associated biodiversity: planned agro-biodiversity is the crops and animal husbandry systems chosen by the farmer, while the associated biodiversity refers to organisms (soil fauna, weeds…) which colonise the agro-ecosystem.

Different approaches to agriculture – biodiversity relationships

Agro-ecology remains centred on the satisfaction of human food needs. It is defined as the application of the concepts and principles of ecology to the development and management of sustainable agro-ecosystems, and more globally a sustainable food industry. The aim is to use an understanding of the functioning of natural systems to develop productive and sustainable agricultural systems. In particular, an emphasis is placed on restoring agricultural diversity, both over time and in space, through the use of crop rotations, companion cropping or through associations between cropping and animal husbandry.

The concept of a doubly green revolution appeared after a consideration of the environmental and social limits of the green revolution of the 1970's. The basis of this concept is to repeat the success of the first green revolution in terms of increases in production, but this time in a "sustainable" manner (environmentally acceptable, economically viable and socially equitable). The main idea of a doubly green revolution would be to use natural processes to benefit food production and other societal needs, in a more intensive manner, through increasing the productivity of the entire system. It would not exclude the use of external inputs but these would need to meet two conditions. The first would consist of simultaneously intensifying all of the components of the system to better use their potential for synergy. The second would consist of using lower doses than in conventional agriculture, in balance with the functions that the inputs are designed to stimulate: for example, chemical fertiliser would only be used in addition to natural functions of soil fertility increase and in balance with the soils capability to cope with fertilisation. The adoption of these principles is expected to result in a significant increase in productivity, and this in a sustainable manner.

Approaches centred on ecosystem services and regional development

The "ecosystem" approach, in contrast to its name, is not centred mainly on ecology. This approach integrates the characteristics of ecosystems and of social interactions that play a role in management. This approach was initiated by American governmental agencies confronted with difficulties in the coordination and establishment of government policies for conservation and development. Subsequently the concept was adopted by the conference of parties of the convention on biological diversity (CBD) to help resolve potential conflicts between agriculture and biodiversity conservation. This approach can be defined as a method to restore, or increase, the sustainability of ecological systems, their functions and their benefits. It is based on a collective vision of desired future outcomes and objectives integrating ecological, economic and social factors. It is applied within a defined geographic area and the primary constraints taken into account are those of ecological limits.

Eco-agriculture aims to reconcile the protection of natural areas and growth in agricultural production. It is both a conservation strategy and also one of rural development. It recognises rural communities as important managers of ecosystems and of biodiversity. It applies a systematic and integrated approach to agricultural areas, taking into account the three pillars on which rural lifestyles are based, the protection of biodiversity, ecosystem services, and the development of productive sustainable agricultural systems. In contrast to agro-ecology, eco-agriculture is broader in scale and integrates biodiversity as a key element of rural development (and not only agriculture). The objectives which flow-on from this framework are numerous: reducing habitat destruction by increasing the productivity and sustainability of land already under cultivation, restoring wildlife habitats on farms by establishing habitat corridors amongst cultivated areas, establishing protected areas near agricultural areas, improving the habitat value of cropped areas through the use of productive perennial plants, using agricultural practices which reduce pollution, modifying natural resource management practices to improve habitat quality within and around agricultural areas.

3.3. Agriculture – biodiversity relationships in space

In the face of the double imperative of food production and biodiversity protection, there has been interest in a segregation of activities across the landscape such as in the concept of "*land sparing*". This concept is based on the idea of concentrating agricultural production in one part of the landscape (in the sense of an intensification in the use of inputs of industrial origin) which would allow for necessary increases in production to respond to increasing food demand, while still sparing a proportion of land which could be dedicated to biodiversity conservation. This option is based on three hypotheses whose robustness is rarely discussed: the technical superiority of the intensive production model (in terms of yield), the absence of effects from one type of area to another, and the absence of mutual benefits between agriculture and biodiversity.

The first hypothesis rests largely on the choice of method used for measuring efficiency, which should include the totality of costs both private and public, and all of the resources utilised, independent of their nature or ownership. This aspect is often not accounted for in arguments in favour of the spatial segregation model. The second, which depends on the landscape mosaic, its connectivity, and the extent to which this allows, or not, compensation for the effects of habitat fragmentation, is addressed in this assessment (see in particular chapter 1). Finally, the third hypothesis is also examined by this assessment (see chapters 2 and 3), and numerous studies suggest that it is indeed possible to develop mutually beneficial production models.

The perspective of the specialisation of regions responds to the demand from international nature conservation organisations for an extension of protected areas and greater protection of these biodiversity rich areas from damage by local populations. In contrast, in European countries, approaches are being developed aiming to recognise the role of certain forms of agriculture in the maintenance of biodiversity, with in particular the concept of high natural (or ecological) value agriculture.

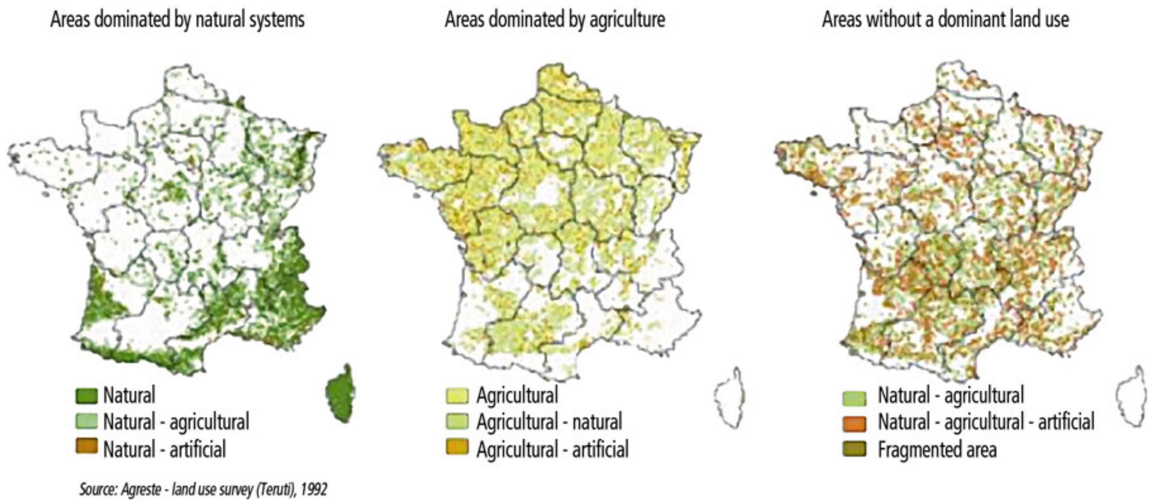
These questions take on a different aspect when the needs in terms of space, of nature and of landscapes of urban populations distributed across the country are considered. Biodiversity and ecosystem services are in general local public goods that should be provided, where possible, as close to target populations as possible. Such new demands placed on agriculture and on regional management bodies require a reconsideration of the advantages of a greater spatial segregation of land uses.

An alternative to the dualist management of space and of the relationship between agriculture and biodiversity is provided by approaches establishing linkages and networks, to favour (non human) population movement by increasing habitat connectivity.

1. The effects of agriculture on biodiversity

Agriculture is the dominant anthropogenic factor controlling biodiversity in Western Europe. Agricultural areas represent a majority of the land area of many European countries: 75% in England, 60% in France… In France, a large number of important regions are characterised by a dominance of agriculture. While recent preoccupations with biodiversity losses are mostly focused on the destruction and transformation of natural habitats, numerous human managed landscapes also contain species diversities comparable to those of natural ecosystems, with in particular the persistence of numerous threatened species. If the conservation of biodiversity is to be based on the protection of 5% of currently existing natural habitats, to be successful it will also require the recognition of the remainder of the area of a country. For example, in Germany one quarter of endangered species are found in the 2% of the country protected for conservation, while the remaining 75% are located in areas managed for agriculture (50% of the country's area) and forestry (30% of the area).

A large part of the national territory corresponds to areas dominated by agriculture



Spatial distribution of areas dominated by natural systems (forests and plantations included), agriculture and without a dominant land use (Agreste, 2001)

The agricultural regions of numerous European countries are over 2000 years old. Over time, a large number of wild species have become adapted to these landscapes, with the result being the development of species rich, human modified landscapes. In parallel, continued growth of human populations and their resulting occupation of space have resulted in the destruction of the majority of Europe's natural habitats. Some species have thus lost their initial habitat and have become almost entirely dependant on secondary habitats, primarily agricultural, to survive. Environments fashioned and managed by human society over millenniums, such as the Landes, have thus become areas requiring conservation. Such areas, particularly widespread in Europe, have become important for the conservation of biodiversity.

Consequently, we have quantified the influence of agricultural management on biodiversity, both in terms of the equilibrium between natural and managed areas and of the quality of areas managed by agriculture. Evaluating and understanding the effects of agriculture on biodiversity is a major challenge in the establishment of generic knowledge useful for stakeholders in this domain of scientific research.

1.1. A developing field of research

Studies of the effects of agriculture on biodiversity are numerous, some 570 publications have been analysed by this assessment. However, it is apparent that few of these studies have developed generic hypotheses and theory capable of efficiently guiding public policy. There are four reasons for this:

- The term biodiversity covers very different biological components and thus very different questions and challenges;
- The spatial scales and the levels of organisation at which the effects of agriculture on biodiversity are considered, are numerous;
- While the theoretical frameworks exist, their capacity to structure current knowledge into general principles has rarely been tested, and they are rarely used:
- The ways in which agriculture, human stakeholders and their environmental interactions are taken into account is rarely sufficient to lead to useable recommendations.

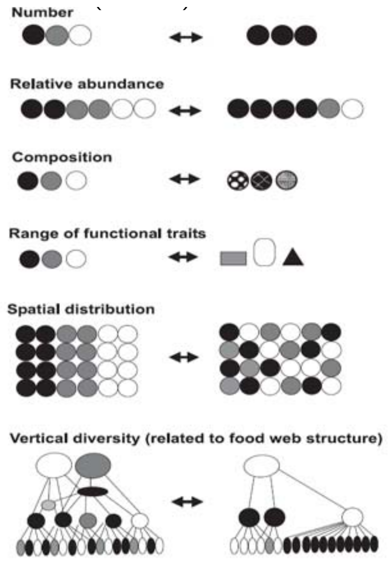
Before presenting the current knowledge in this field of research, we will describe in further detail these four reasons as they clarify why the literature dealing with these questions appears as a loosely connected body of limited knowledge that is of limited utility to stakeholders and managers.

1.1.1. Biological realities and associated challenges

Ecology defines the components of biodiversity either following a taxonomic logic, or a functional one.

For taxonomic approaches, it is possible to describe species richness (number of species present), the relative abundance of different species, species composition (their identity) or their spatial distribution.

For functional approaches, taxa are defined by their functional characteristics (traits). For example, we would group under the term “pollinators” all of those species implicated in the function of pollination regardless of their taxonomic grouping.



The term biodiversity describes very different biological entities (after Diaz et al. 2006)

These various components are taken into account very unevenly in studies analysing the effects of agriculture on biodiversity.

- In the majority of studies, the biological components considered are species. Numerous studies are focused on the effects of agriculture on major taxonomic or trophic groups (plants, coleopterans, bats, earthworms), characterised by their numbers of species (species richness), the relative abundance of species and/or the species composition (identity of species present). While the choice of studied groups may sometimes be of groups important in the context of agriculture / biodiversity relationships, often other considerations are involved such as the expertise of the research group involved, the practical difficulties of studying a large range of species and questions of biological conservation (emblematic species…).

- A non-negligible fraction, but still the minority, of studies, have assessed the effects of agriculture on functional diversity, most often of plants. The focus in these studies is explicit, and links the response of organisms to constraints imposed by agriculture, which are explained by particular biological traits of these organisms. More rarely this is assessed at the level of the functioning of an agro-ecosystem, which is also based on the characteristics of the dominant species from a functional point of view (see chapter 2).

- Very few studies consider the genetic diversity of species or communities. A notable exception concerns the study of the diversity of microorganisms, where the species level is neither more relevant nor more easily identifiable. In this case, diversity is often assessed by the number and distribution of different types of DNA sequences, even though current research in this field tends to characterise the diversity of microbial communities using a functional approach.

- Finally, very few studies investigate the diversity of ecosystems at the landscape scale. Questions at this scale relate primarily to the relationships existing between the diversity of some organisms and the diversity (and quality) of ecosystems, with ecosystems being considered as habitats providing resources and/or corridors or obstacles to the movement of these organisms.

Numerous studies emphasise the species richness or the composition of biological groups more so than the abundance or total biomass of these groups. This makes it difficult to make links with studies evaluating the functional role of biodiversity (see chapter 2) as ecosystem functions and agro-ecosystem services are more often than not linked to the abundance of organisms than to their diversity *stricto sensu*.

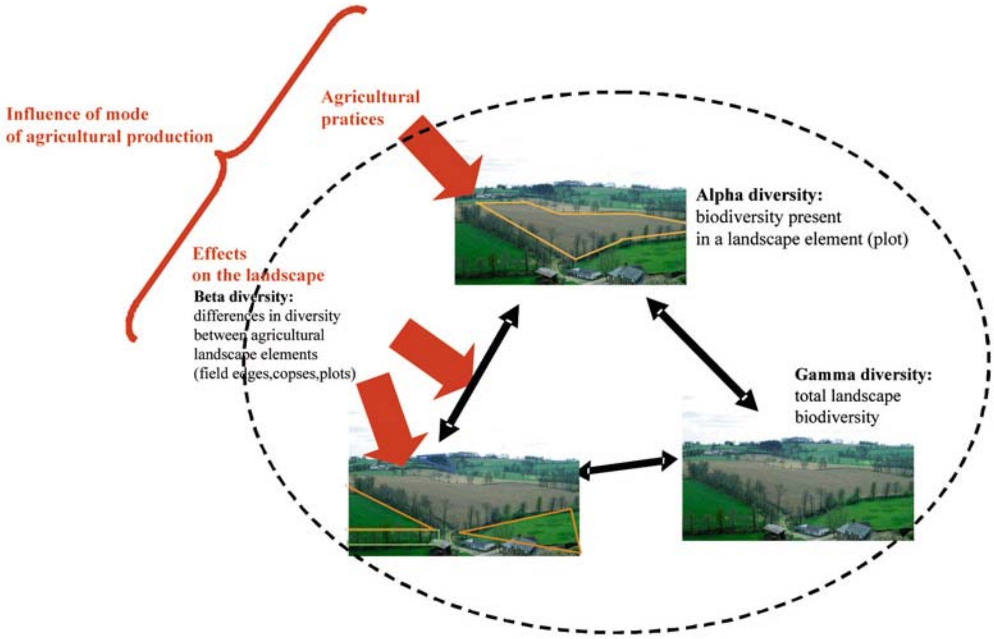
The biological components considered, the methods used to asses biodiversity and the associated biological questions are, in fact, very variable depending on the study. Additionally, different groups of organisms or components of biodiversity (species richness, abundance…) can change in different ways in response to the same agricultural factor. This fact considerably limits the possibilities of responding in a simple and unequivocal fashion to questions such as: "what is the influence of this or that type of agriculture on biodiversity?" or "what opportunities exist in a given system of production to promote biodiversity?".

1.1.2. Varied scales and levels of organisation

As is the case with the concept of biodiversity, the term "agriculture" covers a wide variety of activities which include in particular agricultural practices at the plot level (fertilisation, pesticide use, rotations, field size…), cropping systems, the size and structure of farms and land management at the scale of landscapes or regions. Each of these aspects implies a specific understanding and articulation of issues, from the plot scale to that of the landscape or large region, as well as scales such as the farm scale; each of these is necessary to analyse agriculture – biodiversity relationships.

Agriculture exerts an influence on biodiversity via a complex network of mechanisms. These include the impacts of the ensemble of agricultural practices at the plot level on the environmental conditions experienced by organisms, and also the impact of agriculture on habitat heterogeneity, in terms of the diversity of agro-ecosystem elements (cropped areas, field margins, wooded areas, irrigation canals…) and the diversity of agro-ecosystems and natural ecosystems at larger scales such as the landscape (and in particular, the region).

The effects of agriculture can be assessed across three levels: alpha diversity, which is the species richness at the level of a local agro-ecosystem (the field / plot), beta diversity, which reflects the modification of alpha diversity between habitats/ecosystems, and gamma diversity, which corresponds to the species richness at a large scale of analysis (landscape, region, country…).



Agriculture exerts an influence on biodiversity through a complex network of mechanisms acting from the local scale (plot or inter-plot) to larger scales of the landscape, region or greater. Understanding and evaluating the effects of agriculture on biodiversity implies taking into account, and if possible, developing a hierarchy of these mechanisms.

The ideal would be to have available studies integrating the effects of agriculture on alpha and gamma diversity, with an analysis and identification of the relative importance of the factors and mechanisms underlying these effects. Such studies are very rarely reported in the literature. We have only identified a few such European research projects and case studies, whether on landscapes or for agricultural plots. This issue of integrating across scales or levels of organisation is far from being trivial: emergent properties at larger scales, for example the landscape, are often not predictable from characteristics studied at a lower level, for example the farm scale.

Beyond the issue of spatial scale, levels of organisation relevant to agricultural activities, whether this be the farm, a network of farms or a production zone, are rarely taken explicitly into account. The majority of these studies focus on some characteristics of these production systems (level of fertilisation, type of soil cultivation, impact of pesticides, and role of field boundaries…) but do not deal with the effects of the production system in its entirety.

Concerning time scales, the majority of studies span periods of at best a few years, while it is the longer-term history of plot level agricultural practices and landscape dynamics which determine the response of biodiversity to new practices. The duration of agricultural practices over periods of up to a century has a major influence on biodiversity, in contrast to changes that occur over short periods characterised by regular alternations of agricultural practices. Experimental designs allowing a coupling of the dynamics of agricultural practices and the dynamics of biodiversity at the plot level are still very rare in France and internationally, as well as over the long term at the landscape scale. They are however necessary to integrate spatial and temporal dimensions into an understanding of patterns of biodiversity in agricultural areas.

The scales, the mechanisms, the challenges and the scientific questions considered are very variable between studies. In France the field of research covering questions of "the effects of agriculture on biodiversity" has historically been constructed with on the one hand agronomic studies focused on agricultural plots *stricto sensu*, and on the other hand ecological studies considering landscape elements such as hedgerows as entirely natural. In fact, this field covers a large quantity of work that has only in common that studies are at the interface of the complex concept of biodiversity and the equally complex realities of agriculture. It is therefore natural that in terms of questions, mechanisms, scales / levels of study or scientific disciplines involved (conservation biology, population and community dynamics, functional ecology, landscape ecology…) the field is highly scattered.

This is the reason why, in the context of this assessment, we have presented the available information at two separate spatial scales corresponding to two mostly separate bodies of work: the plot scale (alpha diversity), with the literature in this case dominated by agro-ecological approaches, and the landscape scale (gamma diversity) with the literature naturally dominated by landscape ecology approaches. Landscape ecology is a highly individual branch of ecology often working on controlling factors different to those studied in agro-ecology. It is at the landscape scale that it is possible to integrate the effects of production modes occurring over numerous farms in a given area.

1.1.3. The theoretical context

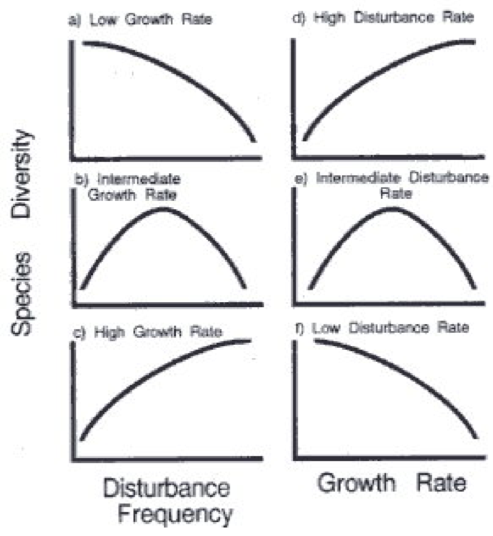
Ecology has produced a number of theories and models taking into account changes in biodiversity and analysing the factors which are responsible for these changes. While these models are rarely used to structure scientific knowledge, some may be usefully applied to agro-ecosystems.

The local scale

Numerous hypotheses and theories aiming to explain variations in biodiversity have been proposed. Concerning the species richness of a particular community, it is considered that this depends on two major factors: the *pool* of available species (the totality of species potentially arriving at a given site), which depends on biogeographical and historical factors, and the ecological interactions present under the given environmental conditions. These interactions act to filter species able to co-exist from the larger pool. Abiotic conditions and biotic interactions are the two main forces present in this "ecological filter". These two types of factors act at local scales (plot level), but also more widely at the landscape scale.

Conceptual models exist which take into account variations in biodiversity. In the majority of these, the level of productivity and the disturbance regime are considered as the determining variables. These allow the prediction of some functional characteristics of species in response to gradients of these two variables. The best known is the dynamic equilibrium model (DEM) proposed by Huston (1979, 1994), which allows the quantitative consideration of variations in plant or animal species richness in a large number of situations.

This model predicts that decreases in the number of species result from the effect of two combinations of conditions:
- those under which local populations disappear as they are not capable of recovering after a disturbance or under a disturbance regime due to a low demographic growth rate (especially when environmental productivity is low),
- when local populations become rare or disappear due to competition from other species (competitive exclusion). Such a situation occurs more rapidly under conditions of high demographic growth (in particular in areas of high environmental productivity) when environmental disturbance is infrequent.



Dynamic equilibrium model (Huston, 1979, 1994)

The effects of these very different processes are to reduce diversity at the extremities of gradients of productivity and disturbance. In the middle of these gradients, the effects of these processes are reduced, and the number of species capable of coexisting can be much greater. This model leads to a number of predictions relative to variations of species richness along gradients of disturbance and productivity.

A very important aspect of this model is the interdependence between effects of the different processes: for example, an increase in the frequency of disturbance at a low level of resources (low productivity) results in a decrease in richness, while at a high level of resources (high productivity) it results in an increase in richness.

This type of ecological theory is useable *a priori* in agricultural situations, as the main characteristics of agricultural systems at the plot level and their level of intensification can be expressed in terms of their resource level (fertilisation) and the intensity, frequency and nature of disturbance (ploughing, grazing and mowing…). In practice, however, descriptions of studied systems rarely offer the possibility of positioning the study along the "resource" axis, and even less so along the "disturbance" axis. The majority of studies report empirical relationships between biodiversity and the level of fertilisation, without referring to overall generic theory. A notable exception concerns species-rich permanent grasslands, environments for which models and theories of biological diversity are more widely used. However, a quantification of agricultural practices in terms of disturbance is often impossible from, for example, descriptions of stocking rates per hectare or measures of biomass removal.

Despite these restrictions, this type of model is useful to take into account the directions of changes in a large number of agricultural situations.

The landscape scale

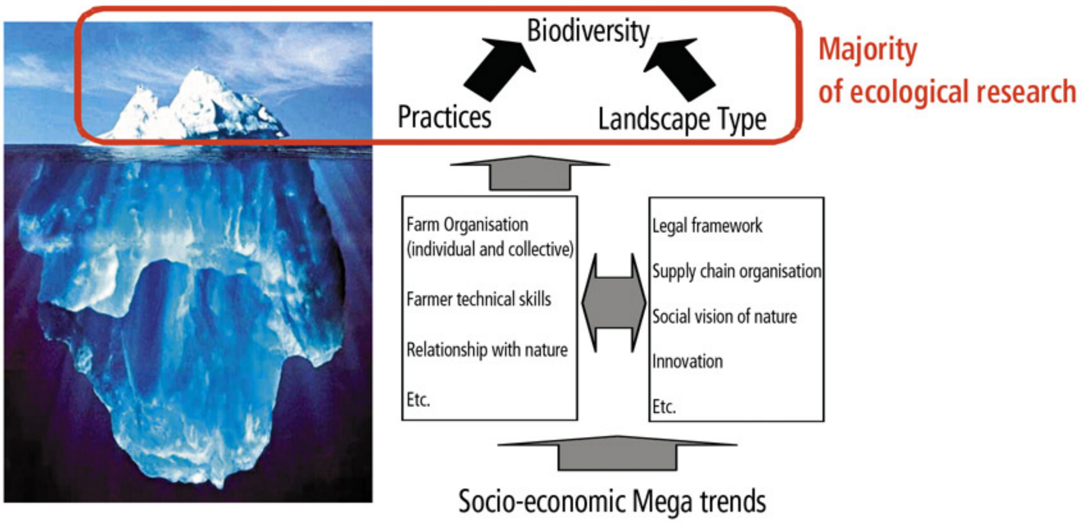
Concerning the understanding of the effects of agriculture on biodiversity at the landscape scale, different ecological theories from general ecology or landscape ecology are also available. Meta-population and meta-community theory is without doubt the best known. Meta-community theory allows the prediction of the species richness of communities as a function of the types of habitats present, the suitability of these habitats to different species and the migration rates between habitat patches.

Such an ecological theory is *a priori* useful to analyse the effects of the structure of agricultural landscapes on biodiversity. However, the descriptions of the studied landscapes provided in most studies remain too limited to apply this type of approach. Many studies are limited to quantifying the percentage of non-productive elements, or use a contrast between "complex" or "simple" landscapes. At best, heterogeneity or complexity are characterised by the composition of landscape elements, the degree of fragmentation or connectivity of some elements (often favoured habitat of target species) and/or their geometry.

Overall, the literature provides mostly information in terms of patterns rather than in terms of processes explaining these patterns, both at the scale of the plot and that of the landscape.

1.1.4. Human stakeholders and socio-economic factors

Both stakeholders and socio-economic factors are to this day ignored in studies investigating the effects of agriculture on biodiversity. Current knowledge is overwhelmingly from ecological or agro-ecological studies and is primarily focused on the effects of local factors directly linked to agricultural practices at the plot level or that of landscape structure. To fully assess and understand their effects on biodiversity also requires an understanding of their sociological, economic, legal and technical processes, determinants and constraints. Socio economic factors, considered mostly by studies of the acceptability of measures favouring biodiversity by agricultural stakeholders (see chapters 3 and 4), are however very rarely taken into account even though they are often powerful drivers of biodiversity changes.



Current knowledge of the effects of agriculture on biodiversity is overwhelmingly from ecological or agro-ecological models and studies. While this knowledge is essential, it covers only the tip of the iceberg in terms of the key processes and determinants necessary to correctly assess the effects of agriculture on the differing components of biodiversity.

1.2. The impact of agricultural practices at the plot scale

By definition agricultural activity seeks to manage and control biodiversity, but in very different manners depending on the agro-ecosystem. The effects of different practices on biodiversity will therefore be considered in this assessment by considering separately annual crops, perennial crops and permanent grasslands. Plot level studies are numerous, but they also provide information that is of limited generic value. The majority of such studies assess the effects of the intensification of an agricultural practice, with often positive effects at the "extensive" end of the gradient and with variable effects depending on the practice and groups considered at the "intensive" end.

1.2.1. Annual Crops

Cropped fields generally have specific ecological characteristics including: large fluxes of materials (particularly in intensive cropping systems) and a strongly human constrained trophic structure (with resources pre-empted for the cultivation of a single plant population and a reduction in the number of trophic levels), which creates systems in permanent disequilibrium requiring constant human intervention. Cropped fields are subject to intense disturbance (interventions for the control of pest species, massive removals of primary production), relative spatial uniformity and a periodic "resetting". The different practices act directly on biodiversity by modifying the environment (for example ploughing) and/or the community (for example pesticides) intentionally, but also indirectly, notably through trophic effects.

In the case of broad-acre crops, the use of synthetic phytosanitary products and repeated deep ploughing, as well as fertilisation, appear as major factors in the decline of the species richness and abundance of numerous organisms (soil microorganisms, soil fauna, insects, plants, amphibians, birds). These effects are at the same time both intentional, when acting to favour the crop, and non-intentional when they exert negative effects on populations of crop pest natural enemies or earthworms.

Soil cultivation

Ploughing when used in a repeated manner has a negative effect on the species richness or abundance of many organisms. It selects for weedy species depending on the ability of their seeds to survive in the soil. The abundance of soil macrofauna, and in particular earthworms is significantly reduced by deep ploughing. This is also the case with shallower methods of soil cultivation, but to a lesser extent. The relative abundance of different species and functional groups of earthworms is also modified by ploughing. In the case of repeated ploughing and unfavourable conditions (low organic resources, constraining microclimatic conditions), the species richness of macrofauna communities can also be reduced. While the abundance of microfauna and mesofauna is less affected than the macrofauna by the different techniques of soil cultivation, the profound modifications of trophic and micro-climatic conditions resulting from these interventions strongly modify the composition of their communities.

Pesticides

In the literature, synthetic phytosanitary products are considered as one of the major factors responsible for the decline of biodiversity in the agro-ecosystems of industrialised countries.

In general, the effects of phytosanitary products on arthropods, and in particular on crop pests and their natural enemies, depends on their life history, demographic parameters and developmental stage at the time of application: the more an application occurs at a young stage and the lower the species growth rate, the more the insect is vulnerable and its population susceptible to disappear. Insecticides that are non-toxic for particular useful species (natural enemies, pollinators) are in reality very rare. Most pesticides have a more or less global effect on arthropod communities, but can particularly affect some taxonomic or functional groups (for example moluscicides affecting beetles that predate on molluscs). The combination of the direct and indirect effects of phytosanitary products on arthropods can be indirectly seen after the cessation of their use in agricultural plots or on farms.

Insecticides can be more toxic than herbicides for soil fauna and in particular earthworms and soil arthropods. Fungicides are even more toxic. The impact of herbicides on soil food webs is generally indirect (reductions of vegetation and soil organic matter). Some however have direct effects on mesofauna and earthworms; the application of various pesticides often has a negative effect on non-target soil fauna.

Effects on vertebrates are in particular known for birds and amphibians. These can be direct, due to the use of high doses, or indirect, sometimes even with low doses (for example due to bioaccumulation).

Herbicide use induces a major reduction in the number of plant species and of their biomass in cropped fields, and also in their margins. The continued utilisation of the same herbicide molecules has caused on the one hand the quasi-disappearance of a number of arable weed species, and on the other hand the development of some species populations resistant to the applied molecule. Such phenomena may be accentuated with the establishment of crops of herbicide resistant genetically modified organisms (see the box below). The likely development of Bt genetically modified crops of elevated toxicity will potentially induce similar risks of the appearance of resistance within targeted pest insect populations. It is worth noting that a part of plant diversity can be recovered with the adoption of integrated management of weed populations.

Pesticide use can also result in the emergence within microbial communities of populations, notably bacterial, capable of degrading them, with consequences of needing to increase doses or frequencies of application with resulting negative effects on other flora and fauna.

Effects of genetically modified organisms (GMO)

The impacts of GMO's on biodiversity are specific to the varieties cultivated and to the genes introduced. In general this consists of varieties resistant to a non-selective herbicide, or made tolerant to an insect pest. In the case of resistance to a herbicide, the effects include more complete vegetation removal, including at field boundaries. The consequences of this may include decreases in populations dependent on weedy species as trophic resources and selection for populations of weeds resistant to the molecule used.

Other effects are linked to the modification of agricultural practices made possible by the genetically modified varieties (direct seeding, simplification of rotations) and should be taken into account for a complete evaluation of possible impacts. The case of varieties producing Bt toxins, which confers tolerance to some insect pests, has been the subject of numerous ecotoxicological studies and the interpretation of these results remains controversial. Finally, the possibility of the transfer of genes to other species in the field depends on the genetically modified species considered and its capacity to hybridise with wild species.

Fertilisation

At the plot scale, crop fertilisation has globally positive results on the abundance and growth of living organisms in the soil and vegetation, as long as this does not reach toxic levels. However, effects on the species richness of plants and insects are generally negative. Increasing fertiliser application has effects mainly at two levels : firstly on the communities of soil organisms directly affected by changes in the physical and chemical environment with consequent effects on species richness and composition, and secondly on the biodiversity of organisms linked to the nutritional status of plants, through modifications of trophic chains.

In general, the increase in fertilisation allowed by the use of synthetic fertilisers, has resulted in the homogenisation of many environments in terms of resource availability, and has lead to the disappearance of species adapted to low nutrient environments (a well documented phenomenon for arable weeds), and the replacement of specialist species by generalists (birds). Mineral nitrogen fertilisation appears as one of the main factors responsible for the decrease in species richness of cropped fields and in adjacent boundary areas. Organic fertilisation appears to have more subtle effects, in particular in microbial communities.

It is worth noting that beyond these effects at the plot scale, increased fertiliser use has effects on aquatic ecosystems both continental and coastal (eutrophication resulting from the leaching of nutrients, nitrogen and phosphorus in particular), and on the totality of terrestrial ecosystems due to volatilisation and the accumulation of mineral deposition of atmospheric origin (nitrogen in particular).

Rotations

While it is often stated that crop rotations induce higher densities and diversities of soil organisms than continuous cropping, observations indicates that this is only the case where a perennial is introduced into the rotation. Where this is not the case, the opposite result is often observed. Nevertheless, the use of any form of rotation, breaks the developmental cycle of pest species and weeds specific to some crops, and is useful for the control of other pests. Rotation can thus allow for a reduction in pesticide use, with consequent positive effects on biodiversity.

Water management

Water management at the plot level, through drainage or irrigation, can have variable effects on biodiversity. Drainage can have a negative effect on groups found in wetlands, for which recent major declines pose a problem for biodiversity conservation. Irrigation has an overall favourable effect on soil fauna but leads to a decrease in plant diversity.

Finally, taken together these agricultural practices lead generally to low levels of diversity at the scale of the cropped plot (alpha diversity), which is consistent with strong human pressure to favour crops.

1.2.2. Permanent grasslands

Permanent grasslands, characterised by a perennial multi-species, or at least multi-year, vegetation cover, do not in general receive pesticides (some cases of the use of selective herbicides against specific species do however exist). The main management interventions are the removal of biomass, and for an increasing number of grasslands, fertilisation. While the term permanent grassland covers a large variety of situations, from those heavily fertilised and intensively exploited to rangelands and summer pastures experiencing low stocking rates, these areas generally have a biodiversity considerably greater than that of cropped fields and are often considered as semi-natural areas. The major factors influencing their biodiversity are grazing regimes and the practices of mowing / hay cutting and fertilisation.

Grazing – intensity and type of herbivore

In general, a high grazing intensity tends to have a marked negative effect on the species richness of different types of organisms: plants, arthropods, small mammals and soil fauna. However, bird richness may be high in heavily grazed pastures, even if the abundance of each species is reduced. Moderate levels of grazing lead to an increase in plant species richness and in the abundance of some soil organisms. For plants, species richness tends to decrease when grazing pressure is very low, especially in productive grasslands (more than 2 t/ha).

It is worth noting that the number and functional diversity of some soil organisms (earthworms, some nematodes, amoebas, mycorrhizal fungi) is positively related to plant species richness. Consequently, moderate intensities of grazing can increase the species richness of numerous groups of organisms.

Grazing by multiple species of herbivores can have positive effects on plant species richness when these different herbivores have complementary diets and the overall intensity of grazing remains moderate. The limited numbers of environments in which such experiments have been conducted does not, however, allow any conclusion as to what extent mixed grazing can increase the structural variability and composition of grassland vegetation.

In functional terms, an increase in grazing pressure selects for plants with shorter life spans, smaller size and with efficient resource acquisition abilities (photosynthesis, mineral element absorption). Modifications of the structure of vegetative cover induce changes in the type of bird species using grasslands. Finally, the functional diversity of soil micro-fauna tends to decrease under conditions of heavy grazing.

In grasslands it is fertilisation and the intensity of grazing pressure that have the greatest influences

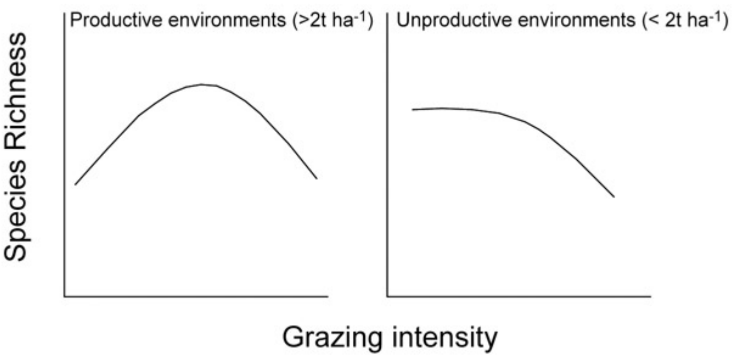
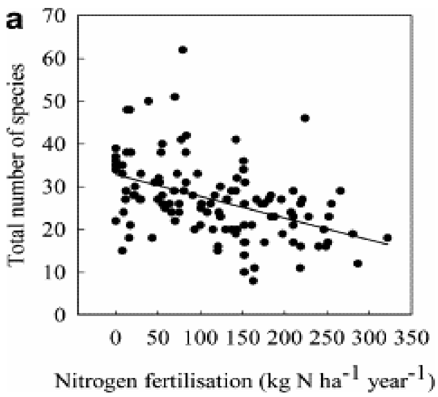


Figure synthesising the results of a review of 39 studies analysing the effects of grazing intensity on plant species richness in both productive and unproductive grasslands (adapted from Cingolani et *al.*, 2005).



Impact of nitrogen fertilisation on plant species richness in 117 permanent grasslands in Germany (Klimek et *al.*, 2007).

Fertilisation and mowing

The effects of fertilisation appear comparable for different types of organisms. However, in situations characterised by low mineral element availability, an increase in soil fertility, if this leads to greater production of biomass and a greater abundance of organisms, tends to decrease the species richness of numerous groups: plants, micro-arthropods, soil bacteria.

Community functional composition is also strongly modified as fertilisation favours larger species, with tissues richer in mineral elements and with greater capacities for growth and the acquisition of mineral elements.

In general, mowed grasslands are richer in plant species than grazed grasslands, which probably leads to an increased richness for other organisms. Changes in the structure of vegetation due to mowing, grazing or fertilisation affect in particular the availability of nesting sites for birds and the availability of food resources to feed young birds and adults, leading to changes in the composition of avian communities. It has also been noted that the synchronisation of mowing dates over a restricted period and early in a season is often detrimental to biodiversity.

Other factors

Other factors can have impacts on the different components of biodiversity in grasslands. This is, for example, the case for sanitary products used for the control of internal and external parasites of domestic herbivores. Some ingested products (mostly anti-helminths) are excreted by treated animals and have a strong negative impact on insects (dung beetles in particular). The further effects on populations of earthworms, chiropterans (bats) and birds predating on these dung beetles deserves further study.

Finally, contacts between domestic herbivores and wild animals can be a source of propagation for some diseases; however this is most often from domestic flocks to wild populations, rather than in the other direction.

1.2.3. Perennial crops

Due to the permanence of their host plant, numerous pest species remain continually present in woody perennial crops (orchards, vineyards…) and their control requires the repeated application of phytosanitary products, which consequently is the major factor affecting biodiversity in these systems.

Apple orchards, for example, are subject to up to thirty pesticide applications per year, and are treated for long periods of 6 to 8 months per season (from budding up until harvest). There are direct effects (mortality, decreases in fecundity), of greater or lesser severity depending on the products used, on the target organisms (arthropod pests) as well as for other species present in the orchard (other arthropods, birds, small mammals…). There are also indirect effects for these same groups due to the suppression of resources (weedy plants, prey species), and the alteration of trophic chains. The use of chemical products and their impact on entomological diversity are documented for some groups of arthropods (spiders), but rarely for the entomological fauna in its entirety.

While the effects of these treatments is indisputable for some groups (spiders) or for some parts of the community (soil surface arthropods, parasitoids linked to leaf miners), overall foliage insect diversity, surprisingly, is often only little affected by recurrent applications of broad spectrum insecticides when compared with alternative methods. Several hypotheses could explain this observation: the resilience of the orchard system with a rapid recovery of insect diversity, a rapid re-colonisation due to the small size of individual orchards and/or a predominant local / regional effect, different responses between groups which are poorly reflected by currently used biodiversity indices.

Nevertheless, the abundance of arthropods in orchards is significantly negatively affected. The structure of their communities is also modified, particularly with alterations to communities of pest natural enemies occurring under intensive pesticide use. Consequently the chemical protection of an orchard has significant negative effects on insect functional diversity and compromises the natural regulation of some pests of apples.

An orchard is a complex perennial environment, in which plant diversity resides mainly in the structure of the vegetation cover within the vineyard or on its margins (hedgerows). The presence of numerous strata exploitable by biological communities (spatial aspect) and their maintenance (temporal aspect) is a situation potentially favourable to the maintenance of food webs and animal diversity. However, the interaction between these structures has been little studied, and available results are inconsistent. In addition, agricultural practices, and in particular phytosanitary protection, do not allow the maintenance of a natural equilibrium in these systems, in particular due to the non-selectivity of the molecules used and major variations in biomass which alter trophic webs.

1.2.4. Fallows

In the context of the Common Agricultural Policy (CAP), the cessation of agriculture in some areas was made obligatory in 1992. It still remains possible today to facultatively place some plots in fallow. In contrast to fields, fallows under the CAP are managed under regulations that define the authorised types of vegetation cover (spontaneous or sown) and seek to limit the production of seed by weeds (obligatory slashing and mulching in spontaneous fallows).

The weedy flora found in fallows is made up of species whose seeds were contained in the soil seed bank. Consequently, these are the same species as normally found in the plot and no additional biodiversity (for example rare arable weeds) is to be expected from the simple placing of a plot in fallow. However, the lower management pressure experienced in a fallow can allow the recruitment of some rare species. The absence of soil cultivation also results in annual species becoming replaced by biennials or perennials.

Such spontaneous fallows can provide resources for arthropods (pollen, nectar, prey or alternative hosts for carnivorous natural enemies of pest species). Management of such areas through mechanical destruction should not take place during periods when their attractiveness to such arthropods is highest.

Fallows established to benefit the environment and wild animals can be sown with mixes of species that are more or less diverse (cereals, legumes, buckwheat…). Their faunal richness depends on the nature and botanical complexity of their vegetation. Flowering fallows, sown with mixes of species of aesthetic or entomological interest have appeared more recently. These are attractive for insect fauna, in particular for flower feeding species such as domestic bees; and can help sustain populations in some regions. However, they have also been criticised as many of the sown species or varieties (cosmos, zinnias…) do not benefit all pollinator taxa and some of these species carry risks of becoming invasive.

When not mown (which is contrary to the requirements for the allocation of CAP payments), fallows provide ungulates some advantages over crops, with food resources that are sometimes less attractive, but more available throughout the year. As with all non-cultivated fields (preferred particularly by Roe Deer), their value as refuges is exploited by animals. They may also allow for a reduction in damage to crops.

1.2.5. Agricultural abandonment

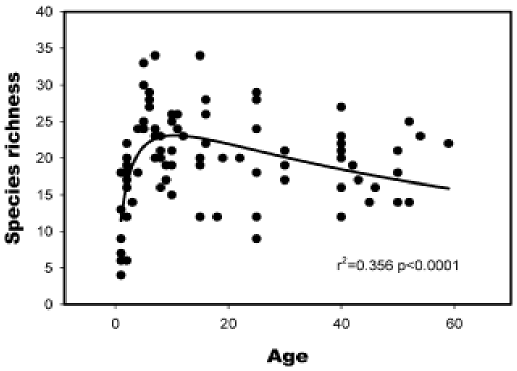
The abandonment of agricultural land is a phenomenon that has been occurring in France over the last few decades and which is linked to multiple mechanisms (marginal lands, intensification, rural exodus). The major increase in the area covered by forest (3.9 % between 1993 and 2003) is one of the most visible manifestations of this phenomenon, and is particularly accentuated in some regions.

The effect on biodiversity of the abandonment of a previously exploited area depends strongly on its initial state:
- In the case of cropped fields (cereals, vineyards, orchards) characterised by an environment initially poor in species, species richness increases during the first few years following abandonment for practically all groups of organisms including microorganisms. In these cases there is an enrichment in species of abandoned areas, with the speed of this process depending on the nature and structure of the surrounding landscape.
- In the case of permanent grasslands, richer in species, abandonment systematically leads to a decrease in species richness, at least for plants. The effect on other groups of organisms does not seem to be so marked.

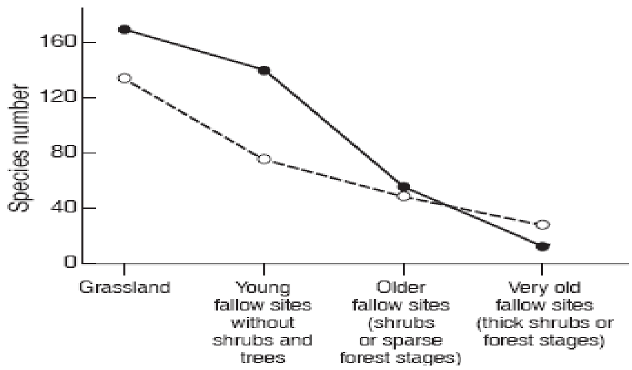
Regardless of the initial situation, as the time since abandonment increases, species richness tends to decrease. This decrease becomes greater when woody species begin to establish and is accompanied by a decrease in biogeographic specificity of species from numerous groups (birds in particular).

In functional terms, abandonment leads to a replacement of plant species with a short life span, small size, wind dispersal and high resource acquisition abilities, by species with opposite characteristics and which are often animal dispersed (birds in forested stages). For earthworms, endogenous and anecic species dominate in herbaceous stages, while the proportion of epigeous species increases with the establishment of woody vegetation.

The abandonment of cropped fields leads initially to an increase in biodiversity, while in grasslands and pastures to a reduction of biodiversity



The relation between plant species richness and length of abandonment in old vineyards and orchards in the south-east of Spain (Bonet & Pausas, 2004).

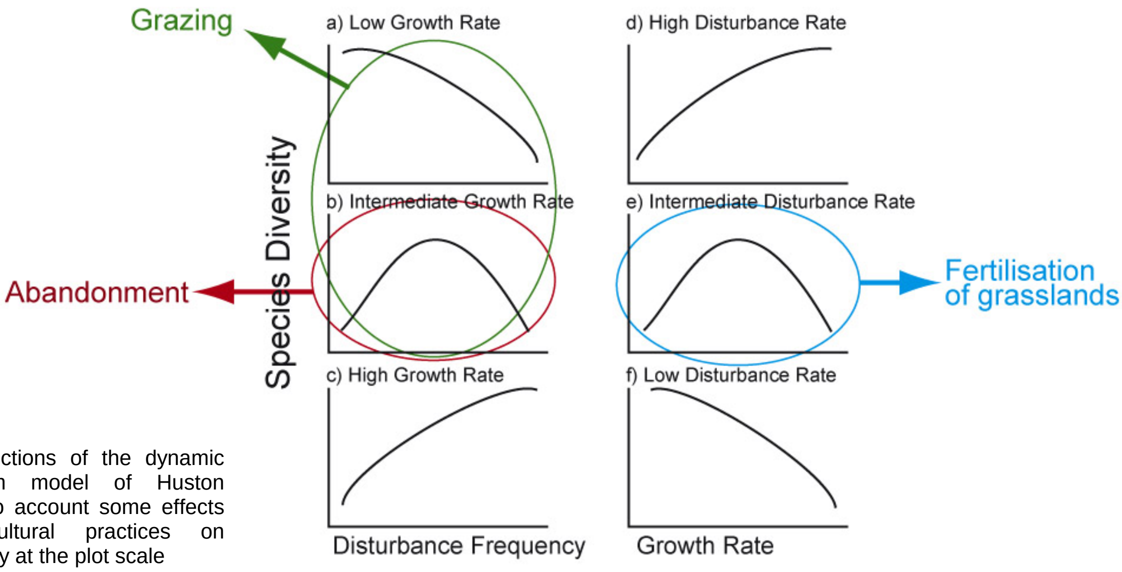


The relation between plant species richness and length of abandonment in calcareous grasslands previously grazed by sheep (modified from Bakker & Berendse, 1999). The continuous line shows the species richness of aboveground vegetation, and the dashed line the richness of the seed bank.

1.2.6. Are there general patterns of biodiversity response?

While very few studies refer to ecological theory in order to assess the generality and implications of their results, it has become apparent over the course of this assessment that the model of Huston allows an understanding of the effects of a number of agricultural practices on biological diversity. The greater diversity in mown grasslands than in grazed grasslands can be interpreted as a consequence of a high disturbance regime in a productive situation (see figures b or c). It should be noted however that precise information on fertility levels is rarely included in published studies. The impacts on biodiversity of grazing intensity in interaction with the level of grassland productivity, as reported in the literature; correspond to the predictions “a” (low levels of production) and “b” (high levels of production) of this model. The impact of fertilisation of grasslands corresponds to the unimodal curve “e”. As for situations of abandonment, these correspond to the predictions presented in “b”, or a combination of “a” and “b”.

The model of dynamic equilibrium does not appear to be applicable in the context of broad-acre cropping, which has very particular combinations of factors. Such situations associate very high disturbance regimes during some periods of the life history of organisms, high productivity AND practices aiming to eradicate other organisms which may reduce crop production. This combination of factors would require the extension of the model along an axis (this may take the form of a selectivity index) which is not currently taken into account by its conceptual framework.

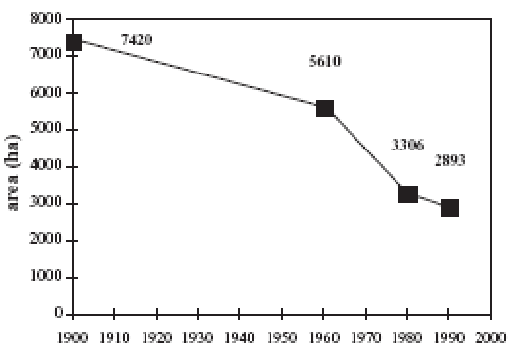


The predictions of the dynamic equilibrium model of Huston taking into account some effects of agricultural practices on biodiversity at the plot scale

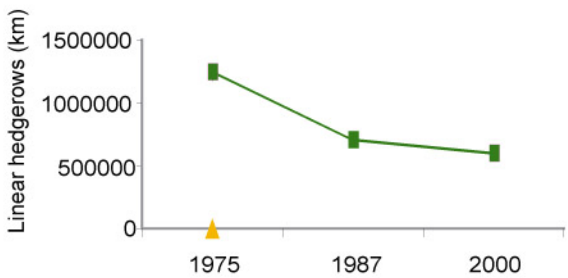
1.3. Effects of modifications of landscape complexity

Historically, the development of agriculture in Europe has been accompanied by major transformations of landscapes and the destruction of natural habitats. More precisely, land use change and the modification of agricultural practices towards greater intensification, since the 1950’s, has resulted in a major modification in the structure of landscapes which can affect biodiversity. These structural modifications have mainly included reductions in the heterogeneity or complexity of landscapes, accentuated by the effects of successive agricultural policies. In parallel, the abandonment of marginal agricultural areas has lead to a homogenisation of vegetation cover which can also affect biodiversity.

The reduction of semi-natural areas in agricultural landscapes



Decreases in the area of calcareous grasslands between 1900 and 2000 in the Bade-Wurtemberg region of Germany (after Poschold et *al.*, 2005).

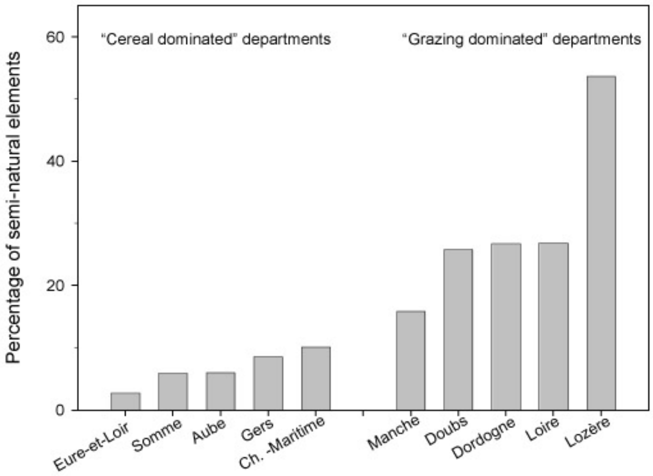


Reduction of linear hedgerows in France between 1975 and 2000 (data from the IFN and the study by Solagro)

Even though the concept is widely used in this field of research, the heterogeneity or complexity of a landscape is often poorly defined. Few studies explicitly outline what is covered by this notion. In general, it integrates the quantity of semi-natural elements in the landscape and sometimes the degree of fragmentation or connectivity between particular habitats. However, the average size of agricultural plots / landscape elements and the diversity of production types are rarely taken into account explicitly.

The percentage of semi-natural elements in French agricultural landscapes is highly variable. In areas of broad-acre cropping, they can represent less than 10% of the agricultural surface area, while in some areas dominated by grazing, they can represent more than half of the surface area. The percentage of the total agricultural surface area occupied by semi-natural elements is less than 20% (a value considered as critical by ecologists) in some 50 French departments, and in these same departments, the cumulative surface occupied by agriculture, a little more than 19 million hectares, corresponds to about 65% of the total agricultural surface area of the country.

The percentage of semi-natural elements (wooded areas, hedgerows, heathlands, low productivity grasslands and alpine summer grazing areas) in some French departments, expressed as a percentage of the agricultural area of the department (data for 2006). For the five "cereal dominated" departments, the area of cereal cropping represents more than half of the total surface. For the five "grazing dominated" departments the surface area covered by grassland also represents more than half of the total surface (source: Agreste, Ministry of Agriculture and Fisheries).



For example, in France the bocage landscapes of the Armoricain Massif or the "Région Centre" are complex landscapes with 31% of the area consisting of semi-natural elements in the commune of Trans-le-Forêt located to the north of Ille-et-Vilaine, while the cereal growing plains or broad-acre cropping areas of the Beauce, Brie, Champagne or Lauragais regions are simplified landscapes where semi-natural elements are poorly represented. Areas with high levels of agricultural abandonment or rangeland grazing, for example in the Massif Central, are dominated by semi-natural elements, but have a landscape structure less complex than that of bocages, as only a few types of land use, abandonment or permanent grassland, strongly dominate.

1.3.1. Effects of landscape heterogeneity

Increasing heterogeneity in agricultural landscapes has, in general, a positive effect on biodiversity. It increases the species richness of the majority of animal and plant groups and contributes to increases in the abundance of most of these. Recent landscape transformations in regions of intensive agriculture, by favouring open areas often to the detriment of semi-natural elements, have lead to decreases in biodiversity.

At the landscape scale, poorly represented landscape elements and non-agricultural elements play a major role as refuge habitats for numerous species, and thus play a large role in increasing biodiversity. The presence of grasslands in a landscape, and in particular low productivity grasslands, is favourable for biodiversity whether this is, for example, for birds, earthworms or soil microfauna.

However, the parameters responsible for these responses vary depending on the taxonomic or functional group considered. The scale of the response of organisms varies as a function of their mobility, their home range and their dispersal abilities. The effects of landscape structure are generally more pronounced for above-ground arthropods and vertebrates than for plants, soil fauna and microorganisms. Regardless of the group considered, specialist species are more sensitive to decreases in landscape heterogeneity than generalist species. From a functional point of view, landscape heterogeneity favours insects that are pollinators or natural enemies of crop pests and limits insect pests. Landscape homogenisation leads to a simplification of communities by decreasing the presence of rare species and increasing that of common species. This dynamics depends strongly on landscape history and in particular on the speed of previous changes.

It is important to note that all of these conclusions need to be modulated depending on the quality of landscape elements, and thus the different practices associated with the management of either grassland or crops. In particular, this interaction with agricultural practices is very important to define the quality of a habitat and the sustainability of extensive management practices needs to be assured for them to have a positive effect on biodiversity. It is however often difficult to completely dissociate the effects of landscape heterogeneity and the degree of management intensity.

Non-productive elements either within or next to agricultural plots play a key role for biodiversity in agricultural landscapes as habitat, corridors for movement, and/or seasonal refuges for numerous species. They increase the diversity of plants and of beneficial insects. Their role has been less studied for soil fauna, but it appears that they may act as refuges for some species such as collembolans and earthworms. Field margins play a particularly important role in the population dynamics of natural enemies of pest species and contribute to the maintenance of the abundance and species richness of these species.

The effect of non-productive elements associated with agricultural plots depends on their nature (which can range from a simple grassy verge to a complex association of hedgerows, drainage canals and rocky areas), but also their agricultural management, the management of adjoining plots and the landscape structure.

Finally, landscape heterogeneity plays a role in biodiversity changes after a reduction of human management pressure (placing an area in fallow for example): the speed at which these changes occurs and the level of species richness reached depends on the landscape around the area, with the presence of a complex landscape structure containing in particular other fallow areas being beneficial. Consequently, fallow areas clearly appear to be landscape elements contributing to the development and maintenance of high levels of biodiversity in agro-ecosystems, both for common species and for rare ones, for species with neutral responses to agriculture and for beneficial species such as pest species natural enemies and pollinators. They have a positive effect on the majority of vertebrate species and it is likely that their impact is greater in regions with low agricultural intensification.

1.3.2. Effects of fragmentation

The fragmentation of semi-natural habitats, with associated effects of decreases in the total number of effectively favourable habitats, a decrease in patch size and increases in fragment isolation, has a generally negative effect on biodiversity. Such fragmentation leads to a decrease in the species richness of most taxonomic groups, even for some low mobility species such as collembolans or soil micro-arthropods, and the decline of isolated plant populations.

Similarly as for heterogeneity, the response of different groups to landscape fragmentation depends on their scale of perception and/or mobility. Consequently, communities of bees and of some species of syrphids are more sensitive to decreases in, and fragmentation of habitats than many other insect species. As a general rule, specialist species are more sensitive to fragmentation than generalists. These effects also depend on the landscape's dynamics and history: specialist species are favoured in relatively stable habitats, but threatened in very dynamic landscapes.

The composition of a landscape and its degree of fragmentation should be jointly assessed, but their relative roles in affecting biodiversity are variable depending on the case. In studies which rank the effects of spatial parameters characterising landscape heterogeneity, spatial configuration often has less explanatory power than the type and composition of landscape elements. In particular, for organisms restricted to specific habitats, the major factor determining the survival of populations is the proportion of favourable habitat in the landscape; the degree of fragmentation of these habitats is less important. This second factor can however become important when the proportion of favourable habitat decreases beneath a threshold level, beyond which the species becomes sensitive to the degree of fragmentation and connectivity of this habitat.

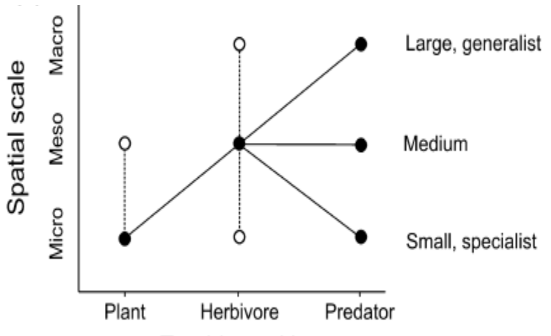
In many agricultural areas and for many species, the percentage of favourable habitat is likely to be well below the minimum threshold value allowing the viability of populations independent of their connectivity. In practice, from the point of view of the management of agricultural landscapes for biodiversity, it is both increases in the proportion of favourable non-productive landscape elements AND their location in terms of connectivity that require consideration.

1.3.3. Differences in landscape perception between species

Different taxonomic groups have differing scales of response to landscape heterogeneity, particularly as a function of their mobility and their requirements for different types of environments. As a general rule, landscape heterogeneity is an important factor in explaining the species richness of mobile groups, with these effects being stronger in crops than in permanent grasslands.

This variability of observed responses can be partly understood by using a classification of species based on the place of a species in the trophic chain and its degree of specialisation. Plants respond mainly to fine scale changes, of the order of a metre to a few tens of meters, herbivores mostly to modifications happening at an intermediate scale, in the order of hundreds of meters for insect herbivores, and for predators at varying scales depending on their degree of specialisation. Amongst predators, specialist species are more sensitive to fine scale changes, in relation to the spatio-temporal distribution of their prey, and generalists at larger scales which can extend over many kilometres as for example in the case of birds of prey.

This distinction on the basis of trophic levels is useful for developing methods for the management of components of biodiversity in agricultural systems: those organisms contributing to agricultural production, whether these are plants or herbivores, can be generally managed at fine or intermediate scales. Predators, which respond to landscape change at whole range of different scales, are linked only indirectly to agricultural production, either as beneficial natural enemies and pollinators, or as species which cause agricultural losses.



Spatial scales of response characteristics of organisms from different trophic groups as a function of their degree of specialisation (after Tscharntke et al. 2005).
The closed circles represent high probability responses, while the open circles uncommon, but possible responses.

1.4. Between landscape heterogeneity and intensification

Landscape heterogeneity, agricultural practices, and production systems act simultaneously on biodiversity, sometimes in synergy and sometimes in opposition, with the effect of one limiting the potential effects of others. Evaluating their relative effects on the state and dynamics of biodiversity in agricultural landscapes is not an easy task, with one difficulty being the degree of correlation often observed between them. There also exists, in the majority of cases, a strong correlation between the intensification of conventional agriculture and landscape homogenisation, with increasing plot sizes and the fragmentation of semi-natural elements. The effects on biodiversity due to landscape heterogeneity and those due to the intensification of agricultural practices have occasionally been ranked into hierarchies using *ad hoc* statistical analyses.

1.4.1. Respective effects of these two factors

In Europe, factors operating at the landscape scale are more important in explaining the state of biodiversity than local factors. This is particularly true for the degree of intensification of production systems and landscape heterogeneity (composition of semi-natural elements and crop diversity) but also, to a lesser extent, for connectivity.

A large study of 25 landscapes across seven European countries including France, shows that at the landscape scale species richness of vascular plants, birds and five groups of arthropods (carabid beetles, wasps and bees, shield bugs, spiders and syrphid flies) increases with the proportion of semi-natural elements. The effects of intensification are often negative, but the key variables explaining these modifications of species richness vary between groups. In brief (referring to the figure):

- bird richness is positively correlated with the percentage of semi-natural elements and negatively with the level of fertilisation (average amount of nitrogen applied per hectare of crop).

- the richness of herbaceous plants increases with the percentage of semi-natural elements and decreases with the percentage of heavily fertilised crops (>150 kg N /ha /year) in the landscape.

- the richness of all arthropod groups increases with the proportion of semi-natural elements, although only marginally for bees and bumblebees, and increases with crop diversity (average number of crops per farm), but only marginally for spiders. Habitat diversity (average number of semi-natural habitats) has a positive effect on the richness of some groups such as wasps and bees, a negative effect on the richness of groups such as shield bugs or beetles, and little influence on the richness of spiders.

In this type of study, variables characterising landscape structure (number, size and density of semi-natural patches, fragmentation indices) do not seem to have a major effect on the species diversity of these major taxonomic groups. However, connectivity influences other characteristics such as the distribution of body sizes and guilds (groups of organisms using the same trophic resource).

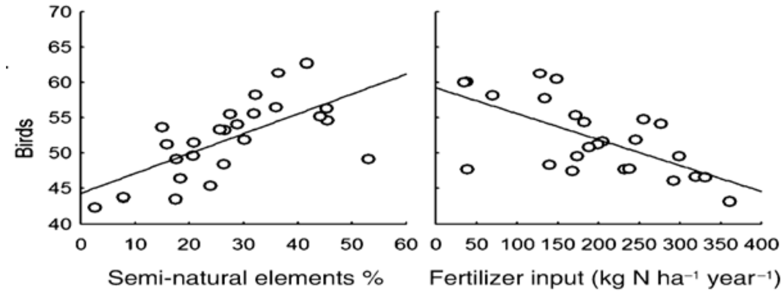
The species composition of communities of beetles, carabid beetles, wasps and bees, shield bugs, spiders and syrphid flies in these European landscapes depends slightly more on the level of intensification than on the landscape heterogeneity of semi-natural elements, with the characteristics of local habitats (composition and diversity) having lesser effects. The effect of intensification is more strongly linked with the percentage of heavily fertilised crops and decreases in crop diversity than with the average level of fertilisation or the average frequency of pesticide application to cropped areas, except for syrphid flies. The effect of landscape can be divided into two:

one half of this effect due to spatial configuration (that is the connectivity between semi-natural elements), the other half due to compositional parameters (the type and diversity of elements).

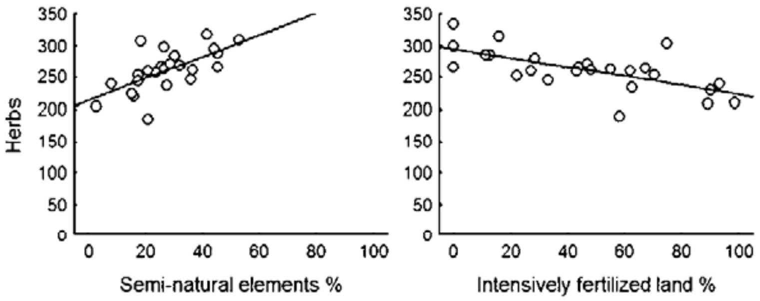
For plants, species richness of natives, perennials, clonal plants and species of particular conservation value are particularly favoured by the presence of semi-natural habitats and non-intensive modes of production.

Frequent positive effects of landscape heterogeneity on the species richness of numerous groups of organisms, and negative effects of the degree of intensification of agricultural systems: observations from a range of European landscapes.

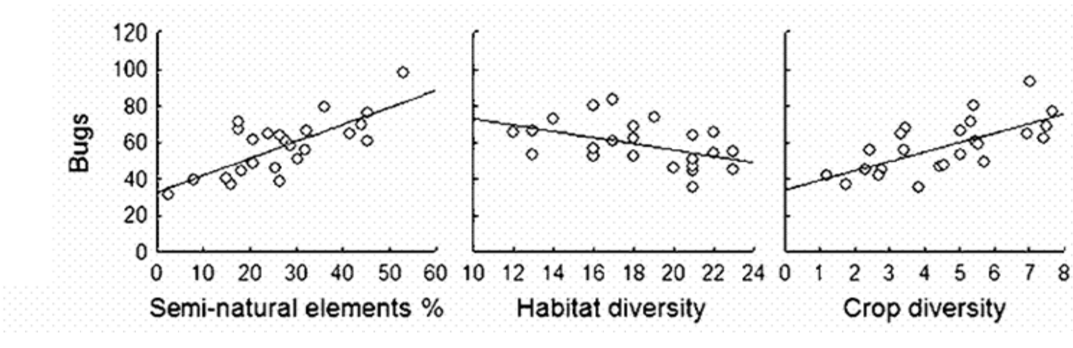
Birds: major effects of the percentage of semi-natural elements and of the level of fertilisation



Herbaceous plants: effects of the percentage of semi-natural elements and of the area of heavily fertilised crops



Arthropods: effects of the percentage of semi-natural elements, of crop diversity and of the diversity of semi-natural habitats



Synthesis of results obtained from twenty five 16 km^2 landscapes from seven European countries: France, Belgium, Holland, Germany, Switzerland, Czech Republic and Estonia (after Billeter et *al.*, 2008).

Agricultural intensification and landscape simplification have opposing effects on beneficial insects and pest insects. Beneficial insects (pollinators and natural enemies of agricultural pests) are favoured by complex landscapes and non-intensive agriculture, while pest insects are favoured by intensive agriculture in highly homogenous landscapes. For butterflies, the landscape effect is very strong and masks that of the production mode.

Finally, the intensification of conventional agriculture has negative effects on biodiversity, with the key factors involved varying between the taxonomic groups considered and the agricultural practices involved. In contrast, landscape heterogeneity and in particular the proportion of semi-natural elements, has a positive effect on numerous taxonomic groups.

Amongst these semi-natural elements, the edges of fields (grassy margins, hedges or woods) play a key role in agro-ecosystems as habitat, seasonal refuges or corridors for many species. There can be genetic differentiation between populations at a field's edge and within the field, as in the case of the grain aphid (*Sitobion avenae)*, in response to the difference in the stability between cropped and semi-natural habitats. Studies of migratory fluxes between cropped and semi-natural environments have shown considerable movement from one area to another. In addition, these studies have confirmed the minimal role of wild grasses (graminaceae) in the migration of colonisers of cereals.

For orchards, local environment, landscape characteristics, agricultural practices and orchard structure all interact. Only some recent studies have quantified the importance of these different factors: in apple orchards in south-eastern France the local environment and phytosanitary treatments used explain the composition of bird communities (25% of variation), more than the surrounding landscape (15% of variation). In pear orchards, the totality of the studied variables (agricultural practices and environmental characteristics) explained 30% of the total variability of arthropod communities. Agricultural practices explained 12% of this variability, while the characteristics of the surrounding environments (hedgerows) explained only 2%.

1.4.2. The effects of organic agriculture

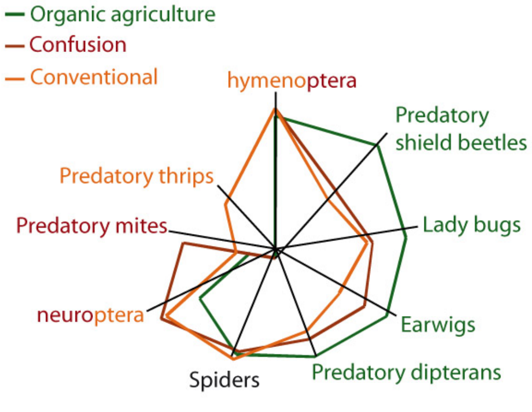
Some studies have assessed the respective effects of landscape heterogeneity and the modes of agricultural production with comparisons of the impacts of conventional and organic agriculture in landscapes of varying complexity. Changing from conventional agricultural production to an organic one often has an overall positive effect on biodiversity. The richness of plants, soil microorganisms, vertebrates and arthropods increases. The abundance of invertebrate predators also increases, while the responses of soil fauna are either positive or neutral.

This overall response can be modulated by landscape heterogeneity which can mask the effect of the mode of agricultural production for mobile species such as carabid beetles or butterflies. For example, the species richness of carabid beetles in a wheat field depends primarily on landscape structure and increases with the proportion of grassy margins (hibernation areas for reproductive individuals during spring), regardless of the production system (conventional or organic). For butterflies, which are not greatly dependant on crops, increasing landscape heterogeneity increases species diversity and has an effect at all scales on community composition. This effect is greater than that of production mode, conventional or organic. For plants, it is possible to determine a threshold of landscape complexity below which the type of agriculture used can increase biodiversity, and above which it has little effect.

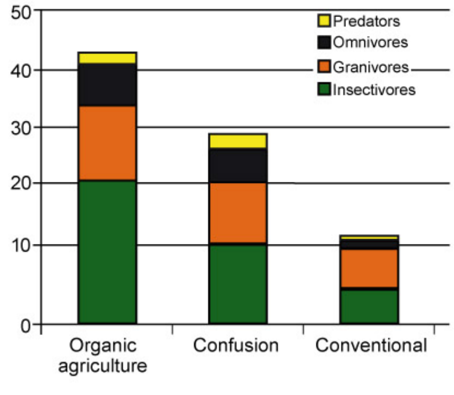
Organic agriculture, as for landscape heterogeneity increases the species diversity of bees and wasps. For spiders, landscape structure influences species richness while the mode of agricultural production has impacts on abundance, organic agriculture being more favourable to these predator species often involved in the biological control of crop pests. For soil fauna, the beneficial effects of organic agriculture occur not only in cropped fields but also in the neighbouring margins and hedgerows.

For arboriculture, a minimisation of impacts on biodiversity is often obtained by limiting the use of pesticides and in particular through the adoption of organic agriculture.

Groups of apple pollinators
and natural enemies of apple pests



Bird abundance by functional group



A comparison of the states of communities of pollinators, natural enemies of crop pests and birds observed over four years in apple orchards near Avignon and Valence. The observations were carried out either under conditions of organic agriculture (OA), control of codling moth using chemical insecticides (conventional), or using the method of pheromone traps (confusion). Beneficial insects: graph constructed from the data presented by Simon et *al.* (2007). Birds: after Bouvier (2004).

The use of organic agricultural practices does not always allow the re-colonisation of an environment by rare species. As well as the adoption of non-chemical management practices, a re-structuring of the landscape (creation of hedgerows, other refuge zones) appears indispensible for the restoration of species of particular conservation significance.

In summary, adopting organic agricultural practices will have few effects on biodiversity in simplified, intensively managed landscapes, due to a lack of source populations. However, in landscapes which retain some semi-natural habitats and source populations, organic agriculture has a particularly positive effect. Finally, in complex landscapes where small cropped fields are mixed with semi-natural elements organic agriculture will have little effect given that biodiversity will already be high across such an area.

1.4.3. Taking into account the functional characteristics of organisms

The majority of studies have analysed the effects of agriculture concentrating on the species richness or species composition of major taxonomic groups. A problem here is that differing species perceive environmental heterogeneity in different ways. A more functional approach to biodiversity can be used to understand the relative effects of the intensification of agricultural practices and landscape heterogeneity by taking into account, in particular, an organism's mobility and degree of trophic specialisation.

For sedentary or poorly mobile species, biodiversity is essentially determined by environmental conditions resulting from agricultural practices at the plot level. The biodiversity of such species will be low in areas with high intensification of annual or perennial cropping systems, especially in simple landscapes. It could be favoured by the use of biological or integrated methods of agriculture and would be higher in extensive grazing systems based on grasslands. It would be positioned between these two situations for mixed systems of polyculture-grazing. Despite this complexity it is possible to propose the hypothesis that an increase in connectivity at the level of agricultural landscapes could favour some species by increasing the size of their habitat.

For mobile species, landscape structure plays an important role which can almost completely or partially compensate for the negative effects of some practices. This effect is particularly marked in systems based on annual or perennial crops. Some studies have suggested that there exists a threshold of composition (a proportion of semi-natural elements and cropped fields) and landscape connectivity below which the influence of agricultural practices on species diversity is dominant, while, beyond the threshold the role of compensation at the landscape level becomes expressed. For grazing systems based on grasslands, it appears that even for mobile species, the management of mowing and grazing is a key element in the responses of biodiversity.

The average effective mobility of organisms in a taxonomic group modulates the effects of landscape heterogeneity and agricultural intensification on their species richness.

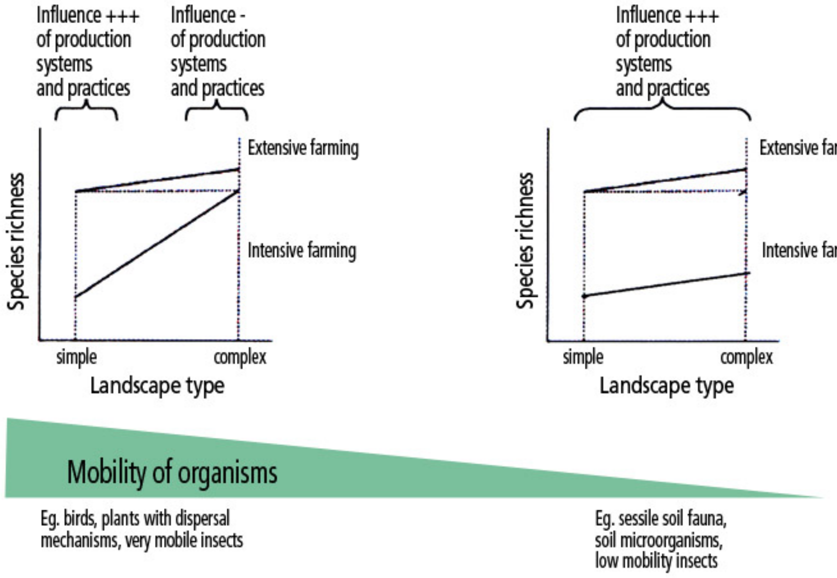


Figure showing the effects of landscape complexity and the level of agricultural intensification on landscape scale species richness as a function of the effective mobility of organisms (modified from Roschewitz et *al.*, 2005).

The species most affected by modifications of landscape heterogeneity are thus mobile species, specialist species and those species for whom the scale of perception of the landscape is close to the grain of the landscape (for example, organisms whose range is of the same order of magnitude as the plot size of landscape elements). For such mobile species, landscape structure can partially compensate for the negative effects of agricultural practices, while for poorly mobile species such as plants, there is a threshold of landscape heterogeneity below which modifications of the production system are necessary to favour biodiversity.

Finally, species richness appears to be an interesting, albeit limited, parameter to assess the effects of agriculture on biodiversity. In fact, these effects manifest themselves primarily by modifications of the composition of communities, with species replacements occurring on the basis of their functional traits. Consequently, for example, specialist bird species respond negatively to pesticide use, and are thus replaced by generalist species, which respond positively.

1.5. Is an overall evaluation possible?

Assessing the overall effect of agriculture on biodiversity is dependant on having indicators allowing the characterisation and quantification of biodiversity. Work on such indices has been carried out both at the national and European levels.

1.5.1. Direct and indirect indicators

The preceding analyses show that it is important to analyse the effects of agriculture on biodiversity by considering the state of biological communities in all of their dimensions: not only in terms of their species richness or the abundance of specialist species, but also in terms of biomass and the number of individuals of a large range of species as well as trophic levels.

The search for indicators of environmental quality (including biodiversity) in European agricultural landscapes and to assess the effects of agri-environmental policies is an active field of current research. A first group of indicators has been developed at the national level for the evaluation of the environmental impacts of agriculture (life cycle analysis) and for the agri-environmental assessment of farms. These indicators are called "indirect" and are constructed from information on agricultural practices. A network of measures of soil quality (RMQS) has been put into place, as well as a database of pedo-climatic environments and land uses (DonSol). This database is associated with databases of biological and microbiological diversity that are currently being constructed. At the European level, the use of large databases can provide indirect indicators linking the use of agricultural inputs and the diversity of land uses for production modes of organic agriculture or low input systems.

Indirect indicators should however be used with caution. In fact, the variability and complexity of ecological processes controlling the dynamics of the diverse components of biodiversity in agricultural landscapes means that this type of approach can fail to take into account poorly known or unmeasured factors. The variability in the intensification of agriculture and the diversity of environmental conditions in Europe mean that we can only place a limited degree of confidence on relationships between agriculture and biodiversity that can be established at this scale. Additionally, as the impacts of agricultural practices are often poorly known, it is difficult to determine the exact nature of data that needs to be collected. It is thus important to define the direct indicators of the current state of biodiversity.

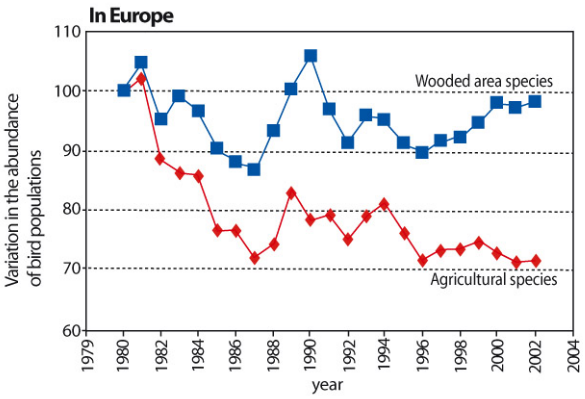
Currently, the indicator species most widely used as direct indicators are vascular plants, birds and butterflies. However, defining such target organisms is far from trivial: while some studies have shown that some groups can be used as indicators of overall biological richness under particular conditions, the majority of studies show only weak links between the taxonomic richness of one group and that of others.

Another method to develop biodiversity indicators is to classify them as a function of the three main objectives of the maintenance and improvement of biodiversity in the agricultural context: indicators of nature conservation (conservation of rare or menaced species), indicators of the resilience of an agro-ecosystem and indicators linked to plant protection (biological control of pests by predators and parasitoids). It is possible to define a fourth category of indicators linked to soil fertility. The first three categories can be assimilated into three primary functions, these being respectively conservation, ecological and agronomic functions. Nevertheless, the complex nature of relationships between biodiversity and agriculture, as already previously described, results logically in difficulties in developing / using appropriate indicators.

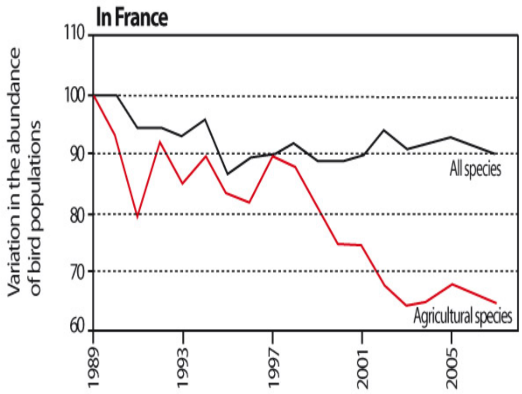
1.5.2. Example: the European indicator "Common Birds"

This indicator, one of the twelve indicators of sustainable development used by the European Union, monitors variations in the abundance of birds nesting in terrestrial environments. Observations are recorded by national observatories, which carry out an annual ‘multi-species / multi-site’ survey of the abundance of nesting birds (10,000 points in France). By focusing on species that are habitat specific, this indicator can assess variations in species diversity, the genetic variability of these species (by considering this as a function of abundance) and in the diversity of ecosystems (by estimating the differences in species composition between different habitats). This is an effective indicator of variation in the conservation status of birds. It is also an indicator of ecosystem functioning, as this group is at the summit of a trophic chain and thus depends on the healthy functioning of the whole trophic web.

Bird populations in agricultural areas are in decline in Europe as well as in France.
A decline correlated with agricultural intensification



Variation in bird populations in different European habitats from 1980 to 2002. A major decline of populations in agricultural areas is evident. (Royal Soc. for the protection of birds – European bird census council – Bird Life International).



Variation in bird populations in France from 1989 to 2006 for all species, and agricultural species. A major decrease is evident for agricultural species.

This data shows, in Europe as in France, a decline in bird populations in agricultural areas greater than that in other areas, in the order of 29% in France over the period 1970-2000 (with the same magnitude over the period 1989-2006, which confirms the continuation of the process). Comparing across European countries, the decline calculated between 1975 and 2000 appears of the same order of magnitude as increases in agricultural productivity (evaluated using cereal production in 1993). Denmark appears as an exception, with an increase in agricultural production and the maintenance of bird populations, due to a policy of reduction of agricultural inputs, pesticides and fertiliser.

These types of indicators strongly suggest that agricultural intensification over the last few decades, in France and more generally in Europe, has resulted in a progressive decrease in habitat for birds in agricultural areas and/or a marked degradation of the quality of these habitats, with a general reduction in available resources. In the first case, this can be a result of, for example, the ploughing of permanent grasslands or removal of hedgerows. In the second case, the major role of agricultural practices reducing available prey (small mammals, insects…) can be identified. The interpretation of such changes over short time scales (a few years) is more difficult, largely due to the lack of suitable data (data concerning insect populations, weeds…) as well as to delays in any responses.

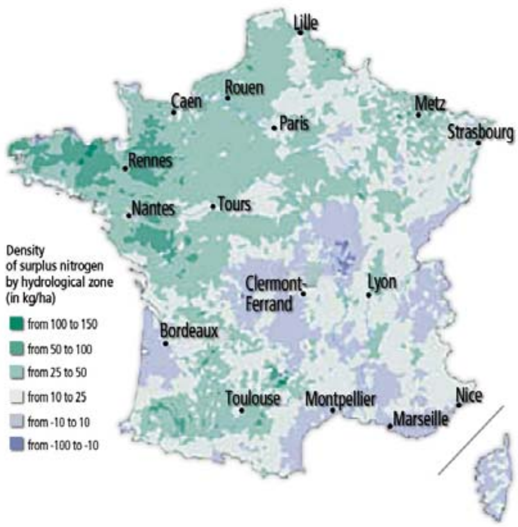
In England, analyses have been carried out on 20 species found in agricultural environments that are used as indictors of environmental quality by the government. These analyses have explored the relationships between these species and a large number of environmental parameters as part of the *Countryside survey* which monitors the changes in landscapes and species every ten years for the last forty years. The species that have not decreased since 1970 are those associated with intensively managed grasslands or landscapes containing large proportions of woods or urban areas. The species which have suffered major declines are often those associated with landscapes dominated by crops.

Such indicators allow the identification the major trends of biodiversity modification up to the national level. They require systems of biodiversity monitoring and observation as well as key indicators of biodiversity trends, the development of which is vitally important.

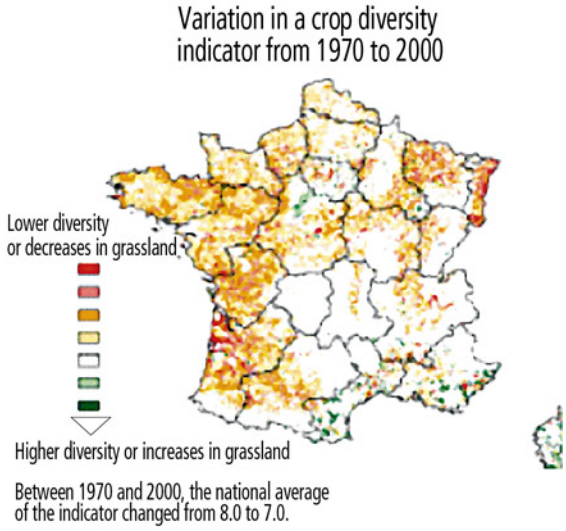
In addition, these types of indicators, coupled with other information, can also be used for retrospective and prospective analyses, or constructing scenarios of future biodiversity changes in agricultural areas. In England, the data produced by the observations of bird populations, coupled with those of additional data from monitoring of the effects of agro-environmental policies (MAE) and genetically modified crops (GMO) have allowed the development of scenarios of the possible effects in the country of the generalisation of either of these practices. In comparison to the reference scenario, which predicts a biodiversity loss of -15% by 2020, these scenarios suggest that the MAE's would slow the loss of bird biodiversity but not prevent it (it would remain slightly above -10%) and that the use of herbicide resistant GMO's would slightly increase biodiversity losses (the decline would reach -18%).

1.5.3. Indicators of pressure on biodiversity

Indices of the intensification of agricultural practices and crop diversity at the national scale



Spatial distribution of the density of surplus nitrogen



Temporal trend for a crop diversity indicator in French communes. This indicator integrates the specialisation of crops and the presence of grasslands (after Pointereau and Bisault, Solagro, 2007).

This assessment has emphasised the importance of, on the one hand, the intensification of agricultural practices and in particular of fertilisation on biodiversity declines, and on the other hand, the importance of the complexity / diversity of the landscape and in particular the importance of extensive grasslands for biodiversity maintenance. Maps of the spatial distribution of surplus nitrogen, an indicator of the intensification of agricultural practices, or of the variation in the diversity of crops (taking into account permanent grasslands) allows the identification of the areas in France most concerned by these factors unfavourable to biodiversity. Together, maps of these two indicators indicate an arc covering all of the western part of France, the north and the north-west, where the intensification of agricultural practices has been accompanied by thirty years of homogenisation of land use and a reduction in grassland area. Consequently, these regions should be considered as priorities for policies of biodiversity maintenance and restoration. The centre and the south-east are, in contrast, less intensified and semi-natural elements are better represented. In these regions the challenge is to conserve the biodiversity currently in place.

1.5.4. Conclusion

From all of these results, it is possible to conclude that agricultural intensification, and its corollary, the simplification of agricultural landscapes in western Europe, are the major factors responsible for the loss and profound modification of biodiversity, in particular over the last few decades. Available knowledge in the literature shows that the ability of landscapes to provide for different species depends both on their structure and the quality of each of their components. These factors are determined by the agricultural mosaic, and by the suite of agricultural practices employed by farmers. Increased landscape complexity, represented in agricultural landscapes by the proportion of cropped areas to semi-natural elements and by their spatial arrangement, favours biodiversity overall, as does the use of non-intensive agricultural practices.

In summary, the type of agricultural and semi-natural landscape elements, their relative surface area at the landscape scale, their spatial arrangement and connectivity, the management of agricultural AND semi-natural elements, are all factors to be considered equally in the development of policies for the promotion of biodiversity. Particular attention should be devoted to the management and connectivity of semi-natural habitats.

1.6. Identification of opportunities for adaptation

The "management" of agricultural areas in a manner favourable to biodiversity requires the definition of explicit biodiversity objectives. However, there are broad management options that are generally positive for biodiversity at the scale of agricultural landscapes, and also opportunities for management modifications that can be identified for the main types of agricultural situations.

Necessary objectives
Given the diversity of the responses of organisms to agricultural practices and the characteristics of agricultural landscapes, managing such landscapes in order to preserve biodiversity cannot be accomplished without defining clear objectives in terms of biodiversity (target species or groups of species…). Only such a definition of objectives will allow the definition of the management and the key aspects of landscapes favourable for the targeted species.

Different strategies for the management of agricultural landscapes depending on biodiversity targets

Management / Conservation Objectives → Ecological characteristics of target species and degree of complexity of favourable landscape → Management leading to the desired degree of complexity

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The same landscape change can be favourable to one species and unfavourable for another. For example, *Abax parallelepipedus*, a forest dwelling carabid beetle requires a network of connected hedgerows or other dense vegetation to maintain its populations in agricultural landscapes. These same hedgerows act as barriers for the butterfly *Lysandra bellargus*, and isolate its populations in agricultural fields from each other.

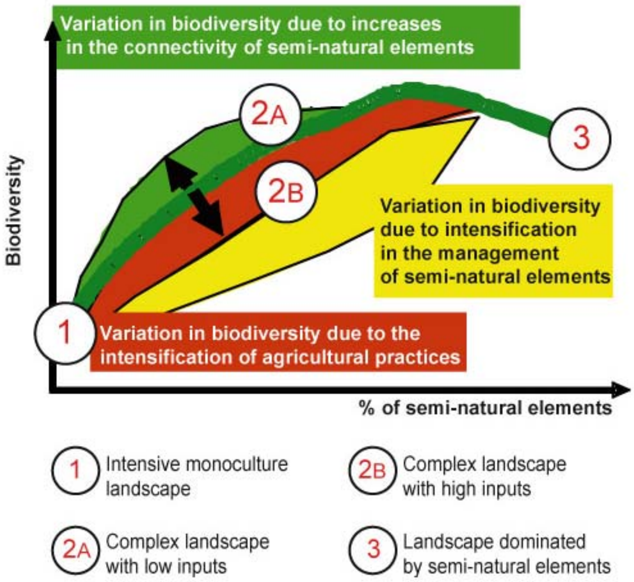
1.6.1. Favourable trends

Even if it is not possible to guarantee a positive effect on particular organisms, there are some trends and modifications of agricultural landscapes and production systems that appear to be generally positive for biodiversity in agricultural landscapes and metropolitan areas.

To help with the identification of these favourable trends, we have, from information scattered in the literature, constructed a conceptual model linking spatial parameters in agricultural landscapes and biodiversity as a function of the intensification of agricultural management.

Proposed conceptual model linking biodiversity and spatial parameters of agricultural landscapes as a function of the intensity of management

Figure showing the effects (i) of the percentage of semi-natural elements in the landscape, often strongly linked with the intensification of agricultural practices, (ii) of the intensification of the management of these semi-natural elements, and (iii) of the connectivity of these elements on biodiversity. This conceptual model is a synthesis of the results of numerous studies. Two difficulties were en encountered in the construction of such a model from the literature: the definition of biodiversity, which is not only the number of species, but also includes the relative abundances of organisms, and also the frequent correlation between agricultural intensification and landscape structure.



This conceptual model emphasises the non-linear responses of biodiversity to the proportion of semi-natural elements present in the landscape and the existence of thresholds beneath which the extinction risk for many species is increased. Above these threshold values, connectivity can buffer the negative effects of fragmentation on biodiversity.

It should also be noted that the context for managing biodiversity in agricultural landscapes has been rapidly changing, moving from an emphasis on nature conservation to one focused on the maintenance and development of ecosystem services (see chapter 2). The areas under consideration are also changing as it is no longer possible to conserve habitat without taking agriculture into account. It is however in this area that the lack of research is the most acute. Additionally, consideration of the intensification of management must now apply not only to that linked to production, but also that linked to the management of semi-natural areas. The generalised increase in the use of herbicides in both contexts, including in semi-natural areas, is a major issue for biodiversity. Finally, biodiversity is only one aspect to be considered in the management of a landscape. Water quality (the degradation of which is often linked to biodiversity losses) as well as the aesthetic and cultural value of landscapes are important aspects of landscape multi-functionality.

What strategies in terms of the management of agricultural landscapes can emerge from this type of scientific information?

- Firstly, in homogenous agricultural landscapes, these results show the necessity of increasing the surface area of semi-natural elements by integrating them into the local agricultural and cultural context and accompanying this landscape restructure with adapted management methods. The results also show the necessity of de-intensifying agricultural practices over some parts of the landscape.
- Secondly, in complex agricultural landscapes, these results show that it is necessary to remain above the threshold of homogenisation and to maintain agricultural intensification within the limit at which landscape heterogeneity can, at least partially, compensate for the negative effects of this intensification.
- Finally, in landscapes dominated by semi-natural elements, limiting the intensification of management and avoiding land abandonment are the most important.

Green and blue veins for biodiversity

Amongst the measures proposed by the Grenelle de l'Environnement summit, is the development at the national level of a system of green and blue veins (links) for biodiversity. This proposition is based on the hypothesis that ecological connectivity is necessary to maintain a good level of biodiversity. The green veins should, in particular, allow wild animals to move around the national territory more easily. Climate change will mean that many species will need to find new migration routes to reach new habitats adapted to their requirements. In general, and especially in a country in which agriculture is very important such as in France, such an ecological network in agricultural areas would play a key role in the establishment of a national ecological network.

The available scientific knowledge clearly shows that landscape complexity is a key element determining the biodiversity of agricultural areas. This fact supports the proposition to develop a system of green veins for biodiversity. In particular, semi-natural elements (woodlands, heaths, fields, hedgerows, roadsides, grassy margins…) provide habitat, refuges and corridors for numerous animal and plant species. Their presence allows the maintenance of species that would have otherwise disappeared from areas of intensive agriculture. Their effect depends on the surface area that they occupy and their "quality", which is linked to their size, their shape and the manner in which they are managed. These elements form a more or less connected network within a cropped area and their connectivity is one of the factors that favour biodiversity *via* the dynamics of meta-populations and meta-communities, and by the survival of species requiring multiple habitats over the course of their life cycle. Such a network contributes to the existence of "green veins" at the landscape scale. A particularly good example is that of the bocage where hedgerows are, or were, inter-connected. Even if their effect on some species of particular conservation value is not strong as compared to larger natural areas, their role in maintaining the components of overall biodiversity is fundamental.

However, weaknesses in current knowledge require some caution in the assessment of the proposed green veins:

- Different species can respond in contrasting manners to landscape complexity, and the type of ecological networks required will differ depending on the desired biodiversity objectives, particularly in terms of targeted species. The criteria for identifying / creating / managing the green veins will need to be specified depending on species requirements. Target species can, for example, be defined for different regions, and the type of network of green veins to be developed and the management measures to be taken then developed for these species.
- A network of green veins which favours biodiversity by facilitating the movement of organisms may also increase the dispersion of pathogenic or invasive species, or possibly have negative effects on some aspects of biodiversity such as diversification linked to local adaptation.
- If the complexity of a landscape is important for biodiversity, the quality of its component habitats, including in cropped areas, is equally important. The development of a network of green veins at the local and national scale does not remove the requirement to also adapt agricultural management so as to contribute to desired biodiversity objectives. It is not just a quality network of green veins that is required, but also good quality habitats in sufficient quantity to maintain biodiversity, which requires also the maintenance of non-linear landscape elements such as, for example, dry grasslands. To effectively change the current situation, it will be necessary to consider changes of management in some agricultural plots, which poses the problem of the acceptability of such changes for the plot owners or users.

Taking into account the current state of knowledge, the proposition of a network of green veins is to some extent an example of a solution proposed to deal with an important problem (the protection of biodiversity) before the scientific information necessary to fully assess its effectiveness is available.

It should be noted that that the scientific resources necessary to adequately address these questions are seriously inadequate, particularly in terms of establishing intensive monitoring programs in order to study the influence of landscape characteristics on biodiversity at multiple spatial scales and at sufficiently large experimental sites. Such resources are however indispensible in order to develop management tools for land managers. In particular it would be necessary to characterise the functioning of meta-populations or meta-communities of important biodiversity components to identify source and sink habitats for these components at the landscape / national scale. It would also be useful to assess the possible risks associated with the strategy of establishing such a network of green veins.

This new policy of a national network of green veins should be highly integrated with agricultural policies, such as for example, the policy of cross-compliance / eco-conditionality by which farms in France with a medium to high production of cereals and oil producing crops are required to establish grassy margins along their watercourses. Agri-environmental measures concerning the management of agricultural field margins (canals, rocky areas, hedgerows) could also reinforce the quality of the network of green veins. Agricultural activities could thus contribute to the creation and management of linear landscape elements at the plot level. The integration of such elements contributing to local ecological connectivity into regional and national scales will be important for the development of a national network of green veins. To achieve this it will be necessary to link agricultural, urban and environmental policies and actions.

1.6.2. Possible opportunities for management change

On the basis of the information available in the literature, we have attempted *a posteriori* to characterise the primary types of agricultural situations in France in terms of their effects on biodiversity *via* their level of intensification and type of landscape heterogeneity. The goal is not to rank in a quantitative and precise fashion all agricultural situations in such a framework (the information required for this is not available) but rather to identify the opportunities and the range of options for these types of agricultural situations.

In a synthetic manner, we have outlined the effects on biodiversity of the levels of intensification and landscape complexity for the major types of agricultural situations in France: grazing of grasslands, grazing-polyculture, annual crops, vineyards and arboriculture. Taking into account the available knowledge, it was necessary to simplify the conceptual model by incorporating a gradient of the effective mobility of organisms.

Proposed conceptual model linking biodiversity and the spatial parameters of agricultural landscapes as a function of management intensification

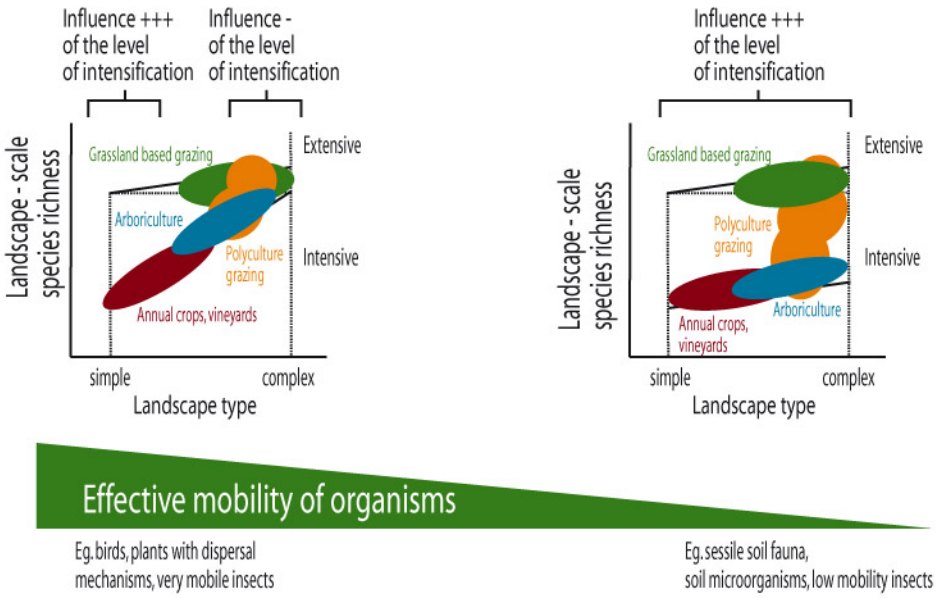


Figure showing the effects of landscape complexity and of the level of agricultural intensification on species richness at the landscape level: the positions of the major types of agricultural situations in France are shown

For sedentary or poorly mobile species, biodiversity is essentially determined by environmental conditions, which are dependent on plot level management. The diversity of such species will be low with increasing intensification in annual or perennial cropping systems, regardless of the landscape structure, either simple or complex. The diversity of these species will be favoured by organic or integrated methods of agricultural production. It will be highest in extensive grassland grazing systems and intermediate in systems of grazing-polyculture. Despite these factors, it is possible to hypothesize that an increase in connectivity at the agricultural landscape scale, in particular through the development of the national green veins network, could favour some of these species by increasing the size of their habitat.

For mobile species, landscape structure plays a major role, which can compensate totally or partly for the negative effects of some practices. This effect is particularly marked for systems based on annual or perennial crops. We can hypothesise the existence of a threshold of composition (proportion of semi-natural elements versus cropped fields) and landscape connectivity below which the influence of management is dominant, and above which management practices can be compensated for at the landscape level, but no studies allow the confirmation of this hypothesis. For systems based on grassland grazing, it appears that even for mobile species, the management of mowing and grazing are key elements in determining the responses of biodiversity.

This general analysis, based on the synthesis of sparse elements available in the literature, but not yet completely supported by robust experimental studies, allows an understanding of why it is desirable, in the context of biodiversity conservation, to implement at the same time methods that develop and manage landscape structure, together with environmentally friendly agricultural practices. In addition, such an analysis provides a context in which to consider the respective roles of the development and management of landscapes and of the level of agricultural intensification depending on the target organisms and the agricultural situations considered (see chapter 3). It is apparent that this is a broad-brush analysis and will need to be expanded by the inclusion of more precise information adapted to local regional specificities and of the characteristics of targeted components of biodiversity.

1.7. Conclusions

Taking into account its coverage of a significant part of the surface area of the French territory, agriculture is an activity that has a major impact on biodiversity, from local to national scales. Understanding the relationships between agriculture and biodiversity is therefore critical in terms of the objective of reducing biodiversity losses, an objective to which France has committed in the context of the convention on biological diversity. Such understanding is also necessary to better inform reforms of the common agricultural policy, or to determine the place of agriculture in the national biodiversity strategy. Agriculture is also an important activity for developing opportunities to preserve and even restore biodiversity (see chapter 3).

Some important conclusions can be drawn from the scientific studies on the effects of agriculture on biodiversity:

♦ At the plot scale, any major intensification of agricultural practices (fertilisation, pesticides, grazing, ploughing…) leads to a negative effect on biodiversity: a reduction in species richness and a simplification of the species present, for a large range of groups of organisms, and a profound modification of the functional characteristics of species. In contrast, a moderate management intensity can favour biodiversity in agro-ecosystems (for example moderate fertilisation of nutrient poor grasslands, moderate grazing of semi-permanent grasslands on rich soils, reduction / improvement of tillage regimes).

♦ At the landscape scale, the effects of agriculture on biodiversity are mainly linked to the level of agricultural intensification and the degree of landscape homogenisation induced: for this second aspect, the percentage of semi-natural elements (including particularly wooded areas, non intensively managed grasslands, field margins and hedges) present in the landscape, and to a lesser extent the quality of local habitats and their connectivity, appear to be important factors for biodiversity.

♦ For complex agricultural landscapes with a high proportion of semi-natural elements, there can be some “compensation” of the negative effects on biodiversity of intensification by heterogeneity at the landscape level. However, for about 65% of the surface area in France used for agriculture, the level of heterogeneity is below the values which would potentially buffer biodiversity from increases in intensification. In these landscapes, it seems necessary to seek opportunities for change both in level of intensification of agricultural systems and in the degree of landscape simplification to achieve explicit biodiversity objectives.

♦ If landscape homogenisation has not been too great and has not led to a reduction in the regional *pool* of species, modifications of biodiversity appear to be reversible, opening the way for restoration measures.

♦ “Indicator taxa”, are very useful for monitoring major trends in the effects of agriculture on the diversity of targeted groups, but should not be used to infer changes in overall biodiversity at large spatial scales. Indicators of pressure on biodiversity, representing the level of intensification and the degree of simplification of a landscape, are useful.

♦ The majority of these conclusions are based on "instantaneous" comparisons, from systems managed in different ways. The time factor (rate of biodiversity changes, history of plot or landscape management…) is generally not taken into account.

The scientific knowledge of the effects of agriculture on biodiversity can be used to propose strategies to preserve and/or restore biodiversity depending on the production systems and regional contexts considered. For example:

- In bocages in Brittany where the landscape mosaic is complex, it is important to maintain the quality of semi-natural elements and in particular field margins (rocky margins / hedgerows) which are subject to strong management pressures. It is also necessary to re-establish the connectivity of these networks where the removal of hedgerows has been excessive.

- In cereal growing plains such as in the Beauce, Brie, Champagne or Lauragais regions, the establishment of new semi-natural elements (perennial grassy areas, hedgerows, trees, copses, ponds…), connected to those already in place, should be accompanied by a reduction in intensive management techniques (pesticides, fertilisation, ploughing…).

- In areas of intensive grazing dominated by grassland, such as in parts of the Jura region, the introduction of cropped fields would increase landscape heterogeneity and also reduce the impacts of damaging species such as voles.

- In low mountain regions in the south and centre of France, agricultural abandonment can lead to losses of biodiversity, which cannot be prevented other than through the maintenance of agriculture over some parts of this area.

More generally, this assessment has also highlighted the manner in which scientists involved in research on the "effects of agriculture on biodiversity" pose their questions:

– Generally, a relatively large scientific community is working on this topic including from the areas of general ecology, agro-ecology and to a lesser extent, landscape ecology. This community generally approaches questions concerning the "effect of agriculture on biodiversity" through questions such as "understanding the dynamics of species and communities, and more rarely genetic diversity, in systems under anthropogenic pressures". These questions are generally focused on conservation issues, often using agricultural systems as model systems as they have been “human modified” and are thus interesting for these types of ecological studies.

– In most cases, scientists dealing with these questions leave agriculture as somewhat external. The major position occupied by humans in agro-ecosystems should have logically led to a field of research considering such systems as *socio-ecological systems*. However this has not occurred, and in the majority of studies agricultural practices from the plot level up to landscape structuring are seen as external to the studied systems, and are considered as external forcings. The number of studies translating the question of "effects of agriculture on biodiversity" by questions of the type "what is the casual link between socio-economic factors and biodiversity *via* the effects of agricultural and non-agricultural actors and stakeholders?" is very few.

– Even worse, the scientific community is currently little motivated and/or prepared to consider questions in this context, with some of the skills required, for example studies of economics at the scale of farms, tending to disappear in France over the last few years.

The challenge for French research in this area is thus twofold, with firstly a reformulation of questions AND secondly a re(acquisition) of the skills required. Evaluating and understanding the effects of agriculture on biodiversity implies in the future improving the understanding of the effects of current production modes, agricultural practices and landscapes, with these effects considered as proximal causes affecting biodiversity. It will in addition be necessary to improve the understanding of the technical, economic and sociological constraints which determine which practices of agricultural production and landscape management are used (see chapter 3) and thus act as powerful distal determinants of biodiversity change. It is indispensible to develop interdisciplinary research around these agro-ecological questions with an approach fully integrating socio-economic, legal and technical aspects, from the level of the farm to national and international markets. Such research could then progress the understanding of the effects of agriculture on biodiversity and analyse in more detail opportunities and barriers for reconciling the objectives of production and biodiversity preservation, whether this be through regulation, through initiatives or participatory methods (see chapter 4).

2. Biodiversity of agricultural areas and the ecosystem services provided by this diversity

After the examination of the positive and negative effects of agriculture on biodiversity in chapter 1, and before an examination of the opportunities to better integrate the dual objectives of production and the maintenance of biodiversity in chapter 3, this present chapter examines the benefits and costs provided by biodiversity to agriculture.

In general, the *Millennium Ecosystem Assessment* (MA) aimed to promote understanding of the value of biodiversity to human society, and conversely costs associated with actual and projected biodiversity losses. In addition to an inventory of global biodiversity, this international assessment implemented and widely publicised the concept of ecosystem services. The report also provided a general methodology to quantify the consequences of changes in biodiversity on ecosystems and on different components of human well-being.

The MA has stimulated considerable research on ecosystem services, including methodological developments, case studies of particular systems and services (for example of primary production or pollination), research on the mechanisms involved in the links between biodiversity and ecosystem services or socio-economic evaluations of services. A number of exhaustive review articles have established the current state of knowledge, in particular in the area of agro-ecology (with several reviews published in 2007).

Three primary questions structure this research: 1) To what extent does the maintenance of biodiversity directly contribute to agricultural production and profitability? 2) Are there long term benefits from the preservation of biodiversity through increased stability of production and greater agro-ecosystem stability? 3) At which spatial scale(s) is the maintenance of biodiversity in agro-ecosystems particularly beneficial, from the individual field, to the landscape or the region.

2.1. Agro-ecosystem services, ecological functions and components of biodiversity

2.1.1. The concept of ecosystem services

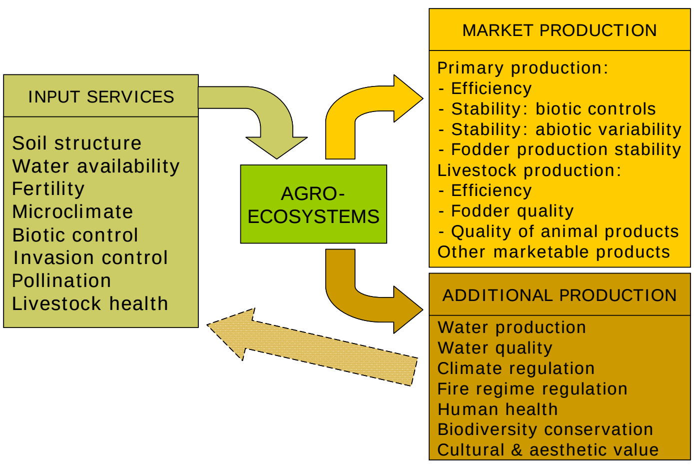
. A classification of services

The MA proposed a classification of ecosystem services into four categories, provisioning, regulating, cultural and supporting. This classification, which serves as a framework to compare individual studies, has been criticised recently for the lack of precision in the definition of regulating and supporting services. For this assessment we have used a more operational classification with the three following categories:

1) "Input" services, which contribute to the provision of resources, the maintenance of the physical and-chemical processes supporting agriculture, and which guarantee the regulation of biotic interactions, positive or negative, for example the maintenance of the structure or the fertility of soils, pollination, protection of the health of domestic animals;

2) "Production" services contributing to agricultural productivity. These services concern plant and animal production including levels of production, the stability of production over time and the quality of products themselves;

3) "Output" services not directly contributing to agricultural income, which include, in particular, the control of water quality, climate regulation through carbon sequestration or the aesthetic value of landscapes.



Conceptual model of agroecosystem services adopted for this chapter (modified after Zhang et al., 2007).

The effects of biodiversity on ecosystem functions contributing to each of these services can be positive – strictly speaking these benefits constitute services – or negative – consisting of costs to agricultural production and/or society (*dis-services* in the terminology used in the MA).

Table 1 presents a list of considered agro-ecosystem services and the ecological functions which contribute to their provision.

Table 1. Agro-ecosystem services whose provision is altered by changes in biodiversity and the ecosystem functions and properties which underlie these services.

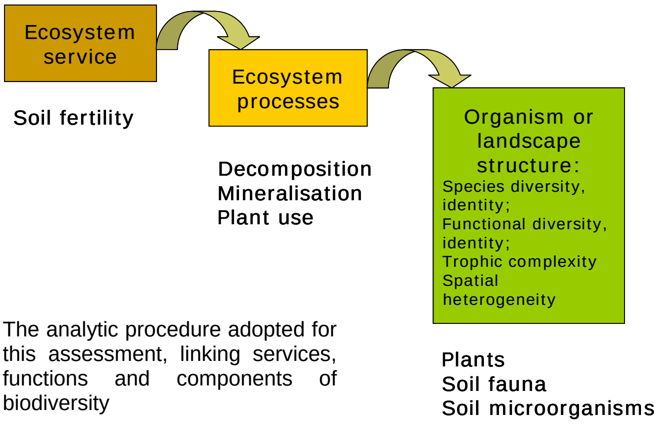
	Services	***Ecosystem function / properties***
"Input" services	Soil structural stability (erosion control, compaction resistance)	Soil structure: porosity, aggregation Stabilisation by roots Soil organic matter
	Water availability for primary production	Water cycle
	Soil fertility	Dynamics of soil organic matter: Mineralisation, Decomposition Nutrient dynamics: Biogeochemical transformations, Solubilisation
	Micro-climatic regulation	Daily and seasonal variation of temperature, humidity ; wind
	Pollination	Pollen transfer and dispersion
	Pest control (plant and animal)	Habitat and resources for beneficial organisms Predation, parasitism, virulence
	Control of biological invasions	Invasion resistance
	Animal health	Animal resistance to disease and parasites Limitation of food toxicity Limitation of allergies
"Production" services directly contributing to agricultural productivity	Plant production (food, fibres, energy, etc.)	Primary production: productivity Primary production: production stability in the face of environmental variation (climate, pests…)
	Animal production	Fodder quality (nitrogen, fibre, particular molecules) Alimentary motivation Secondary production (milk and meat products) Sensory qualities (taste, smell, etc.) of animal products
"Output" services not directly contributing to agricultural income	Water availability (potable, irrigation, hydro-electricity, industry…)	Evapotranspiration Rainfall interception Lateral water fluxes Soil water retention capacity
	Water purification	N and P cycles: trapping / leaching / transformations (e.g. denitrification) Biodegradation and/or sequestration of toxins (notably pesticides) Pathogen retention
	Global and regional climate regulation	C sequestration (soil and vegetation) Greenhouse gas emissions Surface properties (albedo, roughness…)
	Fire control	Flammability Spatial Connectivity
	Diversity conservation, overall and of key species	Habitat and resources Migration, allogamy, biological interactions Habitats Spatio-temporal heterogeneity
	Aesthetic value for tourism, and spiritual	Spatial patterns Quantitative or qualitative biodiversity

. Ecosystem services, ecosystem functions and groups of organisms

Ecosystem services are based on ecosystem functions, which in turn are based on the biological activity of particular groups of organisms or through the effect of landscape structures. One of the difficulties in analysing the relationships between biodiversity and ecosystem services results from the confusion, frequent in the literature, between ecosystem services and ecosystem functions. While ecosystem functions are the typical objects of study in agronomic or ecological studies, services, such as considered by the nomenclature of the MA, are defined by the demands of society, and are often based on a suite of ecosystem functions.

The analytic procedure adopted for this assessment consisted of, for each service relevant to agro-ecosystems, examining the key ecosystem functions on which it is dependent, and then evaluating the manner in which in turn these functions depend on the different components of biodiversity. For example, in the case of the service of soil fertility maintenance (which regulates the provision of nutrients for plants), the analysed functions will be in particular the decomposition and mineralisation or soil organic matter, and in more detail, the provision of nutritive elements to plants, while the organisms involved are the plants themselves and the majority of soil organisms (micro-, meso- and macro-fauna, micro-organisms including those in the rhizosphere which improve the access of roots to resources…).

The components of biodiversity considered are those different groups of organisms potentially involved in ecosystem functioning. For each of these groups we consider the quantitative diversity (species richness, number of functional groups…), community structure (relative abundances of different species…), functional traits (notably those of dominant species, the variability of functional traits in a community), trophic complexity, spatial structure…



The analytic procedure adopted for this assessment, linking services, functions and components of biodiversity

2.1.2. Conceptual tools and methodologies

. Hypotheses linking biodiversity and ecosystem services

The main hypotheses concerning the relationships between diversity and the provision of ecosystem services are that greater biodiversity can allow a higher level of ecosystem functioning and/or a greater temporal stability of the level of ecosystem functioning. These hypotheses are based on the functional complementarities between species, groups of organisms or genotypes, where functional differences allow a better exploitation of available resources and/or adaptation to environmental fluctuations due to differing responses to perturbations.

The mechanisms underlying the relationships between biodiversity (in particular species richness) and the functioning and stability of ecosystems have been the subject of considerable scientific controversy. This debate focuses on the ecological importance of diversity itself. Some researchers consider that the main consequence of high species diversity is statistical sampling, through increasing the probability of the presence of some species particularly productive, efficient or resistant to perturbation, which provide the majority of any augmentation of the service considered. The opposing argument stresses the lack of understanding of the functions of different species, which may be expressed under particular conditions and thereby provide complementarity in resource use. Recent studies have investigated under what conditions complementarities between species exist, and sought the functional mechanisms of complementarities versus the effects of particular species.

Finally, it is important to emphasise that:
- the effects of biodiversity on the functioning of agro-ecosystems and the services provided by these systems results from multiple mechanisms, often acting together, or successively over time (for example, the effects of complementarities between species and the presence of particularly influential species are not mutually exclusive);
- questions dealing with the degree of dependence of agro-ecosystem function on biodiversity result in a particular emphasis on functional diversity (functional identity and complementarity) ;
- functional redundancy, which is the inverse of complementarity, is considered to play an important role in the functioning of agro-ecosystems: under exposure to natural or anthropogenic perturbations, the better adapted taxa or genotypes within each functional group remain, with a resulting greater temporal stability of ecosystem functioning.

. Available studies

Some studies seek to establish relationships between variations in biodiversity and concomitant variations in ecosystem services by comparing real agro-ecosystems differing in a key variable (for example, the level of fertilisation). The interpretation of such correlations is always problematic, for two reasons. Firstly, it is difficult to distinguish between the roles of changes in biodiversity *sensu stricto* and the influence of the management factor (for example fertilisation) on changes in the service. In addition, in real contexts, the ability to control all of the variables that may impact the results is difficult to achieve, except for experiments designed to manipulate management and biodiversity simultaneously. Comparing agro-ecosystems with differing management histories and levels of biodiversity may be misleading as the sites may differ before the study for other reasons such as their soil type (which is generally the case; consequently, this assessment avoided as much as possible using these types of studies.

This assessment then favours experimental studies which manipulate the biodiversity of agro-ecosystems *ad hoc* to evaluate its role in ecosystem functions and properties *a priori* considered important for the provision of services. This approach consists of constructing systems in which the level of biodiversity is experimentally varied. The majority of such studies manipulate the diversity of plants and use a series of created "ecosystems" by sowing mixtures of species in increasing numbers - considerable hand weeding is often necessary to maintain the composition of these experiments. Such experimental designs are the most commonly used for investigating the importance of components of plant diversity on primary production, and, more rarely, soil fertility or the control of biological invasions.

Using a similar logic, the efficiency of the control of pests by beneficial organisms, or the efficiency of pollination are often evaluated by selectively reducing (using exclusion cages) the diversity of predators or pollinators. Finally, other studies manipulate the diversity of groups of soil organisms (species richness of macrofauna or mesofauna, complexity of soil tropic networks, microbial diversity…) to evaluate its role in soil fertility or in the functions underlying this service; these experiments are often carried out in the laboratory in "microcosms" of soil with or without grassland or crop vegetation.

Such experimental approaches to study services are difficult to implement under real agricultural conditions, in particular for crop productivity, the forage value of pastures or pollination at farm scale. Experimental studies of the effects of landscape diversity are almost impossible, and only observations between landscapes of differing levels of complexity, or the effects of particular landscape elements (hedgerows, grassland boundaries...) allow deduction of the relationships between landscape diversity and functions underlying ecosystem services. In these circumstances modelling is an important tool.

The literature reporting these experimental studies, and which constitutes the core of available sources, is relatively abundant. However, these studies provide little information of value to decision makers, particularly in identifying possible opportunities for adaptation to allow a better integration of production and biodiversity objectives. The majority of these studies remain mainly academic and disconnected form agronomic considerations. The manner in which the scientific field investigating the role of biodiversity for agro-ecosystem services has developed both in France and internationally explains this situation.

. An emerging integration of ecology and agronomy

Schematically, the development of research on the role of biodiversity for the provision of agro-ecosystem services has proceeded in three major phases.

Initially, the role of the diversity of organisms, particularly those of cultivated plants, for some services - particularly productivity – was studied by agronomists. At that time, of course, the term “service” was not in use. Numerous studies and reviews were published around this subject, particularly during the period 1960-80, but they concerned primarily tropical areas or particular systems such as agroforestry in the temperate zone. In the northern hemisphere, agronomy was primarily concerned with understanding the fluxes of materials and energy, in response to problems of water pollution or irrigation posed by intensified agricultural systems. Biological interactions were little considered in these studies, as it was considered that the development of pesticides would allow the management of any biological constraints (pests, weeds…).

In contrast, in the face of problems resulting from the modification of planetary biodiversity, ecology, which had already been interested for decades in biological interactions (competition, mutualism…) began to develop after 1990 considerable research activity investigating possible functional roles for biodiversity. In fact, such studies were often carried out in agro-ecosystems as model ecosystems, as they consisted particularly of sown and extensively managed grasslands. However, this scientific community was not interested in the agronomic realism of the studied models, and made little reference to the previous agronomic studies. The primary objective was to determine and develop a hierarchy of the ecological mechanisms underlying the relationships between biodiversity and ecosystem functioning, and the roles of biodiversity were not considered in terms of services to humankind. The model systems created to study these mechanisms often manipulate considerably fewer species than those present in real ecosystems, which limits the possibilities to extrapolate the results. Only very recently has it been recognised that such studies can address questions relevant to real agro-ecosystems, if taking into account factors previously ignored (management of the system, landscape context, methods of biodiversity manipulation).

Recent literature suggests that we are today at a turning point. Ecologists acknowledge that they can no longer ignore the agronomic reality of the studied systems, and agronomists acknowledge the importance of experimental studies to quantify the contribution of agro-biodiversity to ecosystem services. This evolution is manifested in several research programs creating pilot sites to quantify the benefits of elevated biodiversity within cultivated plots and the wider landscape, the taking into account of crop diversity and cover crops as a component of biodiversity or studies of the interactions between the effects of biodiversity and the effects of grassland management. The agronomic reality of these experiments remains however low.

This developmental history allows an understanding of the structure of the actual body of knowledge of the role of biodiversity on the level of agro-ecosystem services, and the difficulties in informing decision makers. Published results are rigorous responses to scientific questions concerning diversity–function relationships and their underlying mechanisms, but are often poorly adapted to respond to the needs of stakeholders.

2.2. Relationships between biodiversity and services under experimental conditions

This section summarises empirical proofs of the effect or absence of effect of biodiversity on agro-ecosystem services established by analytical experimental studies under conditions as controlled as possible. With the acknowledgement that some of the studied systems do not correspond to conditions found in real agronomic systems, it is this type of study that has developed the paradigms existing today concerning relationships between biodiversity and services. The pertinence and applicability of this understanding for developing techniques for the management of ecosystem services is discussed in the following section.

2.2.1. "Input" services

. Plant resource provision services

The currently available literature does not allow the demonstration of an effect of the quantitative level of taxonomic or functional diversity on **soil structural stability**, mostly because of the limited number of experimental studies. Documented effects concern the presence and abundance of particular functional groups or species of either soil fauna (earthworms), microorganisms (fungal mycorrhiza) or plants (large perennial grasses for example). For plants it is possible to identify functional traits favouring soil stability, but a resulting effect of functional diversity via complementarity remains to be formally shown. Functional complementarities over time are exploited in crop rotations. However, the amplitude of the direct effects of agricultural management on soil structure seem in general greater than those of biodiversity, and any effects of biodiversity would be significant only for systems not involving soil cultivation.

In the same way and essentially linked with the same plant functional characteristics and soil biodiversity, **water availability** within a plot depends primarily on plant functional composition and functional diversity (over time or in a plot).

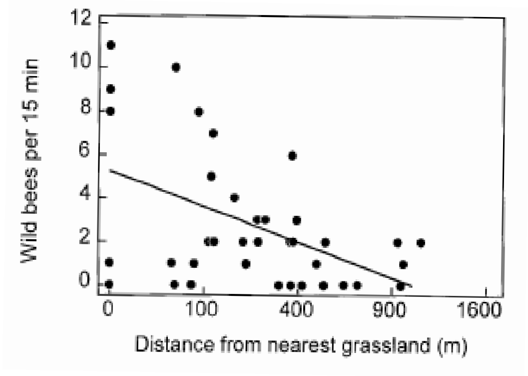
The maintenance of **fertility** appears as an ecosystem service for which the effects of biodiversity are particularly complex, on the one hand as it is controlled by the activities of a very large number of organisms (plants, soil fauna and microorganisms, domesticated and wild herbivores) and their interactions, and on the other hand because the effects of each of these groups are not trivial. Known effects are mainly those of composition or functional diversity, rather than those of species diversity *per se*. Also, different studies show an effect of plant functional diversity, notably a positive effect of the presence or of the proportion of pasture legumes on the availability of nitrogen in the soil. In the same way, crop diversity, and primarily the introduction of legumes in a rotation has a positive effect on soil fertility. Regarding soil biodiversity, some studies have shown that microbial communities involved in soil fertility maintenance have high levels of functional redundancy, probably as a consequence of their high levels of diversity (10^4 to 10^5 bacterial taxa per gram of soil). Experimental reductions of soil microbial diversity do not affect its fertility (evaluated through functional measures such as of mineralisation and nitrification), and it is the abundance and biomass of microorganisms that appear to the major factors determining soil fertility.

. Biotic regulation services

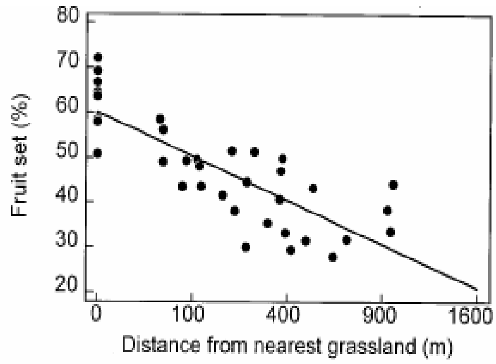
Pollination appears in principle based on the presence and activity of a few generalist species such as domestic bees, which would reduce the vulnerability of the source of pollination to the extinction of particular specialist pollinators, but at the same time make pollination sensitive to reductions in populations of generalists. The limited number of available studies suggests however that the functional diversity of pollinators could contribute to the maintenance of diversity of communities of wild plants, and improve the performance of entomophilic crops (for example, rapeseed). The abundance and diversity of these pollinators is strongly linked to the distribution of semi-natural elements (fields…) in the landscape.

The **biological control of pests depends** directly on the taxonomic and functional diversity of the organisms, whether these are carnivorous natural enemies, below- and aboveground microorganisms or the plants themselves (cultivated and weeds). In the case of natural enemies, their identity is also important. The control of plant pathogens also depends on the functional diversity of soil microorganisms.

Abundance and diversity of pollinators increased due to the presence of semi-natural elements in the landscape, allowing increased pollination

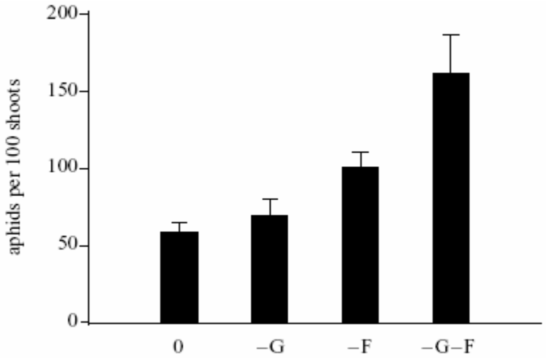


The abundance of wild bees decreases with increasing distance from semi-natural areas (in this case fields in Germany) which act as pollinator reservoirs (from Steffan-Dewenter et al. 1999).
This study also shows that the species richness of wild bees decreases with increasing distance of plants to be pollinated from semi-natural areas.



This effect of decreased abundances and diversity of pollinators with increasing distances between the plants to be pollinated (in this case *Raphanus sativus*) and semi-natural areas (in this case fields) manifests itself at the level of the service of pollination, estimated by the proportion of flowers producing fruits (from Steffan-Dewenter et al. 1999).

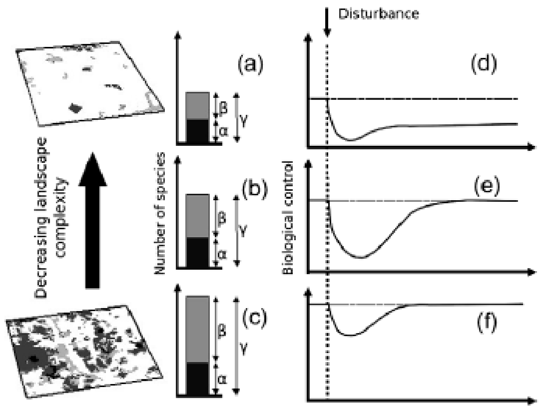
A relation between the efficiency of the biological control of pests, the diversity of natural enemies of crop pests and landscape diversity



The effect of a simplification of the diversity of natural enemies on the population density of aphids in a wheat crop. A high diversity allows better biological control of pests through complementarity between groups. From Schmidt et al. (2003).

0: all natural enemies present; -G: without crawling generalist predators; -F: without predators and flying parasitoids; -G-F: without predators or parasitoids.

Of 7 experimental studies undertaken in temperate zones (4 in Europe, 3 in the USA), 6 have found this type of relationship.



The available knowledge on the role of the diversity of natural enemies for the service of biological control as well as the effects of landscape complexity on the diversity of natural enemies (chapter 1) strongly suggest that at the scale of agricultural landscapes, the higher the alpha, and particularly gamma, diversity (due to landscape complexity) the higher the intensity of biological control, and the better the resilience of this service to disturbance. From Tscharntke et al. (2007).

The **control of weeds** is influenced by the diversity but most importantly the identity of the crops used in the rotation; the introduction of cover plants during inter-cropping has a major repressive effect on weed populations.

In the same way, the **control of invasions** by exotic plant species increases with plant species richness and arthropod herbivores. In the case of plants, the composition and functional complementarities play an essential role. Management also directly influences invasions via the availability of resources and through disturbance, and indirectly through its effects on plant communities (as well as those of arthropods).

Finally, plant species diversity of permanent grasslands appears to favour **domestic animal health** through the maintenance of particular beneficial species (plants rich in tannins, Asteraceae having anti-helminthic (parasitic worms) properties). The effect of species diversity is therefore in this case indirect.

. Conclusion

The available information suggests that input services linked to the provision of resources for plant and animal production in agricultural systems often does not depend on the number of species in itself, but rather on the functional diversity *sensu lato*, that is in general the presence or the abundance of particular functional groups or functional traits, and in some cases the functional complementarities between species or functional groups. It should be stressed that these services are very strongly influenced by the direct effects of agricultural management, as well as by its indirect effects via modifications of biodiversity.

Input services linked to functions of biotic regulation, depend more on the species richness of the involved organisms, in particular plants and arthropods. This diversity has in general beneficial effects, although in a few particular cases it can induce negative effects. However, there exists often little information on the functional mechanisms which may underlie the reported effects of taxonomic diversity.

In addition, landscape diversity benefits a vast range of input services such as soil stability, water availability, microclimatic regulation, pollination, crop pest control by natural enemies, control of biological invasions and domestic animal health. It clearly represents a key component of biodiversity in terms of the provision of input services.

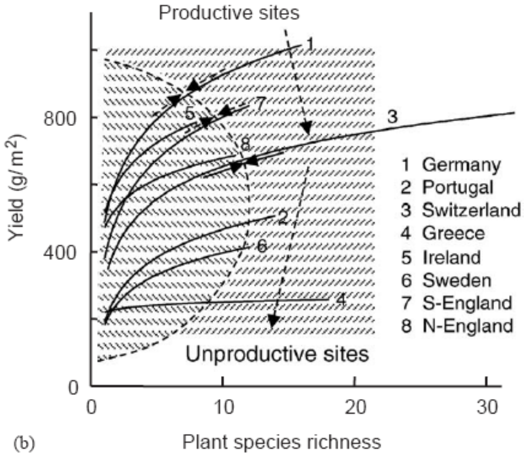
2.2.2. Services directly contributing to agricultural production

Plant production

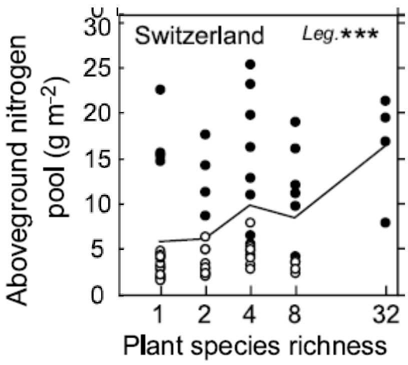
. Plant yields

The question of a positive effect of grassland species richness on grassland productivity has been highly debated. Experimental studies have been therefore implemented to test this hypothesis.

The productivity of extensively managed sown grassland is positively linked to their plant diversity; this effect is due to the functional properties of the species and / or complementarities between them more so than their species richness per se.



The relation between the level of grassland annual production and plant species richness: diagram synthesising the relationships observed at 8 European grassland sites of varying productivity (from Schmid et al., 2004).



The relation between the nitrogen content of plant above ground shoots and the species richness of the grassland: data obtained from one of the 8 sites (Switzerland). The grasslands without legumes (white circles) have significantly lower nitrogen contents than those with legumes (black circles). From Spehn et al. (2002).

Data obtained from these artificial assemblages with increasing numbers of species confirm that primary productivity increases with the number of sown species, with a plateauing of this effect at a level which depends on the environmental resources available (which explains, in the figure, the very flat profile for the Greek site situated in a poorly productive environment). This effect of diversity is linked to functional properties of the dominant species or functional groups and / or to complementarities in the manners in which they exploit resources (light, nutrients, water), which allows the maximisation of this exploitation. An important part of this biodiversity effect is due to the presence of legumes (plants that fix nitrogen form the air and which leave nitrogen in the soil accessible by other species) in the more diverse assemblages.

In broad acre crops, this effect of increasing productivity is exploited in a number of systems of companion planting, put in place for forage crops or in agroforestry. Beyond the number of species simultaneously present in a plot, the diversity of species used throughout the rotation cycle can have an effect on the average crop production, notably in non-intensive systems, but this effect is not always consistent. A recent North American experiment tested the effect of the diversification of rotations on production, under non-fertilised conditions and without pesticides. The remarkable response of corn yields to the diversity of crops and cover plants used for inter-cropping is explained mainly by the presence of legumes in the rotation. In this same trial however, the diversification of crops had little or no effect on soya or wheat yields.

The species richness of soil fauna in itself has little effect on productivity, while the presence of particular species or functional groups is important. Concerning microorganisms, available data suggests that taxonomic diversity matters little, but that the functional dimension of their diversity linked in particular with associations with plant roots, are beneficial.

. Stability of plant production

A certain number of organisms (weeds, pests, plant pathogens, wild animals) can cause short term losses in agricultural production. An objective in agriculture is thus to reduce their populations through, in particular, soil tillage or the use of pesticides. The maintenance of plant diversity within crops (intra or inter-annual diversity, species or varieties), or of semi-natural landscape elements, can also play a role in reducing these losses, and thereby in guaranteeing greater long-term yield stability production.

At plot scale, it could be theoretically expected that more diverse crops increase yield stability in the face of abiotic variation, however experimental data from assembled grassland communities are not convincing. Functional composition may play a more important role than species richness in production stability. It is not possible to predict the net effect of the direct effects of environmental changes on production, and their indirect effects via changes in plant diversity. In reality though, for annual pastures and temporary grasslands, species or genetic diversification over time (rotations, cover or companion crops, intermediate crops) or within the same plot (associated crops, varietal mixes) results in an increase in the stability of primary production due to an increased diversification of functional traits. For forage production systems, a diversity of grassland types at farm scale increases the robustness of livestock feeding systems in the face of climatic fluctuations

. Conclusion

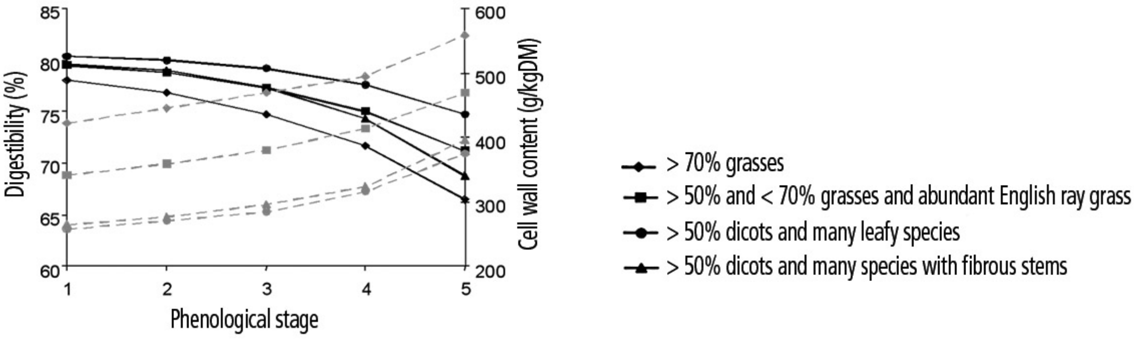
The diversity of crop species or varieties, either over time or within the same plot, can allow the maintenance of higher than average production over the long term, even if it does not guarantee immediate greater production. In contrast, in permanent grasslands under a given management, short-term yield is increased by increased plant diversity via the functional properties of species or dominant functional groups and / or complementarities between species, functional groups or genotypes, but this does not guarantee increased long-term stability at plot level. However, at the whole farm scale, greater diversity guarantees a greater flexibility in the management of forage resources, and therefore finally a greater stability of the farm's forage production.

Animal production

. Plant Diversity and food resources

The hypothesis that diverse permanent grasslands have a lower nutritive value that is more stable over time than grasslands with a lower diversity is only partially supported in the literature. Floristic diversity has an indirect effect in guaranteeing the presence of species contributing to nutritive value (for example dictoyledons, plants rich in tannins) and / or its stability. Domesticated herbivores chose a diverse diet, which contributes to the quantity of ingested herbage in grasslands. In areas of highly heterogeneous vegetation consisting of both woody and herbaceous plants, diversity can also contribute to stabilising animal consumption over time, both quantitatively and qualitatively.

Increased forage quality in grasslands with elevated plant diversity



Evolution of the digestibility (black symbols linked by solid lines) and of plant fibre contents (grey symbols linked by dashed lines) for 4 types of grassland defined by their botanical composition (From Daccord et al., 2006).

. Grassland plant diversity and animal production

Simple associations between species suggest that greater grassland diversity can improve animal performance, but that this does not apply in more complex associations. For these, we observe an absence of effect or heterogeneous effects in terms of individual performance, growth or milk production. Nevertheless, some studies show that increased forage production obtained from complex associations allows a milk production per hectare considerably higher than that from simple associations, and this under a range of climatic contexts. Beyond the simple number of species, it appears that their identity and their proportions play an important role in determining forage production per unit area.

. Sensory characteristics of animal products

The species richness of grasslands and in particular increases in the abundance of dicotyledons, by favouring the **presence of particular species or families,** increases the sensory characteristics of cheeses. The effect of plant diversity on meat products is little studied and concerns the effects of some undesirable species (some lucernes), from which it is difficult to make any generalisations.

. Conclusion

A high species diversity of permanent grasslands allows the greater consumption of better quality forage, in particular over the long term. Their greater forage production, particularly under unfavourable climatic conditions, increases per hectare milk production and increases the sensory qualities of cheeses. The totality of these effects is linked to the presence or abundance of species or groups of particular species rather than to species richness *per se*, with a high species richness increasing the probability of their presence.

2.2.3. Output services not directly contributing to agricultural income

Increasing plant species and functional diversity, together with the abundance of woody plants and the spatial heterogeneity of a landscape contribute to **flood control**, but by increasing the total water consumption of the vegetation, can also decrease the average water availability flowing out of a catchment or the recharge of water tables.

Plant biodiversity when used in a concomitant manner (diversified grasslands and crops) or over time (cover crops, inter-cropping, intermediate crops, crop rotations) plays an important role in the control of **water quality**, in particular via functional diversity *sensu lato*, and also via the complementarities between legumes and grasses. A strong link does not exist between the diversity of communities of nitrifying or denitrifying bacteria, where the level of diversity assures considerable functional redundancy, and the control of nitrates. At the landscape level, nitrate pollution is primarily controlled by the proportion of permanent grasslands and wooded areas. Finally, a high diversity of microorganisms coupled with their high evolutionary potential plays an important role in the fate of toxins (particularly pesticides) in the soil.

Carbon sequestration by agro-ecosystems is directly influenced by management, but also indirectly by its effects on plant and microbial diversity. The net effect of plant species richness cannot be predicted due to the multiple processes involved (of which many are still poorly understood) and their interactions. One can nevertheless expect a large effect of the functional traits of dominant species. As regards soil microorganisms, a communities' fungi : bacteria ratio appears as a more important functional indicator for the sequestration of organic carbon than does diversity.

Plant biodiversity influences **regional climate dynamics** through its effects on the physical structure of plant cover, from the plot scale to the regional scale. These effects remain poorly understood but in general are due, on one hand to the properties of the dominant species, and on the other hand to the spatial heterogeneity at the inter-plot and regional scales.

Fire mitigation is a service that sometimes is an important justification for the maintenance of agricultural activities (especially grazing) in Mediterranean regions. This is based on two characteristics of plant biodiversity, the functional composition of the vegetation and its biomass (which is in turn influenced by biodiversity) which together determines the flammability and heterogeneity of a landscape and can reduce fire propagation.

In Europe, the number of **exotic invasive plant species** of grasslands and crops having a significant impact on biodiversity remains limited. Such species may combine with their negative impacts on biodiversity and human well-being (agricultural production, allergy inducing pollen) some positive services (aesthetic value, honey production, hosts for natural enemies of crop pests). However, **exotic insect predators** such as the Multicoloured Chinese Beetle, introduced to control another invasive pest species, can reduce the resources for off-target native species, or even directly attack native species themselves, resulting in critical demographic losses for some native arthropods.

Plant biodiversity contributes directly to the **aesthetic value** of landscapes, by influencing the variety of forms and colours present, whether this is in cultivated fields or in semi-natural areas including grasslands. It also contributes to the **cultural value** of rural landscapes, particularly when associated with practices of picking mushrooms, berries etc. The aesthetic role of animal biodiversity is lower, but its cultural role is important. Some flagship species such as large herbivores or large predators often foster diametrically opposed radical opinions on the management of rural areas. The perception of other species, notably pest natural enemies in crops, is more unanimously favourable. The diversity of environments is an important component of the rural landscape. The identity of some regions is strongly based on specific landscapes containing significant biodiversity, and can be a key value for **tourism**. This is the case, for example, of the pastoral grasslands of the Grands Causses du Sud in the Massif Central, or bocage landscapes (areas of mixed woodland and pasture). The societal and aesthetic values of biodiversity can however vary across stakeholders.

. Conclusion

Plant diversity influences the regulation of water availability, water quality, climate regulation and fire mitigation mainly via the functional traits of dominant species. Landscape heterogeneity also plays an important, yet insufficiently quantified role for the fluxes involved in these services.

Agro-ecosystem plant diversity favours both overall biodiversity (including the functional diversity of organisms involved in the provision of input services) and that of emblematic plant and animal species. While only very few exotic invasive plant species cause major damages, introduced predatory arthropods can cause significant negative impacts on native species, including keystone species.

Plant diversity contributes directly to aesthetic value and to animal diversity of major cultural value. Landscape diversity has a major cultural value and is a key factor valued for tourism.

2.2.4. Summary

. The contribution of components of biodiversity to different ecosystem services

The analysis of the available literature concerning the relationships between the different components of biodiversity and agro-ecosystem services, which essentially considered experimental manipulations of this diversity, has revealed a number of significant conclusions from the agronomic perspective.

. The majority of input services are dependant on the biodiversity of a number of groups of organisms. For services of provision of resources to crops, it is particularly the functional diversity of plants and soil organisms that is important. In contrast, for services resulting from functions of biotic regulation, such as pest control, pollination or invasion resistance, the taxonomic diversity of organisms appears to be essential.

. The diversification of crops (species and varieties) over time, within a field or at the level of the landscape, allows the stabilisation of yields via its effects on resources and, most importantly, on the organisms involved in biological control. The intensity of these effects depends however on the agricultural practices adopted (fertilisation, pesticide use…), and such systems of companion cropping are more difficult to manage than those based on single crops (see chapter 3).

. For extensively managed permanent grasslands (low to moderate levels of organic fertilisation, low to moderate intensity mowing and / or grazing) plant diversity, and more precisely the functional composition of the vegetation and the presence of particular species, contribute to increasing forage production, the stability of this production over time and its quality

. Biodiversity contributes a range of services which contribute in a non-direct manner to agricultural income, and which often concern spatial scales well beyond that of the farm: water availability, water quality, flood control, climatic regulation and fire mitigation. The effects of biodiversity on carbon sequestration are complex and cannot be predicted in a generic manner.

In particular, the literature review highlighted the key role of some components of agro-ecosystem biodiversity:

. Dominant species' functional traits, especially for plants, determine the provision of input services (soil structural stability, fertility, biological pest control), the production of permanent grasslands and their benefits for animal production, and services at a larger scale such as water quality, climate regulation and fire control.

. The effect of functional complementarity, for example between legumes and grasses, or between species with different phenologies or rooting depths, has been demonstrated in some cases but remains to be fully understood or described for the majority of services

. Due to their very high diversity, soil microbial communities have high levels of functional redundancy and their level of taxonomic diversity matters little for many services. It is the functional components of this diversity, and the presence of particular species which is particularly important for the control of plant pathogens, the development of cultivated plant mycorrhiza and the control of soil xenobiotics (toxins)

. Landscape spatial heterogeneity (composition and structure) contributes to soil stability (erosion control), regulation of water fluxes at the catchment level, pollination and / or the control of pest species through the positive effects of wooded areas or perennial linear structures (hedges…) on dependent arthropod populations. These fixed landscape elements decrease water reserves at the plot level, but contribute strongly to landscape heterogeneity, and are beneficial for the majority of services contributing non-directly to agricultural income.

. Functional links between groups of organisms

There exist essential functional links between the different groups of organisms involved either in the same service, or in different services, In addition, plant diversity influences the microbial community. In turn microbial diversity facilitates plant establishment, improves their performance and favours the control of phytopathogenic microorganisms. In contrast, while the species composition of plant cover influences soil fauna, plant diversity does not have a systematic effect on the diversity of soil fauna.

The maintenance of a diversity of wild bee communities and other pollinators potentially permits the maintenance of the species and functional diversity of plants and their flowers, and reciprocally.

Weed floras are noteworthy, in that they are considered both as a major obstacle to the implementation of environmentally friendly cropping systems, and at the same time, an indispensable component of primary production and of the development of biodiversity in agro-ecosystems. Weed species diversity, in cultivated areas as in semi-natural areas, also contributes to the maintenance of diverse communities of carnivorous arthropods. In return, these protect plants from major impacts from phytophagous arthropods and allow the maintenance of diverse plant communities. Finally, the genetic diversity of cultivated plant species can favour the maintenance of species diversity of other species, for example weeds or winter annuals.

. A link to be developed between the responses of biodiversity to agriculture and the effects of biodiversity on agro-ecosystems

Dependent on whether one is interested in the effects of agriculture on biodiversity (chapter 1) or in the effects of changes in biodiversity on ecosystem services provided by agro-ecosystems (chapter 2), the literature focuses on the different components of biodiversity: a taxonomic vision is dominant in the first body of work, while the second gives particular emphasis to functional diversity (and the presence of particular species). This separation between the two approaches explains why information concerning responses of functional diversity to different management factors, which would be useful to understand agriculture - biodiversity interactions, are only beginning to be understood, and so far only for plants and some microbial groups (chapter 1).

The role of other components of biodiversity, such as spatial distribution and the complexity of trophic networks, has been without doubt underestimated in the literature due to a lack of relevant studies.

In reality, the relation between the response of organisms to an environmental modification (particularly induced by agricultural management) and the potential effects of this response on ecosystem services is rarely established. However, an appropriate analytical framework exists, namely the theory of ecological filters and functional traits. The central idea of this theory is that environmental conditions “filter” the species that can establish and develop in a given place, and that these filters operate on species via their biological characteristics, named response traits (e.g. seed dispersal modes, plant growth rates). Each specific filter (disturbance regime, fertiliser, biological interactions…) acts on species response traits, common or not across filters. The species composition of the community selected by these interactions between filters and response traits has in turn an impact on ecosystem functions, and thus services, via the value of "effect" traits of the species present (e.g. leaf tissue composition - which influences their digestibility, decomposition rate and thereby carbon storage). Effect traits and response traits can overlap, as in the case of leaf traits for the response of grasslands to management and the consequent effects on fertility, but not always; for example seed size is in some situations a response trait to grazing, but this trait does not have an effect on grassland productivity.

Currently, the responses of functional composition to management, for example grazing, are usually described for a reduced number of response traits of organisms. Only some of these traits are quantified in a systematic manner (plant size or architecture for responses to grazing) which does not allow the *a priori* prediction of the consequences for different services which depend often on leaf or root effect traits. An important research challenge for research would then be to articulate the studies of the effects of agriculture on biodiversity – explicitly considering relevant species response traits – with studies addressing the role of biodiversity for ecosystem services of particular interest to agriculture – by explicitly considering the effect traits of species important for these services.

Finally, another important research goal would be to further analyse responses of landscape heterogeneity to management, and the effects of this on the biodiversity of organisms providing ecosystem services of biotic control, as well as on the landscape-scale ecological processes essential for services operating at these large scales such as the control of water quality or floods.

2.3. The importance and management of biodiversity for ecosystem services in agricultural systems

To understand the possible contribution of biodiversity to services for agro-ecosystems, it is necessary to examine to what extent conclusions from analytical experimental approaches analysed in the previous sections can be extrapolated to real world conditions. It is important in particular to analyse for which agricultural practices biodiversity benefits (or in contrast, costs due to weeds or pests) are most likely.

2.3.1. The applicability of the experimental results to agriculture

The following critical analysis is focused both on the limits of, and gaps in the experimental approaches considered for the synthesis presented in previous sections, and on their applicability to agriculture, in particular in interaction with the direct effects of agricultural management factors.

. Limits of experimental studies

In the studies analysing the relationships between biodiversity and ecosystem functioning, the manipulated communities almost always comprise of random mixtures of differing numbers of species, a situation which does not reflect real conditions of establishment or extinction in natural grasslands, nor agronomic situations. Experimental approaches using such assemblages of plants, while unrealistic, allow the elucidation and investigation of mechanisms responsible for the beneficial effects of biodiversity on input services (resource provision, invasion resistance), yields, or water quality (control of losses of nitrates). However, their results are most often expressed in terms of the absolute level of production, and rarely in terms of the efficiency of resource utilisation, e.g. nutrients or water, for production, which would be of interest to assess the benefits of biodiversity for agro-ecosystems. Additionally, the benefits often attributed to plant diversity concerning the stability of production, have in fact been insufficiently addressed by these experiments. While these studies have an important theoretical and heuristic value, the taking into account of community structure (densities, relative abundances), abiotic factors such as fertilisation and disturbances, and longer term periods would now be essential to provide scientific knowledge more applicable to agricultural situations. Finally, the available studies concern primarily the effects of plant diversity on primary production, while more research is necessary to include other functions such as the cycling of nutrients and water.

Experiments on **soil fauna** remain also too limited and do not test pertinent levels of diversity, in particular for exploring the hypothesis of functional redundancy: the number of manipulated species is in fact very low in comparison to the levels found in real agro-ecosystems.

The studies conducted to date have revealed the essential role of **microorganisms** in ecosystem functioning, but they have also revealed the methodological and conceptual obstacles which have until recently prevented an accurate evaluation of the diversity of microbes involved in these mechanisms. The rare experimental manipulations of the diversity of microorganisms underline the important role of their functional diversity, particularly for functions involved in the carbon and nitrogen cycles. But even here the number of species manipulated is in general very low, especially for bacteria, compared to the diversity found in agricultural soils, and the studies reducing the diversity of microbial communities show primarily high levels of functional redundancy.

Studies measuring the impact of the diversity of **pollinator** communities on pollination are only recent and very limited. Research on communities with higher species richness would be necessary to experimentally test the validity of simple correlations between the diversity of natural pollinator communities and levels of agronomic performance, suggested by observational studies. In contrast, the conclusions of experimental studies concerning the biological control of crop pests can be considered as robust; higher levels of species and functional diversity would however be necessary to be representative of the diversity observed in agro-ecosystems.

In all of these cases, the dynamics of species recolonisation after extinction in the context of an agricultural landscape is an essential point not taken into account in experiments, and the functions linked to the stability of ecosystem services (primary production, fertility maintenance, water quality) are very little studied. Finally, the services provided by landscape diversity are generally not amenable to experimental studies, and probably only modelling will allow real progress in quantifying them.

. Biodiversity and agricultural management

One of the difficulties limiting the agricultural application of the experimental results is the absence of analyses of the interactions between the effects of biodiversity on ecosystem services and factors of agricultural management. This question of applicability is particularly pertinent in areas of intensive management, as is the case for the majority of agricultural areas in temperate regions. In reality, as is often stressed in scientific debates on the applicability of studies conducted on artificial “grasslands” of species assemblages, management factors, in particular fertilisation, grazing and hay cutting regimes, can strongly modify the type of relation existing between biodiversity and ecosystem services in agro-ecosystems. These controversies have led to the establishment of experimental designs to address such issues, with initial results due to be published soon. If it cannot be excluded that a high species richness has, for example for the productivity of grasslands, effects of a magnitude similar to those of fertilisation, it is most likely that the effects of biodiversity are of a significant magnitude mostly in situations of low inputs.

It is nevertheless necessary to move on to experimental studies carried out under conditions closer to real agricultural conditions to quantify and organize into a hierarchy the respective roles of biodiversity and management regimes on the functioning of agro-ecosystems, and test which of the preceding experimental conclusions remain applicable in agricultural situations. Only these types of studies will allow the evaluation of the benefits of biodiversity and of the interest of its preservation (or restoration) depending on services, production systems and management regimes.

. Management of services via biodiversity

Despite the above mentioned restrictions, the studies considered above suggest that key methods of management for ecosystem services act through the **management of functional diversity**. For plants this consists primarily of managing for particular functional traits of dominant species, and in some cases for functional complementarities. This approach is already used in agriculture with, for example, the use of legumes or mixtures of species or varieties. Additional research would, without doubt, help to better *a priori* identify the agriculturally relevant functional traits depending on the agricultural context, with the management of permanent grasslands benefiting in particular. In the same way, improving the ecosystem services provided by soil fauna requires management of the abundance and the functional diversity of differing taxonomic or functional groups. At the plot level management of soil cultivation, soil cover and the addition of organic matter are critical for biodiversity management, as well as a reduction in the use of pesticides.

A second critical method for the management of ecosystem services for agro-ecosystems concerns the **management of landscape diversity** which acts directly and indirectly on a whole suite of services and also offers significant potential to improve the provision of ecosystem services.

A key challenge for future studies would be to compare the respective benefits of the management of agro-biodiversity at the field scale and the management of ecosystem diversity at the landscape scale, particularly for services of biological control. Currently, some authors have advanced the hypothesis that ecosystem diversity managed at the landscape scale (the landscape context of fields) would be overall more important for many services than the level of agro-biodiversity managed at the field scale, but this remains to be demonstrated and this type of study will be particularly challenging.

2.3.2. Expected relationships between agricultural management, biodiversity and services

Effects of agricultural practices

Despite the identified distance between data concerning the effects of agriculture on the components of biodiversity and that concerning the effect of these different components on ecosystem services, an analysis of the expected effects of agricultural practices on services via the modifications in biodiversity they induce can be proposed. Some of these linkages have been demonstrated (in the case of responses and the effects of plant functional traits); others can be logically deduced from the available knowledge and should be considered as working hypotheses for future research.

. Fertilisation

High doses of fertiliser have globally negative effects on the provision of ecosystem services by biodiversity, firstly due to their direct negative effects on biodiversity (chapter 1), and secondly by diminishing the potential benefits of biodiversity for services. Consequently, the value of services provided by biodiversity will, in general, be maximal at low or intermediate levels of fertilisation.

In plants, for example, fertilisation mostly favours productive species (or varieties) whose presence in multispecies communities (grasslands or in companion cropping) can, at least in the short term, increase productivity, but also tends to reduce species richness of the vegetation and thus the services benefiting from this richness. In the case of soil organisms, the effects of fertilisation depend on its intensity, but also on its nature : mineral or organic. Mineral fertilisation, by its negative effects on bacterial or mycorrhizal symbioses, leads to a reduction in ecosystem services of resource provision, while organic fertilisation, through its effects on the functional components of microbial diversity involved in biogeochemical cycles and the diversity of soil fauna, favours services of fertility maintenance, soil stability and carbon sequestration.

. Vegetation and soil disturbance: mowing, grazing and soil cultivation

Soil and vegetation disturbances of intermediate intensity can favour ecosystem services of plant diversity via their effects on functional composition. However, in contrast they often have little impact on crop pest natural enemies, but can in some cases be used as a tool to manage their diversity and thus the service of pest biological control. Soil cultivation modifies the functional diversity of soil fauna but mostly reduces soil fauna abundance (chapter 1), which can result in a reduction in the level of provision of services such as soil stability and fertility maintenance. It remains however difficult to separate the direct effects of disturbance on ecosystem functioning from indirect effects linked to modifications of species or functional diversity.

. Chemical protection of crops

Reducing chemical use in crop protection enhances the benefits of biodiversity for ecosystem services, firstly due to a lower impact on organisms involved in crop protection (natural enemies, pollinators…), and secondly indirectly by reinforcing the beneficial effects of a diversity of weed species (resources for natural enemies and pollinators).

For example, the use of herbicides can lead to disequilibrium in weedy floras which increases the damage caused by these species. Conversely, reductions in chemical herbicide use coupled with appropriate management, including at the landscape scale, can allow the recovery of ecosystem services such as soil stability, pollination, biological control, biodiversity conservation and aesthetic value. The benefits of varietal mixes in terms of the control of pests and fungal diseases are particularly significant in situations of low levels of pesticide use. The numerous studies of the direct lethal and sub-lethal effects of insecticides and miticides on natural enemies, but also the indirect effects of herbicides on these same organisms show that their use is generally accompanied by a significant decrease in the ecological service of biological control, a decrease aggravated by the negative effect of fungicide treatments for many natural enemies

Response profiles of ecosystem services to the intensification of management

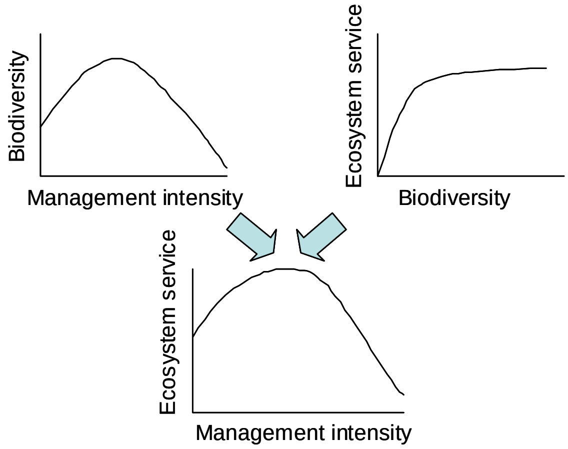
The following profiles allow us to go beyond the qualitative reasoning presented in the preceding paragraphs by proposing, in the absence of studies of the relation "agricultural management → service", a decomposition of this relationship into two sequences "agricultural management → biodiversity → service". These two linkages are not linear (they can even increase and then decrease) and the results are therefore not obvious.

The response profile of an ecosystem service to an intensification of agricultural management can be understood by combining the profile of the response of biodiversity to the intensification of management (chapter 1), and the profile of the ecosystem service to changes in biodiversity (the beginning of chapter 2).

This approach can be illustrated by taking for example:
- amongst the response profiles of biodiversity to increasing levels of a resource or disturbance considered in the model of Huston (chapter 1), the case of a unimodal curve – in which biodiversity is maximal at a moderate intensity of management;
- the classic asymptotic response curve of an ecosystem service (for example grassland productivity) to an increase in biodiversity.

The combination of these two curves (above) produces the resulting curve (below) describing the response of an ecosystem service to management intensity.

This simple graphical, qualitative reasoning is of interest because the response profiles are variable and often non-linear, which means that their combinations are not obvious.



Expected effects of the intensity of management on the provision of ecosystem services by biodiversity via the effects of management on the components of biodiversity.

This model does not take into account the possible interactions between the intensity of management and the magnitude of the effects of biodiversity on services, which are currently poorly known. The majority of studies evaluating the role of biodiversity on agro-ecosystem services by directly manipulating biodiversity are only carried out for one type of management, usually extensive. The response of the functioning of agro-ecosystems and of ecosystem services to variations in biodiversity is however likely to be strongly influenced by management regimes. Understanding the interactions between the effects of biodiversity and management would be necessary to determine the possibilities to better integrate agriculture and biodiversity, but almost no studies have been conducted in this area. It seems however plausible to assume that different ecosystem services could be provided much more efficiently under conditions of extensive management, although not necessarily achieving the level of production obtained in intensive management systems through high inputs or specific cultural practices,.

The next stage of the analysis (chapter 3) consists in determining the levels of impacts by agriculture on various ecosystem services which are useful or acceptable for differing agricultural systems, particularly in extensively managed systems.

2.3.3. Limits of opportunities for the protection and utilisation of biodiversity by agriculture

Scales of biodiversity management

The analyses in chapter 1 emphasized the vulnerabilities of different types of organisms to the intensity of management and the simplification of landscapes, depending on their mobility. Broadening the argument, it is possible to propose hypotheses of the expected effects of these two factors on differing types of ecosystem services, as a function of the groups of organisms that provide them. This approach would then allow an understanding of the expected benefits of biodiversity preservation at the plot scale versus the landscape scale.

The interpretation chart already used in chapter 1 can be applied here to analyse the expected interactions between management and the provision of ecosystem services.

The two complementary axes for the amelioration of ecological services for agro-ecosystems are:

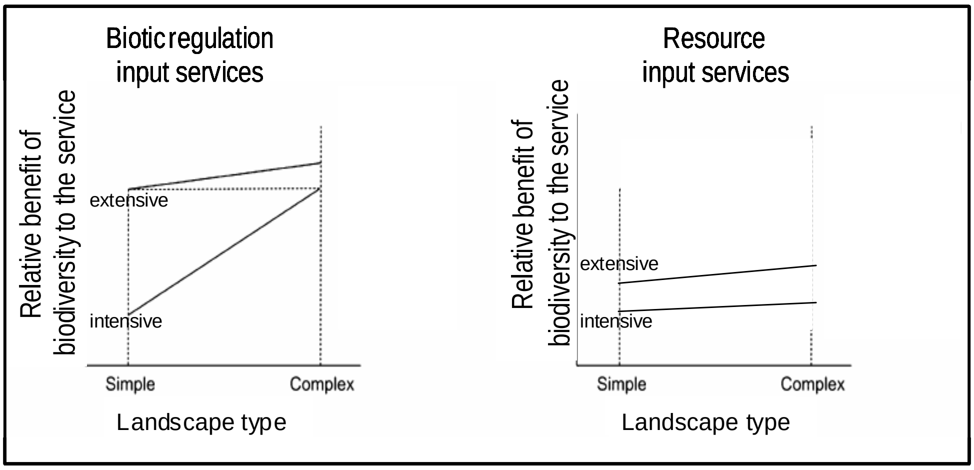
- **increased complexity of spatial structures**, from within intensively managed systems (for example broad-acre annual crops in open landscapes), to field boundaries and up to the landscape scale. Such a strategy can represent an additional work-load for farmers.

- **the de-intensification of cropping systems**, whether this be through decrease in pesticide use, mineral fertilisation or soil cultivation, and through the adoption of long and diversified rotations and multi species and varietal associations. Such a strategy represents for a farmer saving on input costs, but at the risk of production losses.

The expected benefits of these two axes differ depending on the services considered.

Input services dependant on biological interactions, such as pollination and the control of pests by natural enemies, rely on mobile organisms. This type of biodiversity is sensitive to local conditions resulting from management applied at the plot scale, but also on the surrounding spatial structure, from the plot to the landscape. The result is that these services are strongly effected both by the intensity of management of plots (and the resulting negative effects on the biodiversity of these organisms) and by the spatial complexity of the landscape (and its beneficial effects on the biodiversity of these organisms). They can then be promoted by two types of management modifications. An increased landscape complexity would at the same time benefit other services such as micro-climatic regulation within plots, flood regulation, the preservation of ordinary and keystone biodiversity, the cultural and aesthetic value of landscapes, and especially in the case of broad-acre annual crops, water quality.

Opportunities to ameliorate the provision of ecosystem services for agro-ecosystems as a function of the degree of intensification, landscape complexity and type of service



Effects of landscape complexity and the level of agricultural intensification on the level of relative dependence of input ecosystem services on biodiversity, as a function of the type of service considered: (left) biological regulation services such as biological control, and (right) resource provision services such as soil fertility maintenance. This diagram is proposed by the experts of this assessment as a summary of their analysis of the literature.

Input services linked to resource provision (soil structural stability, maintenance of soil fertility, crop water availability, as well as crop yields) rely on organisms with little mobility (plants, soil fauna and microorganisms). Landscape-scale processes have limited effects on this type of biodiversity. Therefore increased complexity of spatial structure will have little effect on the provision of these services. However, services of resource provision may be ameliorated, *a priori*, by de-intensification within plots, which favours plant and soil biodiversity. Nevertheless, for these services, the benefits of biodiversity within plots is often, beyond a minimal threshold of representation of key functional groups, of only minor amplitude in comparison to the direct effects of management (soil cultivation, fertilisation).

Benefits of biodiversity restoration

The introduction of species for management, for example restoration of the biodiversity of permanent grasslands, and the creation of ecological infrastructure, offer possibilities to augment the ecological services provided by biodiversity, although managing such a process remains delicate. A major risk involves the possibility of introducing exotic or undesirable species.

For example, the **restoration of permanent grasslands** with local species increases the chances of reconstituting services of animal production as well as the medium-term stability of pasture composition and production. The restoration of plant diversity can also affect the functional composition of soil microorganisms and thus services such as maintenance of soil fertility. However, it is currently difficult to predict to what extent projects of plant biodiversity restoration in fallows and grasslands will affect the services provided by soil fauna as their effects on this type of biodiversity are not systematic.

The possibilities for the **restoration of communities of natural enemies and pollinators** are numerous, and the most common approaches involve the creation of permanent ecological infrastructures serving as refuge zones for natural enemies during the different stages of their life cycles. In the same way, restoration projects of populations of insect pollinators involve the establishment of communities of entomophilous plants and the conservation of semi-natural areas as refuge areas and sites for insect emergence, but their real impact on insects and thus on the service of pollination remains to be quantified in detail. These projects should in all cases be accompanied by decreased pesticide use, a measure favourable to the maintenance of diverse communities of natural enemies and pollinators.

Strategies for the biological control of pests

The available knowledge on natural enemies in crops and their activities of pest control allows the development of viable agro-ecosystems minimising the use of pesticides. Three types of mechanisms could be implemented to limit the development of pest species populations :
- control of pests by natural enemies including predators and parasitoids,
- control of pests directly by the type (species, variety, mixture) and / or the layout (planting density…) of the cultivated plants,
- attraction of pests to trap wild plants or crops, and their subsequent destruction.

These three mechanisms can be combined to develop diverse strategies for the biological control of pests.

Favouring the multi-functionality of agro-ecosystems

The analysis of relationships between the components of biodiversity and ecosystem services has shown that different components of biodiversity can simultaneously contribute to multiple services. For example, plant species richness is beneficial for yields, and also for the utilisation of nitrogen and water quality, which allows the simultaneous optimisation of these two services while maintaining a moderate level of fertility. In the same way, the taxonomic and genetic richness of mycorrhiza favours simultaneously soil stability, the efficiency of primary production (via plant mineral nutrition) and the stability of production through its effect on the health of plants. In contrast, the same component of biodiversity can be a source of benefit for some services, and induce losses for others. This is the case for weeds, whose effects are negative in some contexts such as during drought, when they induce negative effects in water availability and thus crop production, but can also be beneficial for soil stability, pollination, maintenance of populations of natural enemies and cultural and aesthetic values.

Obtaining a level of biodiversity beneficial for the majority of services in an agricultural system depends on a large number of complex phenomena, and can lead to making choices as to which services and associated biodiversity components are to be favoured, as part of a larger strategy to integrate the objectives of agricultural production, biodiversity and environment protection.

Determining the choice of priority objectives (when not all of these are compatible) and the management to be put into place to achieve these requires an examination of each of the different services and the biodiversity type and level required for each, and a consideration of their respective responses to a modification of management. These response profiles may be different depending on the group of organisms or the service considered. The superimposition of these different response curves then allows the identification of the gains or losses in services induced by a management change, and thus a discussion of which services are to be prioritised. Developing this approach is a new field of research of high priority.

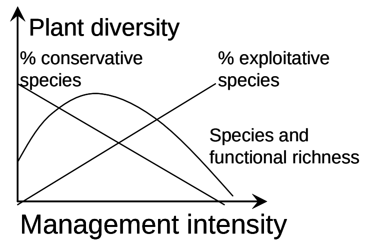
The example of permanent grasslands

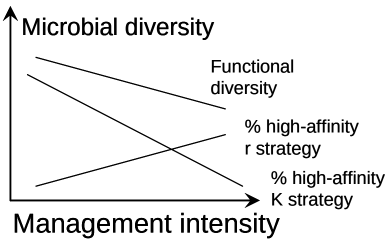
The management of biodiversity for the simultaneous provision of different services is an important challenge in permanent grasslands, which are required to produce a large range of ecosystem services : biodiversity conservation, forage production, water quality regulation, climate regulation via carbon sequestration and the limitation of greenhouse gas emissions… All of these services, and the types and levels of biodiversity underlying them, do not have the same response curves to the intensification of management – which, in such grasslands involves increases in fertiliser use and/or the intensities of mowing or grazing. The key challenge for management is thus to find an optimum, or an acceptable trade-off between these services.

Determining the compromises between services responding differently to agricultural intensification in permanent grasslands

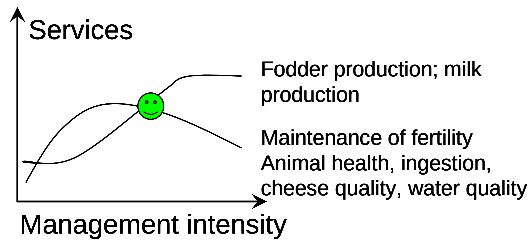
A graphical analysis of the trade-offs between different services dependant on plant and microbial diversity in permanent grasslands.

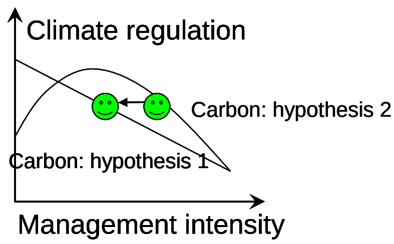
Effects of management on biodiversity





Effects of management on different services





The two above figures summarise the effects of the intensity of management on plant and microbial diversity.

The lower left diagram presents the expected effects of the combination of management and biodiversity on different input services, on milk and forage production, and on water quality. Forage and milk production are essentially controlled by management intensity, while for the other services a unimodal response (with a maximum for intermediate intensities of management) is expected. A trade-off point between services, as defined by stakeholders, is indicated by ☺ and corresponds to an intermediate intensity of management. More intensive management leads to a progressive loss of services other than production. More extensive management leads to a marked decrease in production with initially only small gains in other services, and for very low intensities of management or abandonment, the potential loss of these services.

The taking into account of the objective of carbon sequestration complicates the analysis. With the relationship between plant diversity and carbon sequestration being uncertain, two contrasting hypotheses are proposed (lower right diagram). If the effects of management (through soil cultivation and mineral fertilisation) are dominant (hypothesis 1), the service of carbon storage decreases directly with intensification. This may result in a displacement of the trade-off point (☺) towards lower management intensities (associated however with a loss of productivity). If, in contrast, increased plant diversity allows an increase in carbon sequestration, we would expect a net positive effect up until an intermediate level of management, beyond which the negative effects of management intensification on biodiversity and thus on carbon sequestration would begin to operate (hypothesis 2). Under this second hypothesis, the trade-off point for multi-functionality would not change significantly with the incorporation of the objective of climate regulation.

However, it would be essential to test these hypotheses with rigorous experimental studies quantifying the different functions involved under manipulations of the intensity of management and of biodiversity. An economic analysis should also be undertaken, taking into account payments / or not for services such as water quality, climate regulation as well as biodiversity conservation

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Interactions with global change

The interactions between biodiversity – ecosystem services relationships and the factors of global change are little known and have been rarely studied, essentially other than for grasslands. Factors such as temperature increases, increased frequencies of summer droughts, increased winter rainfall, nitrogen deposition or atmospheric CO_2 concentrations have direct effects on ecosystem functioning (for example on primary production or litter and organic matter decomposition), as well as effects, not all well understood, on biodiversity.

For broad-acre crops, it is not possible to conclude with certainty that there exists a greater stability of production in the face of climatic change for more diverse rotational cropping systems. However, an analysis of the effects of such rotations and environmental conditions suggests that they lead to a cultivated environment that is able to better cope with biotic or abiotic stresses. Organic farming, with its emphasis on the return of organic matter to the soil increases soil water retention rates, and thus appears to be better adapted to cope with drought periods, during which production decreases would be lower than those in conventional systems.

Existing data for experimentally constructed grasslands do not allow the prediction of whether a higher diversity of plant communities would result in a greater stability, or an increase (via fertilisation by CO_2 and nitrogen) of production in response to global change. The net effect of the different factors will be a compromise between their direct effects on productivity (for example increases due to fertilisation by CO_2 or nitrogen, or decreases due to drought) in interaction with management, and the indirect effects via modifications of biodiversity, in particular changes in species or functional composition. It is also not possible to predict if increased biodiversity would lead to increased soil carbon sequestration as this will also be decreased directly by temperature increases (increasing soil respiration) and drought(decreases in the activity of plants and soil microorganisms), while also being stimulated by atmospheric nitrogen deposition and increasing atmospheric CO_2 (via the stimulation of soil microbial activity).

There exists little research on the consequences of global change on phytophagous arthropod communities, and virtually no research for carnivorous arthropods and the ecosystem service of biological control. While it is likely that continuing trends of landscape simplification will lead to decreases in ecological services, the effects of increases in temperature and CO_2 concentrations on the same organisms remain at the stage of hypotheses.

Finally, the impacts of global change on plant invasions will probably occur via effects on resource availability and on disturbance regimes. The impacts of such invasions on soil structure, soil fertility, water availability, or fire regimes may become more important under conditions of increased aridity, especially for grasslands and rangelands in southern regions.

2.4. Conclusions

Before addressing questions of technical and economic feasibility (chapter 3) and the possible implementation (chapter 4) of approaches reconciling the objectives of agricultural production and of respect for the environment, in particular biodiversity, it is necessary to better understand the possible benefits for the major ecosystem services of agro-ecosystems. In particular, what level of key services could biodiversity assure under new modes of management requires evaluation.

Within this framework, some conclusions can be drawn from the scientific studies conducted on the role of biodiversity in agro-ecosystem services:

♦ Biodiversity is at the same time a service of agro-ecosystems through its intrinsic value and its associated cultural services, the result of the management of other services (in particular production), and a component in the delivery of a large range of other services. This makes the analysis of relationships between management, biodiversity and ecosystem services particularly complex.

♦ The ecological and agronomic benefits of the management of biodiversity for input services linked to resource provision (soil structural stability, maintenance of soil fertility, water availability for crops) appear often to be of a small magnitude in comparison to the direct effects of management (fertilisation, soil cultivation, phytosanitary treatments). A simple reduction in the direct management of these services (reducing for example the level of added fertiliser or pesticides used) poses the risk of short, and even, long term reductions in the agronomic performance of these systems. The challenge is thus to modify agricultural practices to develop a greater efficiency in the utilisation of resources by crops and a lower dependence on inputs over the medium and long term. Similarly, the judicious use of organic fertilisers (when these are available given the disappearance of grazing in areas of broad-acre cropping), acts simultaneously on fertility and soil activity / biodiversity, and in the medium to long term on soil structural stability and water availability. The management of the location of cultivated plants within plots or within rotations in relation to the location of nitrogen-fixing plants is another example. These methods require the promotion of more technical approaches to agricultural management (chapter 3).

♦ The ecological and agronomic benefits of the management of biodiversity for input services dependent on processes of biological regulation (pollination, biological control of pests and invasion resistance) can be significant for farmers, particularly for crops dependent on insects or particularly sensitive to insect pests (numerous broad-acre crops, orchards, vineyards, seed crops such as Lucerne, seed producing legumes). Not only do these services act to reduce the expenditures on agricultural inputs, but they can also in some cases avoid the development of management failures for example in chemical control (in the face of the development of pest species resistant to pesticides) or the loss of organisms, such as pollinators, that cannot be replaced by inputs. Favouring the biodiversity of organisms responsible for these services can be achieved by management at plot level of the diversity of their supporting organisms (for example weeds or annual flowering plants), with in addition the promotion, at the scale of the field margin or the landscape, of various semi-natural elements, not in themselves productive, but which act as reservoirs for organisms involved in these services.

♦ The biodiversity of different organisms is often involved in the provision of a given service (for example plants and soil organisms in the maintenance of soil fertility) In addition, each component of biodiversity often contributes to a range of services (in the case, for example, of grassland plant functional composition or mycorrhizal diversity) and sometimes, but more rarely, leads to decreases in particular services (for example some cultivated plants that favour certain pests or predators of the natural enemies of crop pests). It is therefore difficult, and incorrect, to consider these different components in isolation when developing production systems to better integrate production and biodiversity. In some situations, the management of biodiversity for one service in particular may have positive effects on a wide range of other services, and / or on the biodiversity of other organisms associated with other services. This is how in semi-natural permanent grasslands, intermediate levels of management intensity can preserve at the same time a high biodiversity, improve the long-term stability of the performance of the system and increase the stability and quality of animal production. However, in other situations, favouring biodiversity and / or certain services may have costs for other services, or even for overall biodiversity.

♦ On the basis of available knowledge (chapters 1 and 2), the management of non-productive elements contiguous with agricultural plots and of landscape diversity, which includes the type, quantity and layout of semi-natural elements as well as the diversity of crops, appears to offer a good compromise to achieve environmental objectives while maintaining those of production. In fact, landscape diversity contributes not only directly to the provision of some services, but also to favour the biodiversity of mobile organisms, on which input services of biological regulation often depend. This does not negate the need to determine how to adjust practices to best utilise biodiversity also at the plot level, in particular through judicious use of fertilisers and chemicals, the use of crop rotations or polyculture techniques, increasing the number of species cultivated simultaneously (within the same plot or same locality): varietal mixes, companion planting, establishment of other useful plants, grass establishment in orchards and vineyards (see chapter 3).

More generally, this assessment is an opportunity to identify the manner in which scientists are involved and how they tend to formulate questions when investigating the "roles of biodiversity for agriculture":

♦ Overall, a large scientific community is working on the relationships between biodiversity-functioning-stability in model ecosystems, but in a very academic fashion. The use of the term services here is often inaccurate, as this work rarely incorporates interactions with human society, and thus the information is often not directly applicable to or useable by stakeholders. In contrast, the scientific community working on the role of biodiversity for agro-ecosystem services in temperate areas is extremely small (research on biological control is an exception).

♦ It appears however that the field is evolving with the establishment of research programs combining rigorous experimental approaches with agronomic reality.

In this context, agronomy needs to move from a vision dominated by fluxes of matter and energy to one fully integrating biological interactions in agro-ecosystems, as the multiple links between biodiversity and ecosystem services within agro-ecosystems provide potentially important opportunities for the future of agriculture. Nevertheless, the management of biodiversity for ecosystem services provided to agriculture should be continually subject to evaluations linked with contemporary economic, social, agronomic and environmental contexts, so as to assure necessary re-adjustments to harmonise modifications of practices with general production objectives and the available resources.

Finally, a challenge for all of the stakeholders interested in relationships between agriculture and biodiversity would be to better integrate research, environmental engineering and experimental agriculture through collaborations between scientists, agronomists and farmers.

3. Agricultural practices favorable for biodiversity: technical and economic approaches

The protection of biodiversity cannot be limited to the protection of natural areas: equal attention must be paid to promoting biodiversity in agricultural landscapes. The deleterious effects of the over-intensification of agricultural practices and the simplification of landscapes have been identified in chapter 1. Consequently, it is necessary to re-assess these major evolutions in agricultural activity, initiated with the modernisation of agriculture after the Second World War.

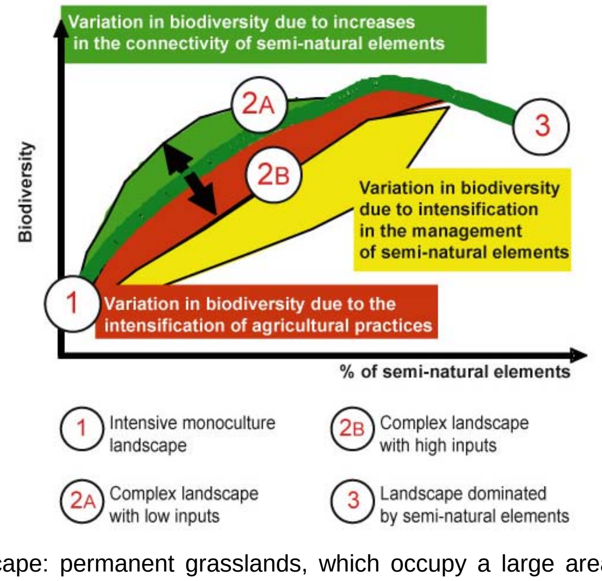
While some components of biodiversity can create losses for agriculture, others may have considerable beneficial effects (see chapter 2), notably for services of biotic regulation. The challenge is to develop agricultural practices and to conceive agricultural systems more favourable for biological diversity, and in particular to ensure that such practices allow agriculture to benefit from the beneficial effects of biodiversity. This also includes the management of the margins of agricultural fields, potentially important reservoirs of predators and parasitoids of some pest species which can help in the regulation of pest species populations. In the same manner, management of grassland biodiversity appears as an essential aspect of the development of agricultural areas in low-productivity regions or mountain regions, especially in areas recognised under systems of protected designation of origin such as for some cheeses.

How can such potential changes be integrated into current agricultural practices, or into the development of new production systems? How will it be possible to integrate such modifications of agricultural practices favourable for biodiversity into farm management? How will such changes be accepted by the agricultural community given their potential impacts on production, the regularity of revenue and the scheduling of farming activities? This chapter explores the relationships between agriculture and biodiversity from the point of view of the farm and the farmer. Given the almost complete absence of scientific research concerning these issues, this assessment has been largely based on publications dealing with relationships between agriculture and the environment or concerning innovations in agricultural techniques.

Regional and field level management

Agriculture exerts its effects primarily through two major types of drivers: the structuring of landscapes, which largely determines their diversity (notably through the proportion of semi-natural elements present and the connections between landscape elements), and the practices of agricultural use and management of these various landscape elements, both productive and non-productive. In this context, it is necessary to obtain complementary information on the three essential elements required to quantify biodiversity in agricultural systems (see figure): the quantity of semi-natural elements present in the landscape, the heterogeneity of the crop / landscape mosaic and the associated cropping practices and grassland management.

This figure, whose complete caption is developed in chapter 1, presents changes in biodiversity as a function of the percentage of semi-natural elements present in the landscape. Biodiversity increases until a certain level, and then decreases as shown by research on agricultural abandonment. Increasing connectivity amongst semi-natural landscape elements increases biodiversity (in green) at intermediate levels of the presence of semi-natural elements, but not at high or low levels. Biodiversity is reduced by the intensification of management practices both in agricultural fields and in semi-natural elements (in brown and yellow). Such practices (fertilisation, tillage, herbicide and insecticide use…) induce changes in biodiversity within a given landscape context.



- The quantity of semi-natural elements in a landscape: permanent grasslands, which occupy a large area in France, but with a highly variable distribution and degree of naturalness, are a major type of semi-natural element. Temporary or sown grasslands are not usually considered as being semi-natural elements and do not often have, in contrast to permanent grasslands, a positive effect on biodiversity. Another category of semi-natural elements comprises of structural landscape elements (hedgerows, grassy margins, drainage canals…) that have been established since the development of sedentary agriculture. Even while the surface area of these elements is not great, their organisation in networks increases landscape connectivity and is thus favourable to biodiversity. Due to the expansion of broad scale cropping in many regions and decreases in the use of grassland grazing in animal breeding systems, the representation of such semi-natural elements has been greatly decreased in many landscapes.

- Crop mosaic heterogeneity: the type and diversity of crops is dependent on the production system, and the spatial arrangement of fields which is in-turn linked to the tenure system. Agronomy uses the concept of cropping systems, which refers to "the totality of agricultural techniques used in a group of identically treated fields". This concept is primarily used at the field scale. It would be useful to develop it further at the regional scale to distinguish those landscapes characterised by similar land uses.

- Cropping systems and grazing management: the type of management determines variations in the quality of the environment for a given production system, which leads to the concept of the technical plan, defined as the ordered sequence of technical operations. Such technical plans are usually internally coherent and should be considered globally: rarely would it be possible to change only one part of a technical plan. Similarly, the management of semi-natural landscape elements strongly influences their quality as habitat for biodiversity, for both species conservation and the provision of ecosystem services.

Protecting and benefiting from biodiversity

This double objective is confronted by multiple difficulties. The relationship between the landscape and agricultural activity is not direct: a landscape (in the sense of a functional ecological unit) most often corresponds to numerous farms, with farm size playing an important role. The question here is different to that for agro-environmental measures targeted at the field level which, not having been designed to take into account the farm level, have contributed little to the management of biodiversity. Another difficulty arises from the fact that for the effective management of biodiversity, it is necessary to oppose the dominant paradigm. This paradigm emphasises the complete control of the physical and chemical environment in order to favour crops, and the elimination of other biological components (The direction of the development of agricultural innovation has however changed, as shown by the recent report by the assessment of innovative agricultural systems conducted by INRA.

As regards the innovation potential for the integration of biodiversity into production systems, both for objectives of its protection and for its beneficial effects, a considerable amount of literature can be retrieved using the keywords *"biodiversity*" and "*farm management*". However, this literature is often based around techniques and infrastructures for which neither the on-farm feasibility, nor the diversity of farms has been taken into account. A technique favourable for biodiversity and even profitable at the level of experimental plots will not necessarily be adopted on farms.

Two primary criteria differentiate farms: the diversity of production systems (broad-acre cropping, animal husbandry, polyculture, arboriculture, *etc*.) and farm size. The first criterion describes the differing types of land use present, and the second the footprint of farming in a region. Taking into account the economic dimension of a farm, which largely determines the opportunities for adaptation, is also important.

Firstly, the general factors determining the adoption of innovations and the existence of opportunities for adaptation will be presented, followed by the opportunities for adaptation for the major types of agricultural production (broad-acre crops, grasslands, and arboriculture). Secondly, the question of the management of semi-natural and non-productive landscape elements (fallows) will be considered. Finally, we will present a short analysis of organic agriculture, and an examination of the obstacles to its adoption. In conclusion, we will outline future research and management perspectives based on currently existing information.

3.1. Three groups of interacting factors

Currently existing published reviews show that the factors determining the adoption of environmental protection measures by farmers are numerous, and in addition strongly interacting. Three types of factors can be distinguished: technical, social and economic. Another essential point is that the adoption of innovations is greatly facilitated by group dynamics: successful adoption is most often collective and policy initiatives can be used to facilitate this. Such a situation is found with the facilitation of the phase of "agricultural intensification" beginning during the 1960's with, in France, the centres for the study of agricultural techniques (CSAT), agricultural development groups (ADG), agricultural equipment cooperatives (AEC), *etc.* and an agricultural orientation law. These changes are most often regionally based.

The little data available concerning the integration of biodiversity management on farms indicates that measures concerning biodiversity, within the context of agro-environmental measures, are better accepted if considered within the context of multi-functionality in agriculture than if biodiversity is considered as a single objective. Finally, the adoption of "biodiversity" measures for a few fields can progressively lead a farmer to analyse his practices over the whole of his farm and potentially leads to broader changes.

3.1.1. Technical factors

Work on the functioning of farms has shown that for any change in the techniques used (new cropping methods, establishment of a new rotation, establishment of non-productive elements on the farm, or changes in scheduling of farm activities) to become durably adopted, it must be adapted to the general scheme of functioning of the farm, and to the production logic of the farmer. This logic demands that any changes correspond to a certain number of objectives for himself and his family, and takes into account the various constraints and advantages particular to the farm: farm history, available workforce (family and employees), equipment and buildings, farm environment (farm size, field structure, soil types, climate…).

At the scale of the agricultural field, constraints to adoption can be linked to the necessity of acquiring technical skills (or a suite of technical skills) favouring biodiversity. It is also necessary that any changes, even if technically feasible, are compatible with the functioning of the farm. The most commonly encountered problems are of three types: the scheduling and organisation of farm activities (techniques favourable to biodiversity are often more time consuming), farm equipment and infrastructure (e.g. buildings, equipment - replacing an all corn system with a fodder system based on grass requires specific equipment) and modifications of the spatial structure of the farm (establishment of hedgerows, changes in the size of fields…).

At the whole farm scale, the regional organisation of agricultural activities plays a central role particularly regarding the dynamics of animal and plant populations (for the control of pests or the promotion of their natural enemies) or, more generally, that of biodiversity. The regional organisation of agricultural activities is the driver that spatially orders agricultural objects and their interactions: the distribution of cropping systems, location of fields, combinations of crop rotations, location of herds, fences, hedgerows, water points…). Such objects are ordered through multiple decision making processes occurring in interaction with each other. To successfully change the management of these areas in favour of biodiversity requires an understanding of how agricultural activities are organised. Very little research explicitly addresses such questions in the context of the adoption of measures aiming to achieve better management of biodiversity; the majority of such work focuses on the adoption of measures increasing the sustainability of production systems, with the protection of biodiversity being, at best, only a part of the objectives.

Agricultural activities can be classified into two major categories as a function of their impact on biodiversity. The first group includes the methods of agricultural exploitation of fields and animals as well as the management of non-cultivated interstitial areas (hedgerows, field margins, irrigation canals…). These impacts rapidly modify the state of the environment and can result in rapid impacts on biodiversity. The second category corresponds to practices which structure the regional landscape, including the type, size and type of field margins, the hydrological network (canals, ponds, streams…) and the major land-use types (crops, orchards, pastures…). The consequences of this second category on biodiversity can be expressed and persist over much longer time scales.

Modification of cropping systems

The intensification of agricultural production, increased specialisation on a reduced number of crops and the suppression of non-productive areas are most often considered as the key causes of the loss of biodiversity in rural areas (see chapter 1). Action to reverse these trends must thus be taken for these three types of causes.

- Agricultural de-intensification

There exist a number of definitions of intensification, amongst which we have retained the following: the notion of intensification has no meaning unless linked with a factor affecting production, for example soil productivity, workload or required capital. A factor is exploited in an intensive manner when a given quantity of the factor is combined with increasing doses of other factors. This concept is intimately linked with the productivity of the factor. If this factor is relatively rare, the aim of obtaining the maximum possible global revenue leads to choices ensuring an increased productivity of this factor. Historically, in France and in Western Europe, it is soil that for a long time constituted the most limiting factor. To increase production or revenue, the focus has been on increasing productivity, historically through increasing work input, and then with the modernisation of agriculture, through the use of synthetic inputs and investing in materials, buildings.

From this stems the current definition: an "intensive agriculture is an agriculture which uses increasing factors of production per unit of surface area. The more such agriculture is intensive, the greater is the production per hectare" (Terminology Commission, 1993). The emphasis is often placed on the use of two factors of production to increase productivity: the work and the capital. Depending on the case, there are then either *labour intensive* types of agriculture (with work input representing the principal expenditure) or *capital intensive* types of agriculture (using large amounts of inputs and with high fixed capital per hectare). In fact, the conventional economic approach considers exclusively three factors of production: land, work and capital (inputs, materials, buildings). However other factors enter into the process. The production of an area of land also depends on knowledge and / or understanding (traditional knowledge and/or scientific and technical understanding), information (concerning in particular the environment and the state of crops and animal husbandry systems), energy and ecosystem services (water availability, the activity of microorganisms, the presence of crop pest natural enemies, biotic interactions, symbioses, biotic regulation, *etc*.).

In contrast to the definition of intensive agriculture, "extensive" agriculture uses low quantities of production factors per hectare, and in particular low quantities of inputs, fixed capital and/or work input. Extensification is thus a process of change where the production per hectare is lower due to the use of lower amounts of production factors. However, such that the farmer’s revenues remain at a sufficient level, the surface area for production required is consequently greater. In contrast, de-intensification is the process which consists of progressively reducing agricultural inputs and capital per unit of surface area. It is in this context that this chapter is framed, as the surface available per farm in France remains limited. The type of de-intensification considered below concerns therefore the "classic" factors of production (the resulting agricultural systems can however be highly intensive in comparison to the other factors mentioned below).

- Diversification of production types

This approach poses an economic problem in that, by diversifying a farmer reduces the use of crops or animals that provide the highest productivity margins. In this context, technical obstacles to implementation stem primarily from supplementary technical requirements, investments in additional equipment due to the greater variation in production techniques and conflicts in the scheduling of farm activities (conflicts between differing crops or other management activities).

- The management of "non productive" elements

The management of "non productive" elements within and immediately adjacent to agricultural fields (fallows, grassy margins, trees, road shoulders, canals…) can result in various technical problems. For example, modifications to techniques to prevent the off-target drift of herbicides into such non-productive elements can result in time and efficiency penalties for farmers.

Studies analysing these technical factors focus essentially on the technical efficiency in terms of effects on production or the state of the environment. Few of these studies analyse the capacity of farmers to actually adopt the studied measures targeting the protection or greater use of biodiversity. In addition, the majority of the literature examined is based on work carried out by agricultural extension services (experiments on field stations or on farms), without being published in the scientific literature.

Territorial organisation and management

The preceding chapters have outlined the effects of landscape structure on biodiversity and the effects on agro-ecosystem services that can result. This landscape structure is strongly linked to the decisions farmers make in terms of the spatial allocation of land uses, which determine at the same time the structure of vegetation cover and production practices. In addition, the management of field margins is also linked to the use of adjacent fields. To our knowledge there are no publications linking land use allocation decisions with the mosaic configuration and the biodiversity characteristics of the landscape. Publications on these topics are generally carried out at the regional scale at coarse spatial resolutions, both in Europe and in North America. At such scales specific agricultural practices are difficult to take into account.

At the farm scale, the decision-making processes concerning landscape configuration occur at two levels. The first concerns technical considerations: each part of the farm should be adapted as well as possible to the technical operations to be carried out in that area. The most obvious example is that of the field: field size, form and distribution, should facilitate the mechanisation of cropping operations. The second level concerns the farm as a whole, at which issues of complementarity or competition between land uses are managed. Consequently pastures would be located close to feedlots and outbuildings, while sale crops would be located further away, *etc*.

The spatial arrangement of fields is not without consequences for management: for example, the furthest fields tend to receive less manure than closer ones or have less frequent applications. The spatial structure of fields plays a determining role. The distribution of fields is characterised by the degree of segregation Often the result of a long history, such segregation is not necessarily a handicap as it allows the targeted exploitation of different environments and the spreading of risks. However, it often leads to excessive movements which, with the increasing size of farms and also of equipment (leading to difficulties in moving equipment along narrow roads) can become a major problem. In many cases, such constraints have a major impact on agricultural activities: for example, the dates, or the doses of a treatment are no longer those considered optimal by agronomists, but rather the result of adaptations to the constraints imposed by the organisation of the farm.

The development of "no-till cropping", adopted for the preparation of about one third of the cultivated surface area in France, has been primarily developed to save time for farmers. Crop rotation systems are also developed to optimise movements. Finally, the management of fields also depends greatly on their shape: long fields for broad acre crops, with a width corresponding where possible to multiples of the width of cropping machinery, and preferably square (for an optimisation of the ratio of surface to the perimeter) for grazed pastures and areas requiring fencing.

3.1.2. Economic factors

The costs of the adoption of technical changes aimed at better reconciling the objectives of production and the preservation of biodiversity is obviously an important element determining their integration into agricultural production systems. The greater specialisation of farms and the intensification of production techniques respond to a clearly identified economic logic: this trend is particularly linked to the increases in labour costs, which has lead to pressures to replace manpower with inputs of industrial origin and has lead to the search for economies of scale particularly for dairy and cereal production, and for feedlots. These changes have been particularly favoured over the last few decades due to a relatively low price for fossil fuels and the lack of costs associated with the environmental impact of such energy consumption or of the use of synthetic inputs.

The majority of measures favourable for biodiversity are based on changes in the opposite direction: the de-intensification of production, the diversification of cultivated species, the reintroduction of hedgerows… Economic evaluation of such changes is less obvious than it first appears, especially when dealing with systems for which biodiversity is indirectly involved in production and marketing (for example for products having controlled terms of origin explicitly mentioning this aspect).

Studies considering both the preservation / utilisation of biodiversity together with the maintenance of the economic efficiency of production systems are still extremely rare. Current studies consider either technical options for which the primary objective is environmental protection (for example the adoption of sustainable fertilisation), or on complete modifications of production systems (for example conversion to organic agriculture). In most of these studies the results presented do not include measures of the effects of changes on biodiversity, which represents a considerable limitation for this assessment.

Amongst the economic and social constraints are the sectors upstream and downstream of agriculture. For example in the case of production sold on the basis of contracts, farmers are forced to adopt production methods that are not necessarily favourable for the preservation of biodiversity. Some contracts demand the delivery of products without blemishes, other traces of insect damage, *etc*., which leads farmers to use an arsenal of phytosanitary products. Another example is, for cereal production, where farmers are required to respect strict controls concerning the presence of fungal toxins (some of which can be dangerous for human health), which leads farmers to use large quantities of fungicides (even if there exist alternative control methods, such as varietal choices, soil cultivation, the adoption of long rotations…).

Similarly the food industry, often analysed in the direction of the circulation of goods from the producer to the consumer, also exercises a pressure from downstream (retailers, distributors, processors) to upstream (producers). Producers find themselves constrained to adopt agricultural practices imposed by their downstream partners. The importance of this factor in modifications of agricultural production systems is increasing: the expectations of consumers are becoming more and more important, and this international trend is resulting in agriculture becoming more and more a system driven by demand. In fact, agriculture has been partly driven by demand for a long time. The following table presents a list of examples for aspects of agricultural production systems influenced by the demands of the food industry and retailers.

Demands of the food industry and retailers	**Influence on the evolution of agricultural systems**
Strong growth of the food industry and retail sectors through which an increasing proportion of the total volume of agricultural production is concentrated, coupled with the extraction of increasing proportions of the value added from processing and commercialisation.	Concentration of production on primary products with decreases occurring in on farm processing and in direct sales.
The food industry and retailers search for the lowest priced primary products: competition at the scale of world markets is strong and increasing.	Need to increase the productivity of labour to reduce costs: the use of productive races and varieties; increasing size of farms and associated buildings; standardisation of production methods. The transfer of some types of production towards countries with lower labour costs (market gardening).
In general the food industry demands standardised products adapted to processing (the criteria of homogeneity is important) and to commercialisation (multiple criteria can require standardisation in terms of size, health standards…) while distributors also require products able to survive lengthy storage periods.	A homogenisation of varieties used. The choice of varieties depending on demand is imposed. This can have consequences for the rest of the production system (for example the impossibility of choosing resistant varieties and the consequent need to use pesticides).
In parallel there is demand for strategies to differentiate products in the eyes of consumers, which implies increasing specialisation in production	Increasing fine scale adaptation to diverse downstream demands, limiting farmer flexibility and opportunities for adaptation.
Payments depending on various quality criteria are becoming generalised, retailers are requiring high quality as regards the presentation of products (absence of marks, other damage)	No real alternatives to the use of phytosanitary products to achieve the required presentation quality objectives.

3.1.3. Social Factors

The life experience of a farmer, his / her attitudes towards environmental issues and influences from his / her social network also need to be taken into account to understand the degree of acceptability of cropping techniques or changes to farming infrastructure favourable for biodiversity.

There exists an extensive literature dealing with this subject, in particular in Europe, where since the establishment of the common agricultural policy in 1992, numerous teams (associating sociologists, anthropologists, psychologists…) have carried out studies to identify the constraints on the adoption of agro-environmental measures or participation in collective programs focused on nature protection. These studies have highlighted the importance of psychological factors in explaining such reluctance, which in contrast to common assumptions, is not solely explained by economic considerations.

3.1.4. Conclusion

The three groups of factors interact: a farmer will adopt a measure if it is not contrary to his value system, if it can integrate into the overall scheme of functioning of his farm and if it does not compromise the economic viability of his farm. However, the relative weight given to each of these factors will depend on factors external to the farm itself: type of region, types of production, types of ecological systems, type of social dynamics (farmer organisations, associations…).

The adoption of technical changes usually occurs in a progressive manner. It is thus important to consider the problem integrating this temporal dimension. One of the important characteristics of such adoption, when observed over the long-term, is the capacity of farmers to adapt, transform, avoid, or ignore policy measures. There is rarely a simple binary situation with only the adoption or rejection of biodiversity measures. Additionally, contrary to expectations, such non-standard responses to policy measures do not systematically decrease their impact. While often the manner in which farmers implement agricultural policy measures leads to decreases in their effectiveness, in other cases, it may lead some farmers to go further than required by policy.

Some farmers have, for example, considerably changed the organisation of their farms and have integrated biodiversity as a major dimension in their farm planning even though, from the point of view of environmental contracts, their commitment was limited to only a few fields and often only for limited amounts of environmental payments. The experience of the implementation of the agro-environmental policy "flowering grasslands" in Germany (Baden-Wurtemberg) is interesting from this point of view (established in France since 2007 in the Bauges Natural Regional Park). The objective to reach a minimal threshold of grassland biodiversity was the starting point for major change in how farmers viewed biodiversity. From initially an imposed constraint, biodiversity has for many farmers become a technical challenge of the same level as the milk production of a cow or the productivity of a crop.

3.2. Cereal and industrial cropping systems

The adoption of measures favourable to biodiversity in systems of broad acre cropping is determined, on the one hand at the level of the management of cropping systems, and on the other through the re-development of the infrastructure of broader agricultural areas. Here we will deal primarily with the first case, and only marginally with the second (the literature which would allow a better treatment is sadly lacking). The supposed availability of compensation for any supposed costs appears to result in most scientists evaluating agricultural policies not analysing further effects on the functioning of farms. The three types of possible actions at the level of the management of cropping systems are de-intensification (including reductions in soil cultivation), greater diversification in production systems and the management of "non productive" elements on farms.

3.2.1. De-intensification

De-intensification raises not only economic issues, but also technical ones like the maintenance of soil fertility or the control of pest populations. In broad acre crops, the establishment of methods of integrated pest management, and limiting the use of synthetic fertilisers, represent the most efficient technical changes in terms of better biodiversity management. Decreasing soil cultivation and adopting no-till techniques (e.g. direct drilling) is a practice globally favourable for biodiversity (see chapter 1), even if this positive effect can be reduced by an increase in pesticide use, or when such practices are only applied occasionally.

Reducing pesticide use: integrated control

Other than for organic agriculture (which is treated separately), possible solutions are primarily based on the principles of integrated pest management (IPM). The INRA-Cemagref collective scientific assessment carried out in 2005 (Pesticides, Agriculture, Environment: reducing pesticide use and limiting their environmental impacts) established a classification of the relative importance of crop pest species of and of the efficiency of control methods (see table).

Principal pest groups	Degree of impacts of pest group	Efficiency of currently used control measures				
		Chemical control	Varietal resistance	Biological control	Physical control	Cropping system (7)
Pathogenic fungi	++	+++ (1)	++	+ (4)	+	++
Weeds	+++	++ (2)	-	-	++ (6)	+++
Bacteria	+	-	+	-	-	+
Viruses, viroids and mycoplasma	+	+ (3)	-	-	-	++
Mites	+	+	-	-	+	
Insects	+	++ (1)	-	+ (5)	-	++
Nematodes	+	-	-	-	-	+
Snails	+	++	-	-	-	+

1. Seed treatments or at the crop stage
2. Pre or post emergence treatment of seedlings
3. Control of vectors
4. Control of Sclerotinia (*Sclerotinia sclerotiorum*) in various crops by the fungus (*Coniothyrium minitans*)
5. Control of the European corn borer (*Ostrinia nubilalis*) by wasps of the genus *Trichogramma* (*Trichogramma brassicae*)
6. Mechanical control of weeds, heat control
7. The effect of crop rotations is important for poorly mobile organisms (fungi, weeds, nematodes…). Soil cultivation allows the burial of residues that may carry inoculates and also manages weed seed banks. Adaptive management allows planning of cropping activities depending on the vulnerability of different crop types to pests and weeds.

It is apparent that the alternatives to chemical control, which constitute the key elements of integrated pest management, are based principally on the choice of cropping system. Physical control is also a method of control than can reduce the use of herbicides. For the control of animal pests, methods of biological or varietal control are, however, currently very limited (one crop and one pest amongst a large number of plant-parasite relationships: see the appendix table for this chapter). Currently, this limits possible reductions in the use of pesticides. Farmers have tested few of the available solutions and scientific and technical progress is necessary in this domain.

In contrast, farmers have a large range of solutions for resistance to pathogenic fungi through choosing plant varieties adapted to broad acre cropping. Such resistance, is however not always available for all cultivars and other varietal elements of choice must also be taken into account: speed of development, quality, cold resistance, *etc*. From the point of view of scientific understanding, numerous experiments, mostly derived from field experiments, have demonstrated the technical and economic feasibility of integrated pest management (see the appendix table for this chapter). It is nevertheless difficult to generalise this result to all possible situations.

Beyond the context of integrated pest control, technical-economic assessments of management methods using low levels of inputs have also been conducted based on on-farm experiments. For wheat crops, the network of field trials called "rustic varieties and low input management systems" has tested for different varieties the effects of management integrating a low input system (reduced sowing densities, reduced nitrogen fertilisation, absence of growth regulators and a reduced number of fungicide treatments). These experiments, carried out under very different geographic and agronomic contexts, have shown that better per hectare profits can be obtained through the adoption of rustic varieties managed at low cost, while at the same time maintaining sufficient quality as long as appropriate varietal choices are made together with later than usual applications of nitrogen. These results have been shown to be robust with a wheat price of 100 €/t (see the table below).

Results of the network of Agricultural Chambers of commerce, Arvalis Plant Institute, INRA from 2003 (9 trials) and 2004 (14 trials)

	2003		2004	
	Margins (€/ha)	Protein (%)	Margins (€/ha)	Protein (%)
Apache standard management	448	12,0	370	11,2
Apache low cost management	473	12,1	413	10,9
Caphorn standard management	465	12,4	396	11,3
Caphorn low cost management	499	12,3	442	11,0

Hypothetical wheat price: 100 €/t, corrected depending on wheat specific weight and protein content.
Source: Perspectives Agricoles, n° 312; May 2005.

While, technically, the opportunities allowing the reduction of pesticide use are numerous (soil cultivation, row spacing, sowing dates, rotations…), the adoption of these techniques by farmers, in the context of implementing effective strategies of integrated pest management, come up against important obstacles, of which there are three main types:

- *The lack of technical references*

In many cases, the knowledge of any given farmer falls short when determining the optimal approach for a given technique. Even though agronomic research has been based on increasing numbers of field trials, it is true that it lags behind the development of conventional broad acre cropping. In addition, the thresholds of infestation, beyond which the degree of development of the disease or of pest populations become unbearable, are often unknown.

- *The time scales involved in integrated pest management*

The alternative strategies to chemical control often require continual monitoring of pest populations in fields and more numerous interventions, as for example for the mechanical control of weed species. The additional time required may, especially at certain times of the year, be incompatible with the organisation of agricultural activities on the farm.

- *The strong dependence of the success of integrated pest management on climatic conditions*

The effectiveness of alternative control methods, much more so than conventional chemical methods, is highly dependant on the timing of the development of pest species populations, which in turn is highly dependant on climatic conditions experienced during the life cycle of the pest species (see the appendix table for this chapter).

Despite these obstacles, it appears that it is often possible to significantly decrease the use of pesticides and to reduce their dispersion into the environment. In broad acre cropping, the preceding INRA-Cemagref collective scientific assessment showed that a more conservative use of phytosanitary treatments could significantly reduce pesticide use. Decision making tools exist (disseminated by plant protection services) that allow farmers to make decisions regarding chemical treatments. These tools are generally based on the coupling of models of pest species population dynamics as a function of climatic conditions. However, this current assessment has shown that the most sustainable manner to reduce the use of pesticide products is to aim to reduce phytosanitary risks in a preventative fashion rather than simply comparing alternatives with conventional chemical control. It is therefore through a re-assessment of the complete cropping system that solutions must be sought, by involving the entire array of available techniques for pest control, rather than simply reducing the doses of chemical products or the number of chemical treatments.

Examination of the literature (see the collective scientific assessment previously cited) shows that in broad acre cropping the opportunities for adaptation can be classified into five types of actions:

- *Organisation of long rotations and optimisation of regional crop distribution*

The implementation of this strategy can be complicated by economic imperatives: farmers often organise their crop choices to maximise market opportunities as perceived at the planning stage. However, a number of studies have shown that the introduction of a greater degree of diversity in crop rotations can allow yields at least as high as for monocultures, with all other factors being equal (see chapter 2): this being known as the rotation effect. This effect of rotations can however be extremely variable depending on environmental conditions, the type and state of the crop and also climate, and it is difficult to quantify. It is however more pronounced in poor environments and /or where the amounts of inputs used is low. Those situations where we do not observe a difference in yields are usually in very intensive cropping systems, in which any positive effects of rotations are masked or replaced by high levels of fertiliser and pesticide use.

- *The use of disease resistant varieties*

The key difficulty of this strategy is the availability of appropriate cultivars. The creation of disease resistant cultivars requires a selection process carried out under a wide range of conditions. The selection criteria for disease resistance are different from the classic selection criteria based largely on increased productivity. For example: it is important to select, in the case of cereals, for varieties with a strong competitive ability against competitive weed species to allow for a reduction in herbicide applications. It is indeed possible to modify the development of weed populations through the choice of crop varieties, and this strategy has been implemented in cereal crops. Concerning reductions in the use of fungicides and insecticides, selection for resistance to pathogens (both resistance induced, or not, by pathogen attack) is a method already extensively implemented, but for which considerable development remains necessary.
New advances in molecular biology (for example using molecular markers) can be used for the selection of cereal varieties with high nitrogen use efficiencies. Another possibility is the use of ancient varieties, which although largely surpassed by more recent varieties (productivity, grain quality) especially in intensive cropping systems, can offer numerous advantages for low intensity cropping systems and for organic agriculture. The superiority of ancient varieties in the context of low intensity systems is however controversial, and some trials indicate that more recent varieties can provide higher yields even in the context of organic agriculture.

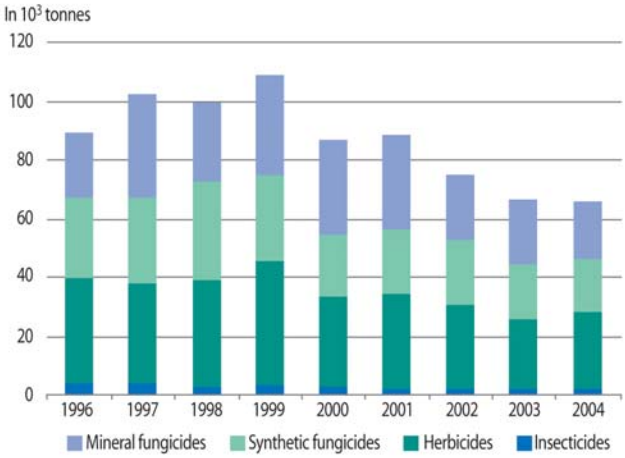
- *Establishment of lower and better adapted production goals*

Numerous field trials have shown that adapting the management of each field to its different productive capacities can remain profitable. However this approach is incompatible with the tendency towards the standardisation of production methods over the whole farm.

- Implementation of soil cultivation methods reducing weed development
The rapid development and adoption of methods of no-till cropping is currently incompatible with the goal of reducing pesticide use, as it has led to increases in the use of herbicides.

The data acquired by the Central Service for Surveys and Statistical Studies (SCEES), from surveys of "cropping practices" during 1994, 2001 and 2006, show that the use of phytosanitary products has been, for broad acre cropping, relatively stable since the year 2000. This analysis, based on the calculation of an indicator of treatment frequency per hectare (IFT) which takes into account both the dose and the number of applications, shows a different trend to that shown by the Union of Plant Protection Industries (UIPP) shown opposite. The latter shows a decrease in the tonnage of product sold. In addition, when changes in the surface area of broad acre crops considered by the survey are taken into account, it is apparent that the chemical footprint has tended to slightly increase. These trends mask however the differences between crops: for example, the mean IFT has decreased for sunflowers, it has increased for potatoes and rapeseed, and has been stable (since 1994) for soft wheat.

Changes in the tonnages of active phytosanitary materials used for agriculture in mainland France



Source: Union of Plant Protection Industries (UIPP)

Towards the establishment of new agricultural practices considering some weeds as useful species?

By definition, weeds are a component of plant communities whose negative character is unanimously recognised. The management of these species requires farmers to carry out numerous interventions to destroy the maximum number of weeds possible prior to sowing a crop, limiting the competition of weeds with the crop and then reducing weed seed production. The long-term risk of the contamination of fields by weed seed banks and the increasing resistance by farmers to use time consuming and expensive manual control methods led farmers from the beginning of the XXth century to begin using plant poisons (sea salt, copper and iron sulphates, sulphuric acid…), and since the 1950's almost exclusively industrially synthesised herbicides.

Since the end of the 1990's, environmental considerations have led to the removal from sale of numerous herbicide types, a reduction of doses, and a focus on optimising herbicide use (integrated weed control). However today, the very perception of the role of weeds is changing. They are becoming viewed as one of the bases of diversity in agro-ecosystems. Decreases in the richness of floras, due to the intensification of agriculture, is being viewed as one of the reasons for decreases in the presence of other biological components in cropped fields. In fact, the seeds of these weedy plants seem to constitute a fundamental trophic resource for a large number of insects, birds and small mammals, especially when these seeds are available during winter. Some botanical families (Cruciferacea, Asteraceae, Polygonaceae…), and some species (chickweed, fat-hen...) appear to play an important role in the over winter survival of birds such as the common quail or the little bustard. It would be possible to determine, for each crop, the weed species for which their presence in cropped fields would be of the most utility in maintaining high levels of biodiversity.

Managing weed species with the objective of maintaining biodiversity has today become a research subject, and is developing into a real agronomic objective. Organic agriculture, through the cessation of herbicide use, has allowed an increase (generally non-desired) in the density of such plants, but has not led to a satisfactory re-establishment of species richness: in fact, the restructuring of landscapes (hedgerows, field margins), a decrease in field size and also an acceptance of the presence of a certain type of flora due to reductions in the intensity of manual control appears to be necessary to increase species richness. Planting seeds of "good weeds" is certainly not yet envisaged, but some scientists have proposed the development of techniques of weed control that favour some "beneficial" and non-competitive species such as annual meadow grass, groundsel or chickweed, which are small sized species whose seeds are eaten by a variety of animals. The objective would remain however to maintain these species at densities acceptable to the farmer through some form of agronomic management (crop rotations, soil cultivation). However, only herbicide use allows for a selectivity of sufficiently fine scale to be able to filter differing species. Regardless of the type of agriculture, the need to use herbicides to favour biodiversity would be a technique difficult to accept.

Reduction of mineral and organic fertiliser use

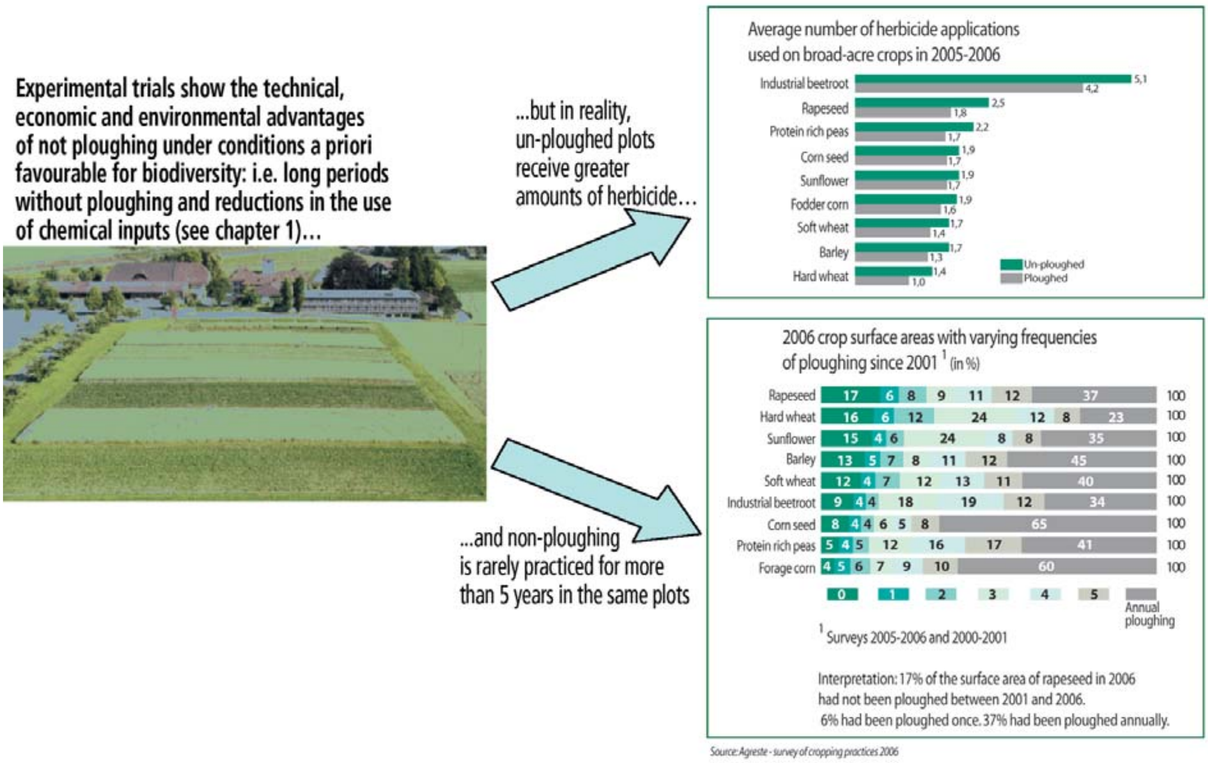
Reduction of either mineral or organic fertilisation generally results in a decrease in productivity and variable effects on crop quality. In the case of nitrogen, a decrease in wheat protein concentration is generally observed, as well as decreases in sugar concentrations in beetroot and oil in rapeseed, and also effects on the concentrations of secondary metabolites. Reducing applications of mineral or organic fertilisers, while minimising impacts on yields and product quality, could be achieved through genetic improvement of the efficiency of fertiliser use by plants. In the short or medium term, the option of reducing fertiliser use, whose effects on biodiversity are not major, does not appear to be a relevant option for broad acre cropping.

Abandonment of ploughing

"No-till" techniques cover a wide range of simplified cropping techniques (TCS). They have in common the fact that the soil is not turned over and that crop residues are not mixed into the soil, and can cover different practices that range from deep tillage to fragment the soil without turning it over to direct drilling. Since the beginning of the year 2000, no-till agriculture has developed rapidly, essentially for economic reasons, i.e. to reduce the costs of mechanisation, manpower and fuel. The proportion of crops established using no-till methods (a factor that is difficult to estimate due to the lack of appropriate statistical information) represented in 2004-2005 approximately 1/3 of the total cropped surface area in France. There exist however major regional differences.

The cessation of ploughing is favoured by the existence of erosion risk, rocky soils, and systems with a short inter-crop period. Constraints on the adoption of no-till methods are linked to the presence of spring crops requiring specific soil conditions for successful emergence and establishment that are more easily obtained after ploughing, and in systems in which weed control is difficult, in particular where herbicide resistant weed populations are present (such as the case of foxtail grass). This second point casts doubt on the positive impact of no-till practices on biodiversity, a subject still of lively debate.

Limiting soil cultivation can have a positive effect on biodiversity… if this is not accompanied by an increase in the pesticide use and if the practice is sufficiently long-term



Source: Agreste - survey of cropping practices 2006

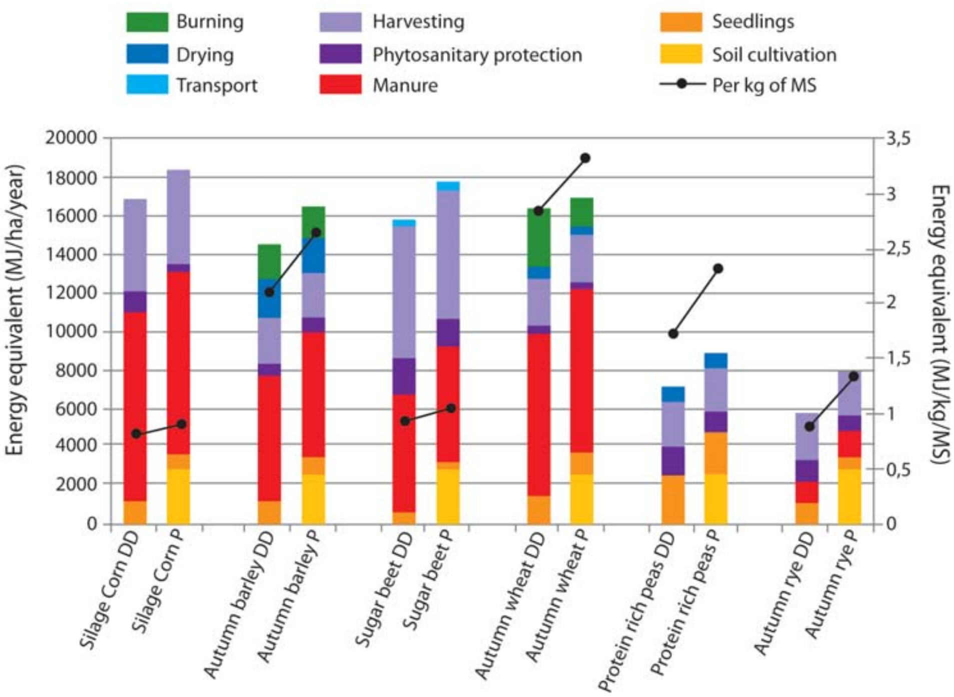
The literature shows that lower levels of soil cultivation over the long term (typically in the order of 10 years) can be favourable for biodiversity, notably for soil biodiversity (see chapter 1). However, while the technical and economic feasibility over the long term of lower levels of cultivation associated with lower input levels has been shown in the context of experimental trials, the adoption of no-till practices in France is often accompanied by a greater use of herbicides and is rarely used in the same field for more than four years at a time. These two factors are likely to strongly reduce the positive effects of the use of no-till methods on biodiversity.

However, even if the statistical data show an increased use of herbicides, numerous experiments have shown that this need not be inevitable. It is possible to implement other methods of control practices, and any increase in the number of applied treatments can be compensated for through reduced doses. Finally, the risks of impacts on biodiversity can be reduced by a better control of surface runoff in non-ploughed systems.

Regardless of the situation, the cessation of ploughing complicates the control of weeds and, in general, increases control costs. In some cases, increasing costs of weed control can cancel out the savings due to decreased mechanisation. However, the order in which crops are planted represents an interesting control option. Weed control is in general much less problematic in fields where autumn and spring crops are alternated. Spring sown crops also have the advantage of allowing a spreading out in time of the most important periods of work, which limits the risks of not being able to complete operations due to adverse climatic conditions.

Cessation of ploughing also allows for a reduction in equipment costs (number and required power of tractors on a farm), energy expenditure and in general the amount of workload per hectare. The net economic result is variable depending on the type of soil treatments applied (number of passages, purchase of appropriate machinery…). In general the productivity obtained is slightly reduced.

Crop management techniques based on methods of no-till agriculture can often reduce energy input requirements



Energy input requirements of crops planted between 1999 and 2005 using either direct drilling (DD) or ploughing (P) in long term experimental plots "Oberacker, Rütti-Zoll Ikofen" (Switzerland). After Schaller et al, 2007.

The cessation of ploughing is a change of cropping technique more or less risky depending on the environment (soil, climate) and requires the re-organisation of the totality of a cropping system. For example, not turning over the soil leads to the maintenance of a cover of plant residues (mulch) on the soil surface which has effects on evaporation, soil heating and water infiltration. Consequently the number of days available to accomplish some tasks and the conditions for crop germination and emergence are modified, which in turn requires a reconsideration of the dates and methods used for sowing, and perhaps even the varieties used. Similarly, the surface accumulation of poorly mobile minerals and organic matter in the soil as well as the impoverishment of deeper soil horizons change the conditions of soil mineral nutrition for crops and require changes to fertilisation strategies. For the farmer, the cessation of ploughing requires a complete change in his technical system, the success of which determines the long-term adoption of no-till techniques.

If the proportion of surface area cultivated using no-till methods is tending to increase, largely due to the economic context, the practice remains sporadic: most farmers have little hesitation in returning to ploughing to deal with technical difficulties, as the permanent adoption of no-till agriculture requires a profound change in the whole farm system. Consequently the impacts on biodiversity are considerably lower than is possible with an exclusively no-till system.

3.2.2. Spatial and temporal diversification

To increase the diversity of plant species in an agricultural region, it is necessary to develop diversification both over time (crop rotations, intermediate crops) and in space (companion cropping, combinations of crops and beneficial plants).

Diversifying rotations

Rotations are fundamental in the establishment of strategies of integrated pest management. Diverse rotations also have a favourable impact on the diversity of habitats and thus the diversity of resident fauna.

The effects of rotations are often highly variable and less pronounced, in general, than the effects of the use of fertilisers or pesticides. Even under highly intensive cropping systems, a monoculture is not always possible, with some crops (corn, winter wheat) being more adapted than others. Under conditions of conventional agriculture, there are a large number of situations where a rotational effect is attributable to the positive impact of the diversification of crops over time on the differing components of cultivated soils (amelioration of soil structure, increases in the reserves of mineral elements and in the efficiency of their use, better conservation and use of water resources) and on the control of pest species.

From the technical point of view, the degree of crop diversification on a farm is not only determined through adherence to agronomic best practice. It is the result of a compromise between the advantages and constraints offered by the physical and economic environment of a farm, the characteristics of the available farm equipment and manpower, economic opportunities and the attitude of the farmer towards taking risks. To induce changes in the decision making process determining the choice of and sequence of crops, with an aim of biodiversity preservation, it is necessary to induce a change in the objectives of the farmer (to encourage him to integrate this new objective), or to modify the economic conditions and incentives.

Financial aid distributed through the common agricultural policy can be decisive for the profitability of a crop, and as a consequence the surface area that the crop will occupy. For example, the virtual "monoculture" of hard wheat found in the Languedoc-Roussillon region is linked to European subsidies paid for this crop since 1992. A series of trials carried out in a network of on farm experimental fields showed that without subsidies profit margins for hard wheat monocultures are negative for two reasons: a higher expenditure on inputs and lower production (by 27% on average) Under the new common agricultural policy, including in particular subsidies for rotational agriculture, simulations based on these experimental results show that with a rotational system the situation returns to profitability.

Companion cropping

The use of companion cropping is particularly developed for the production of fodder, with mixtures of grasses and legumes. There is a double benefit: in terms of both the quality of fodder and also in the costs of production. The adoption of this approach is however constrained by the difficulty of maintaining an equilibrium over the long term between two species with different environmental requirements (in terms of water, light and temperature). Maintaining a sufficient proportion of legumes, the more delicate of the two species, often requires limiting the productivity of the grassland by reducing the level of nitrogen fertilisation and respecting the requirements of the legume. The adoption of such species associations can also be constrained by some animal-based requirements (digestibility of the produced fodder) and the fact that many legumes are highly sensitive to repeated defoliation or are poorly adapted to silage production. In contrast to many other European countries, France resisted for a long time the use of complex fodder mixtures. The sale of such seed mixes was not accepted until very recently, and then only as a result of a European Union directive. Understanding of the usefulness of such complex mixtures has not been widely available or disseminated (only a few dispersed trials using highly variable protocols), but some species associations present major advantages for fodder production. The advantages in terms of biodiversity concern mostly animal species (birds, insects, small mammals).

Crop associations have been mostly abandoned for broad acre agriculture, except for organic agriculture. For cereal production, there is however interest in associations of pea-wheat (whose advantages include the ability to easily separate the seeds of these species due to their very different sizes). Currently, there is not enough data to evaluate, on the basis of scientific studies, the constraints and advantages of the use of crop associations, for example in cereal cropping systems. The majority of currently published studies in this field also concern areas with a warm climate.

Establishment of intermediate plant covers and transition crops

The systematic establishment of intermediate crops between during the autumn and winter periods is an effective method to prevent erosion and the leaching of nitrates, factors which are positive for the protection of aquatic biodiversity. Additionally, vegetative cover in fields between crops also provides habitat for a wide range of fauna. Finally, the presence of vegetative cover aids in the control of weed species and thus can allow a decrease in the use of herbicides. Nevertheless, the adoption of such crops in broad acre agriculture can pose some difficulties: for the organisation of farm activities (competition with harvests and early emergence during September), for weed control (reduction of the period allowing the mechanical destruction of weeds) and that of certain plant pests, for the management of nitrogen levels for the following crop (effects due to the decomposition of the intermediate crops), for the management of soil moisture (decreases in soil water reserves).

Numerous elements support the development of intermediate and transition crops: benefits for soil fertility, production increases in some cases, agricultural subsidies. Currently such crops cover 550 000 ha, which represents only 4% of the total crop surface area, but 11% of that of spring sown crops. This second value can even reach 35% in some river catchments, when the practice attracts effective local aid (financial aid and technical advice).

These results show that the adoption of intermediate crops into current cropping systems does not pose insurmountable problems. Agronomic research is well developed to help farmers with this technique (the use of crop models to optimise the dates of sowing and harvesting, controlling the effects on the nitrogen cycle and water levels). In addition, many extension services have put in place numerous field trials. These trials allow the development of criteria to evaluate the effects of intermediate vegetation covers for on-farms situations and to develop appropriate management techniques. It remains, however, to further develop research concerning effects of intermediate crops on improving soil structure, controlling certain pest species (notably snails) and on biodiversity.

3.2.3. Conclusion: conditions for the evolution of agricultural practices in broad-acre crops

The appendix table to this chapter takes into account those actions, from the individual field up to the landscape, which contribute to better biodiversity management. In broad acre agriculture the principal objective to be attained is to increase the diversity of cultivated plants, to reduce the use of fertiliser and phytosanitary products and to reduce the amount of soil cultivation. This literature analysis of experimental results shows that it is technically possible to alter production methods in order to favour biodiversity, but generally with a cost such as yield reductions. This negative is however often compensated for by decreases in production costs.

Some technical changes with the objective of lessening the impacts of agriculture on biodiversity have already been adopted by a large number of farmers. This is the case for no-till agriculture (even if its effects on biodiversity can be highly variable). Other changes do not *a priori* present major problems as regards their greater adoption. Examples include: the systematic establishment of grassy margins for fields, or the systematic use of intermediate crops when the period between primary crops is long. Finally, more profound changes of cropping systems, such as the establishment of permanent cover crops, the simultaneous cropping of multiple species or the drastic reduction of pesticide use, pose a number of problems: in general there is an absence of technical understanding and a decrease in yields. It will be necessary to establish appropriate methods of financial compensation and in particular to increase the technical understanding of such methods through research before such approaches begin to be generally adopted. A number of the practices identified as being favourable for biodiversity can also have positive effects on other aspects of environmental protection: carbon storage, water resources protection, erosion prevention… However, some others can equally have negative effects such as the case of no-till agriculture, which often results in the increased use of herbicides and can induce higher emissions from the soil of N_2O (an important greenhouse gas).

In broad acre agricultural systems, landscape structure has been modified to conform to a logic entirely focused on efficient production: land consolidation, drainage and the removal of hedgerows have also been used to maximise the efficient use of agricultural machinery (size and shape of fields, locations of roads) and to optimise productivity (clustering of fields, minimisation of trajectory duration). The establishment of intermediate areas favourable for biodiversity consequently goes in the opposite direction to the current tendency whose current major expression is increases in the size of farms. The result of increasing non-productive elements would be a decrease in the useful agricultural surface (SAU) and also increases in the risks of the dispersal of weed seeds or of other agricultural pests. Hedgerows can also decrease the availability of resources (light, water...) in those parts of fields that they border. Finally, a decrease in field size would result in a decrease in the efficiency of farm activities.

However, the establishment of such areas in agricultural landscapes presents a number of advantages. For example, hedgerows can have positive effects by decreasing surface runoff and erosion, and they can also act as refuges for beneficial species (see chapter 2). A final aspect, rarely considered, concerns the possibilities of exploiting these "non productive" areas. Such exploitation could counterbalance the negative impacts of "classic" forms of production (see the appendix table for this chapter): in a hedgerow or forested area with a high level of biodiversity, it may be possible to exploit some species for wood or other commercial products.

3.3. Management practices for perennial crops: fruit and vine arboriculture

Decreases in pesticide use need to be coupled at the same time with the implementation of techniques of integrated pest management, and on the management of the whole orchard or vineyard through the establishment of grassy areas, and the management of orchard margins.

3.3.1. De-intensification and diversification

Reduction in pesticide use

For the farmer, reduction of pesticide use has a particular importance, due to the role of pollinators and the necessity of controlling parasites for the success of his production. The approaches to this problem are diverse, in particular in the context of integrated fruit production (PFI).
In orchards, a preventative strategy is through varietal choices and the use of multiple different varieties in the same orchard. However, varietal choice remains a limited control strategy, taking into account the life span of an orchard (rarely less than 10 years). Another possibility is the establishment of flowering grassy strips in-between the lines of trees. Increases in aphid predating fauna (lady beetles, cicadas, lacewings…) have been observed using this technique, and also a greater number of spiders which can capture aphids during their migration flights back to the apple trees. These grassy strips need to be mowed at the end of the season, which requires additional labour, and the degree of damage to fruit remains higher than that in an orchard treated with pesticides. The addition of grassy areas in orchards is nevertheless very practical taking into account its other advantages (see the below chapter on the "Diversification of plant species").

A difficulty in reducing pesticide use is linked to the multiplicity of targets, which require the farmer to perfect and apply a range of alternative treatment methods. During the 1980's, a reduction of more than 50% in the number of applied phytosanitary treatments was recorded. This reduction was due to a series of reasons: improvements in knowledge of the population biology of pest organisms; the use of economic thresholds for decisions on the application of controls against codling moth; and demonstrations of the efficiency of predators of pear psylla. The assessment of potential risks and the use of these methods require the farmer to observe and monitor the status of pests within his orchard.

The principles of integrated fruit production (PFI) were published by the international organisation of biological and integrated pest control (OILB) in 1992. This publication was followed by the first requests for the certification of integrated fruit production in France, followed by the first certification of product conformity in 1997, for use as an advertising argument in supermarkets. The term "integrated", initially poorly received by producers in France, has slowly replaced the notion of environmental fruit production (production "raisonnée" in French). The current PFI can be considered as an environmental approach to production. However the terminology is not only the result of a semantic change, but rather the sign of a deeper issue, linked to a divergence between farmers, whose objective is centred on the volume of production, and the wider market. This divergence leads to difficulties in drawing profits from technical innovations destined for the production of high quality fruit. The concept is also somewhat ambiguous to the end consumer of the fruit, who is often more sensitive to the external appearance of the fruit than to the absence of pesticide residues.

Diversification of plant species: integrating grassy areas into orchards and vineyards

It is in the domain of perennial crops that associations with beneficial service plants is the most understood and the most utilised. The establishment of grassy areas between the rows of perennial crops is becoming more and more common. It facilitates the movement of machinery while protecting soil structure, it maintains soil carbon levels and, especially in vineyards, it reduces the effects of water erosion.

Managed natural grass establishment (ENM) consists of leaving natural grassy vegetation present over winter. This is destroyed at the moment of bud emergence (usually through the use of glyphosate or mechanical destruction) to minimise competition with the trees. Permanent grass establishment consists of maintaining vegetation cover between the rows of trees or vines. This technique, which has a greater effect on beneficial fauna, is most often used in orchards and is an essential element of the requirements of integrated fruit production (PFI).

Grassy strips can however have a number of disadvantages, both in vineyards and orchards. It can favour the presence of some parasites (fungi in vineyards, insects in orchards), but these risks are manageable by using regular mowing of the sward. It does however increase pressure on water resources, which can be a factor when water availability is limited (orchards on dry soils with low water reserves, vineyards in Mediterranean regions).

3.3.2. Conditions for the evolution of agricultural practices

The conjunction between the energy crisis and current price decreases are an opportunity for a reconsideration of the composition and structure of vineyard landscapes, especially for establishing a situation hosting greater diversity. At the vineyard scale, organic production or integrated production can be developed reasonably rapidly, since changes to improve quality are more reconcilable with decreases in production than for many other types of agricultural production.

In addition, the establishment of grassy strips between rows concurrent with the reduction of herbicide doses has been widely investigated. For fruit production, where the role of pollinators, both natural and domesticated, is extremely important, research into methods of integrated fruit production have become a major priority for the profession.

3.4. Practices for the management of permanent grasslands

In permanent grasslands, the most important measures for the preservation or amelioration of biodiversity are the reduction of fertilisation and changes to management (decreasing stocking rates, delaying the date of initial harvest: see chapter 1). Due to the wide variety of intensification levels characterising these systems (much greater than for most other forms of plant production), permanent grasslands offer real opportunities for de-intensification.

3.4.1. De-intensification

"De-intensification", which has generally negative consequences for fodder production, can be beneficial for biodiversity, as long as it does not reach the stage of quasi-abandonment (see chapter 1) as is sometimes observed in mountain regions.

Reduction in mineral and organic fertilisers

Experimental studies concur on the conclusion that reductions in the fertilisation of permanent grasslands have generally negative effects on the quantity of fodder produced. These studies are consistent with older, and more numerous studies which show the positive effects of fertilisation on biomass production, both for nitrogen and also for other elements such as phosphorus and potassium. As for effects on fodder quality, these depend on the way in which fodder quality is characterised.

Despite these generalities, the consequences of a reduction in fodder productivity depend greatly on the particular situation:

- In production systems for which fodder production is not a limiting factor, or is mostly based on creating added value from grassy areas – either due to the presence of a low carrying capacity in comparison to the potential supplied by the grassland, or due to a feeding strategy largely based on other resources (maize, silage), the level of grassland intensification is moderate. Consequently possibilities exist for compromises between fodder production and biodiversity. In these cases there are some opportunities for de-intensification, by reducing the proportion of a farm used for fodder crops.

- In systems where fodder production is limiting, with limited security margins in the face of climatic variation, any loss of production will have major consequences. The possibility of acquiring additional fields or supplementary fodder resources constitutes an essential condition for any de-intensification of the grasslands. The additional costs of this would be a major constraint to the adoption of this strategy.

- When the main feed source of a herd is pasture, the effects of decreases in fertilisation are lower than in a system in which fodder is produced by mowing, given the effects of animal dejections on the pasture (80 to 90% of ingested minerals are returned to the soil).

In some situations of low production, such as in high altitude regions, the interest of fertilisation is unclear, as some experiments have shown minimal effects on production and soil fertility after the cessation of fertilisation.

Regarding the quality of fodder, the most common changes are an increase in species diversity, with a decrease in the contribution of grasses, and an increase in the proportion of legumes and other dicotyledonous species, fodder that is lower in concentrations of major elements, less digestible but richer in micro-elements and secondary metabolites. The low energy or protein density of fodder resulting from diverse grasslands is not compatible with feed for animals such as high production dairy cows. This observation remains, however, to be confirmed as some studies show that animal production can be maintained after reductions in nitrogen fertilisation. Nevertheless it is usually necessary to reduce the stocking rate, which does result in a decrease in milk production on a per hectare basis.

In contrast, a variety of food resources, including both diverse grassy and shrubby vegetation can be a favourable factor for sheep and goats. The higher content of secondary metabolites in fodder from extensive (lightly fertilised) grasslands modifies the quality of animal products (meat and milk), and this can be commercialised through controlled terms of origin (AOC, branding). Research however remains to be carried out to understand the effects of these secondary metabolites on animals (performance, health…) and on animal products. Such questions are not simple due to the wide range of such metabolites and the complex results of their transformations by harvesting (direct consumption by an animal, hay or silage), ingestion (including the effects of the microorganisms in the digestive system of ruminants) and by food processing technologies (milk, cheese, meat). Answers to these questions are central to the challenge of understanding the economic value of grassland biodiversity.

Decreasing grazing and / or mowing intensity

There are two ways to decrease the intensity of mowing: by decreasing the number of cuts and/or delaying the date of the first cut. For mowing, as for grazing, a decrease in intensity leads to a decrease in the amount of usable fodder: the rapid *turn-over* of the organs of grassland species (in particular grasses) means that in the absence of frequent harvesting, a part of the primary production begins to senesce and becomes integrated into the litter before being grazed or harvested.

In mountain areas, the maintenance of the productivity of a rangeland depends on an adequate balance between grazing pressure and productivity, with this relationship being modulated by fertilisation. Attempting to decrease the intensification of a grassland system can be very complex from the viewpoint of managing the timing of grazing: in many regions, problems with the ability of soil to sustain traffic (due to water logging etc.) represents a major problem in developing good pasture management. Fertile pastures risk being invaded by pre-forest species if grazing pressure is too low. Similarly as for decreases in fertilisation, decreases in the intensity of mowing have an impact on fodder quality, through decreasing the proportion of grasses and leading to fodder lower in energy and nitrogen, but richer in secondary metabolites.

Decreases in grazing pressure due to decreases in stocking rates lead to increased heterogeneity of grassland cover, as animals can become more selective, which leads to increasing areas of less-palatable species being refused. However, a carrying capacity close to the maximum potentially allowed by the soils and climate of a pasture is neither the optimal solution for all categories of animals. In fact, experiments investigating reductions in stocking rates have shown that in many cases there is very little difference in the performance of animals between differing levels of intensification in a range of grassland types.

Some possible options

A uniform decrease in the agricultural management intensity of grasslands is not necessarily optimal from the production point of view, or that of biodiversity. It is possible to consider solutions which combine intensive management of one part of the farm's fodder production surface area (grasslands or fodder crops) to allow, both economically and technically, the management of the rest of the farm's grasslands in a more extensive manner.

In general, decreases in a farm management intensity result in a modification of the structure of the vegetation: the plant species present are the same but the proportions of their total biomass changes, plant heights are greater and more heterogeneous, and some plants are able to flower. These changes can be rapidly favourable to animal species (nesting birds, insect pollinators…) and can result in major changes to fodder production (quantity and quality of fodder produced, grazing animal performance). It is in general after a number of years (sometimes more than 10 years) that new plant species begin to establish leading to significant increases in biodiversity. There is therefore a major gap between effects on fodder value and those on grassland biodiversity.

It should be noted that factory farming (pigs, poultry) or the feedlot feeding of cattle are rarely based on local plant production (although some systems are adopting this approach). Their impact on biodiversity stems from the production of effluents, which contribute to soil and water eutrophication, as well as at the level of those countries exporting soya, corn, *etc.* In many of these countries these crops are grown in a very intensive manner using genetically modified varieties and strong doses of herbicides (glyphosate) in very simplified landscapes. Such indirect effects are not taken into account in government policies.

3.4.2. Conclusion: conditions for the evolution of agricultural practices

In some geo-climatic conditions (high altitude regions, very humid or dry areas), only low levels of agricultural intensification are possible due to the environmental limits imposed on fodder production. Irrigation (rare due to difficulties with repaying the costs of equipment) and drainage (mostly carried out during the 1970-1980's) no longer pose a major threat to permanent grassland biodiversity. The major threats are linked to:
- increasing intensification of grasslands and fodder production systems in areas where this is possible (valley plains, foothills, areas with an oceanic climate);
- the expansion of fodder crops (corn and silage notably) and other types of cropping at the expense of areas of permanent grassland.

As regards this second aspect, agri-environmental policies and the profitability of cropping play a key role, but the desire of farmers to innovate and change their activities is also essential. Some examples show that it is possible to consider less intensive systems (in terms of inputs) that have the same economic viability (see below). The limits of the agri-environmental herbage payments (PHAE) are currently being reached, as the value of payments for grasslands is not competitive with cropping (especially with the current prices for cereals). In addition PHAE does not differentiate between grasslands on the basis of their biodiversity value. Under the same category of permanent grassland older than 6 years, it is possible to find both grassland dominated by ryegrass and composed of only 15 species, and a meadow containing more than 80 species. Regional agri-environmental measures have been, mostly for budgetary reasons, concentrated in Natura 2000 areas, which has strongly limited the possibilities of using permanent grasslands for restoring biodiversity at the national level.

Depending on whether we are considering mountain grasslands, within in more or less densely forested areas (Alps, Vosges, Massif Central, Jura…), grasslands in humid, flood prone areas dependant on water control measures (Wetlands of the Atlantic coast, Saone Valley, Camargue), or grasslands in plains and bocages, associated in one way or another with trees (either in hedgerows of within field), the approaches to managing for biodiversity are not all the same.

Mountain farms

Mountain agriculture guarantees maintenance of biodiversity and a high quality cheese production.

In mountains, grazing systems are particularly sensitive to management (stocking rates and grazing practices) and their abandonment results in the beginning of a process of encroachment by woody species. The continuation of grazing activity is an important condition for the preservation of biodiversity. In the context of the depopulation of small mountain settlements, and the consequent increases in woody species encroachment into mountain grasslands, numerous control programmes for these woody species have been investigated. Farmers have benefited from these programmes, whose ecological and landscape effectiveness requires continuous and selective control measures. Obstacles to the local implementation of such actions stem largely from issues of local politics, in particular between farmers and hunters.

An acknowledgement of the role of biodiversity exists for the production of some cheeses. Farms in remote and marginal areas have, in general, greater costs of production than their counterparts in more favoured areas due to, for example, greater costs for the collection of milk, which leads to limitations in production. Some way of favourably differentiating their products from others is thus essential for their profitability, and such differentiation is an important factor for the sustainable development of these regions.

The Comté cheese is a good example. The production area delimited by the controlled term of origin Comté is subject to a cold and humid climate. Grasslands and alpine summer ranges are the only possible areas for agriculture. Due to the production of Comté, this massif has avoided depopulation and the loss of grasslands to forest. In 2003, 5000 farming families, 182 small cheese production plants and 20 processing plants for cheese ripening were involved in the production of Comté. This production is important for local employment, regional development and environmental protection, and is based on a strict list of product standards, forbidding any form of intensification or industrialisation of the product. The product has entered a virtuous circle: the consumer can appreciate an authentic cheese made in a traditional manner, consequently cheese sales increase and ultimately prices can become higher. The producers and cheese makers thus accept to adhere to ever higher production standards, based on traditional production techniques. Milk producing farms can be much smaller in this region, young farmers are more likely to set up farms in the region and the cheese factories making Comté create more employment than non-controlled term of origin factories in the same region.

Lowland farms

The challenges are focused around the role of grasslands in fodder systems and the diversity of management methods for grasslands.

Cattle farms in plains areas, notably dairy production farms, have evolved over the last few decades, with increases in the amounts of grassland areas converted to grain crops and corn destined for silage. This trend is linked to the amounts of common agricultural policy payments for cereal cultures and oil producing crops as compared to those for grasslands, as well as to the promotion of systems of winter feeding of dairy cows with maize and protein complementation (soya oil cakes). These systems are today faced with price increases for animal feeds, and in regions in which feedlot and factory farming are highly developed, problems of water pollution and the resulting necessity of surfaces where animal wastes can be spread. These changes have led to some farmers considering a return to fodder systems based more on the use of grasslands. In other cases, an even greater intensification of animal production is considered as a solution (increases in herd sizes, milking machines…).

The majority of examples of extensification show that the viability of such systems can be achieved through increases in the productive surface area in order to compensate for revenue losses per hectare. Individual animal performance is in general little affected by practices favourable for biodiversity. Adopting extensive agricultural systems leads to adopting a logic of decreasing inputs (fertilisation, animal feed) to ensure the systems sustainability.

In dairy systems, an experimental de-intensification conducted in Western France (Network of Cattle Farmers for Tomorrow) resulted in a wide variety of implementations of various technical systems. For the 12 farms involved in the network, the primary system retained was an increase in the duration of grazing in order to produce the milk quota using the lowest possible feed cost. The farm rotation needed to be modified, with increases of 20 acres of perennial grasslands (legume-grass associations) per unit of cattle (UGB) per year. In parallel, the useful agricultural surface was increased by 20%. During the course of these changes, the management of the grassland and of feeding needed to be continually adjusted. The practices used on each of the farms were very diverse, but a central theme was the simplification of tasks and the favouring of greater autonomy and increases in revenue. While total farm income slightly decreased, the actual profit margins of the various farms slightly increased over a period of five years due to major reductions in overall costs.

For meat producing cattle, to encourage a reduction in beef production, two types of extensification contracts were proposed in France from 1990 to 1992: firstly a quantitative extensification contract, involving a reduction in herd size of at least 20%, and secondly a contract involving extensification coupled with increases in the surface area grazed applicable only in marginal areas. In the case of a permanent size increase, a reduction of 20% in stocking rates was required. In the Creuse and Allier regions, changes on 7 farms managed under these contracts were compared to those on 28 "control" farms from the same region. The technical and economic results observed at the end of two years showed that the generally more "low-cost" management practices of the extensive farmers did not compromise either animal performance or the economic results (the profit per cow was even 8% greater for farms under the extensification – size increase as compared to "controls"). This type of measure has been shown to be effective in reducing meat production on farms and for achieving regional development goals, while limiting the risks of farm abandonment.

In beef production systems using the Belgian Blue race, possibilities for increasing the system's profitability through extensification have been demonstrated. The conclusions of these experiments are difficult to generalise, but it was observed that grazing systems based on a system of extensive grassland management allowed the maintenance, and even improvement, of economic performance, even without the commercialisation of the product under special systems of labelling.

The technical and economic feasibility of such changes have been tested by various cattle farmer networks. The results show that it is possible to sustainably manage a farm through increasing the proportion of grazed grasslands and pastures, and reducing the production of corn, the use of nitrogen fertilisation and complementary feeding. The management trajectories leading to this result are quite variable, both regarding the proportion of grasslands on the farm (from 45 to 60%) as well as the degree of reliance on purchased complementary feed (concentrates): from 58 to 80%. However, these changes lead to viable farming systems. The changes were also often accompanied by other changes in regional improvements reducing the risks of soil erosion and rehabilitating bocage landscapes.

Over the next few years, French milk producers will be confronted with a double challenge: the reform of the common agricultural policy and new constraints and conditions for the single payment scheme (DPU) based on environmental practices. It will be necessary to also anticipate a continuation of the phenomena of restructuring which will exacerbate the gaps between regions developing their milk production and those that have already largely reorganised their systems of production and collection, upon which transfers of quotas are likely to be imposed. Finally, finding strategies to improve the quality of life for milk producers is unanimously considered as a determining factor for any future changes. This aim is likely to be compromised by the capacities of farms to finance any improvements in the face of other investment priorities resulting from the imperative to increase farm sizes and/or production capacities.

This context has stimulated interest in research into less costly production methods, based on a return to systems based on grazed grasslands. The new conditions established by the reform of the common agricultural policy have made such approaches more attractive. This will also provide an opportunity to reassess the place of strategies which have up until now resulted in the encouragement of more intensive, labour demanding, but not highly profitable production systems (cropping, non-prime young cattle).

Farms in wetland areas

During the 1970's, even though a majority of farmers identified marsh and wetland areas as grazing and grass production areas, the technique of marsh draining became widespread along the Atlantic coast. This allowed the development of cereal cropping (essentially corn) in these humid areas, beginning in coastal areas where the soils are richer in nutrients and had not been modified by salt production. Since the middle of the 1990's, this intensive cereal production model in these wetlands has been strongly criticised by a range of stakeholders (environmentalists, hunters, fish farmers…). A proposed solution is based on the maintenance and re-introduction of animal grazing in the marshes, but this activity is not longer economically viable without government intervention.

Government institutions have already taken numerous measures and established regulations aimed at protecting these marsh areas from intensive agricultural development as well as from agricultural abandonment: creating areas of special interest for the conservation of wild birds (ZICO – European Birds Directive of 1979), the implementation of a "marginal area" (in the context of Objective 5b) allowing access to structural development funds from the European Union, and the creation of special protection areas (ZPS). The coastal conservancy has also acquired land for protection in these areas. Finally, since 1992, a number of wetland areas have been subject to a procedure of communal environmental land tenure reform (OGAF-Environment) applying common agricultural policy agri-environmental measures. This has taken the form of a five-year contract during which a farmer agrees to respect a set of standards and regulations aimed at improving environmental protection in exchange for a per hectare payment.

The beginnings of a system of remuneration for the biological and landscape value of these wetlands paid for by taxpayers are already visible. The major problem of these OGAF systems is that they are focussed purely on environmental protection and not on agricultural systems in their entirety, systems which firstly need to confront their viability before they can continue to exploit the wetlands. The systems of cereal production close to the wetlands are also threatened: for example, cereal production in the Charentes region cannot compete equally with the capacity of that in the Parisian basin. This shows that it is necessary to not only focus on the protection of fragile or sensitive areas, but also on other areas which are integral to the functioning of farms and which they cannot do without to continue their activity.

These changes are difficult to accept for many farmers who perceive these phenomena as external pressures and as criticisms of the fundamentals of their activity (free enterprise, private property, a model based on production…). The involvement of a range of new bodies in the management of the marshes, which previously was in the hands of the farmers themselves, such as environmental groups, hunters, the coastal conservancy and other various government administrations (Regional departments of agriculture and forestry, Regional departments of environment, *etc.*), is sometimes difficult to accept.

As de-intensified systems have been shown to be viable, additional efforts in terms of training and the dissemination of information are necessary to encourage more farmers to adopt the use of permanent grasslands and to apply within these practices favourable for biodiversity. The very low number of agricultural schools in France offering training in the management of permanent grasslands shows that unfortunately there remains a long way to go before this strategy becomes generalised.

3.5. Management of non-productive elements: hedgerows and field margins

Non-productive landscape elements contribute to the biodiversity of agricultural landscapes in two ways: they provide habitat for numerous species (perennial plants, insects with low mobility) and networks of such elements can favour the movement of many species. Hedgerows also modify the microclimate of fields and exert an influence on the distribution of numerous species within the field. Considered for a long time by ecologists as system separate from the adjacent fields, hedgerows and field margins have long been interesting to agronomists due to their possible effects on production (microclimate, disease sources…).

Scientific journals have published very little concerning opportunities for the possible extension of non-productive elements in agricultural areas and how to manage them so as to favour biodiversity. However, surveys of hedgerow management do exist, in particular for farms in Brittany. These surveys support the hypothesis that hedgerows are more advantageous (or less an inconvenient) for animal husbandry than for cropping, hedgerows being found in higher densities in animal based farms and around grazed fields.

In terms of management, studies show the existence of a wide variety of practices, and thus states of hedgerows and field margins, which may explain the diversity of the flora and fauna. Depending on the techniques used and the periods that they are applied, the effects on the life cycles of the species living in hedgerows and margins are different: for example chemical vegetation clearance has different effects depending on whether plants are in flower or have already produced seeds (seed production and food resources for nectar feeding insects). Finally, there appears to be considerable inter-annual variability in the practices used to manage hedgerows.

The factors influencing this diversity of management practices are linked to the type of field margin (type of vegetation, accessibility…), the adjoining field (type of crop rotation) and the type of farm (type of production, manpower available). This last parameter is important: on some farms with a large amount of hedgerows, the sum total of maintenance operations can represent a non-negligible amount of labour (up to one month for pruning, for example).

While the concept of retaining hedgerows is becoming more and more accepted, taking into account biodiversity in their management is not always as well understood, with excessive herbicide and shrub killer use being common. Poor management of hedgerows can not only greatly reduce the health status of the hedgerow, but decrease their economic benefits (wind-break, provision of wood, habitat for game animals…). The explosion in the number of wood heaters has generated questions regarding the management of hedgerows in Brittany: newly planted hedgerows have in general been neither established nor managed for wood production and wood harvesting from an ancient, already greatly reduced and fragile, bocage system, easily risks becoming excessive.

Grassy strips, a measure established under the common agricultural policy, are obligatory on farms receiving aid under the single payments scheme. This is an example of an environmental measure that is (almost) generalised. Its adoption was accomplished without major problems, even though the establishment and management of these areas may raise some issues: technical constraints due to the presence of two separate uses in what is effectively one field, the width of the strips being fixed without reference to the agricultural machinery available to sow and manage them, authorised cover species not always being agronomically well adapted. A similar situation exists for fallows (non-cultivated) which have been put into place by farmers without posing major agronomic or organisational problems.

Other examples are also presented in the appendix table for this chapter: grassy margins, wild animal fallows…

3.6. Spatial organisation of land uses

The development of practices in favour of biodiversity has, in itself, consequences for landscape structure due to the diversification of crops. The location of crops and the different uses of grasslands follow rules which at larger scales determine the organisation and diversity of landscapes, and thus of biodiversity. Such rules are determined on the one hand by the characteristics of the physical environment (soil type, slope, microclimate), and on the other hand by the spatial characteristics of fields (size, shape) and farm territories (distance of fields from farmstead, other fields, accessibility).

In general, fields with land uses requiring many movements are located close to major farm infrastructure (dairy cows in pasture). Fields that are less favourable due to their physical and spatial characteristics are reserved for secondary uses (long duration fallows). The increasing size of dairy farms makes it impossible for grazing cows to be moved around all of the fields on a farm. Often there is consequently a specialisation of uses amongst fields within the same farm, with cropping areas often in the most remote fields.

Land consolidation has always had the objective of reducing spatial constraints through increasing the size of fields and by re-grouping them. For a long time such consolidation was done without taking into account the environment, and in particular semi-natural elements. Few analyses exist relative to the consequences of this for the operation of farms, and increases in farming opportunities, including for those for better environmental management, and in particular that of biodiversity. Re-grouping fields can facilitate the spreading of animal effluents over larger areas: as this operation requires transport of the effluent and farmers generally limit the distances over which this is done. The situation where a field has at least two parallel boundaries allows the even spraying of pesticides without double doses, which is not possible in irregularly shaped fields.

The consolidation of fields thus remains an important tool of public policies with potentially major impacts on the management of biodiversity, with the possibility of collective actions for the establishment of semi natural elements, and also as it can lead to changes in agricultural practices. More widely, it can be a focus for establishing collective dynamics, not only amongst farmers, but also amongst all of the stakeholders in a given region. Such dynamics are important in, for example, reconciling plans for urbanisation with those for the protection of agricultural lands.

Cooperatives for the use of agricultural equipment (CUMA) are an example of another form of dynamic collective offering opportunities for efficiency to farmers. Other than just the sharing of equipment, they often induce a form of work organisation that provides farmers with a large number of tractors and trained operators, which can reduce the constraints of long distance movements.

3.7. Organic agriculture

Conversion to organic agriculture of agricultural production systems

Currently, France is one of the European countries in which the proportion of the useful agricultural surface dedicated to organic agriculture (OA) is the lowest (2% versus the European average of 4%). However, pushed by strong increases in demand, and increasing interest from supermarkets, BA is experiencing significant development. This is also a result of a series of policy measures: the multi-year plan for the development of organic agriculture, begun in 1997, together with the establishment of the regional farm contracts in 1999, have led to almost a doubling of financial aid for conversion to BA. Nevertheless, these promising developments have somewhat stagnated since 2003. The number of farms using BA increased by 12.3% between 2001 and 2006, with an increase in surface area of 32%, or 76% for certified areas. In contrast, the surface areas being converted to BA have decreased since 2001 (by 62% according to Agreste), which illustrates the decreasing enthusiasm, especially since 2004.

In 2005, BA in France was far from attaining the objectives that were proposed at the end of the 1990's. BA is highly demanding in terms of its technical aspects and the few statistics that are available show a large *turnover* in farms using BA in some countries (from 6 to 15% between 2005 and 2007 according to Eurostat, no data is available for France). It is estimated that in France, about half of departures are due to a cessation of activity. If BA seems at first to have a good future in Europe (increasing consumer demand, extra payments based on high biological quality that can compensate for otherwise low agricultural prices, a good image in the media and with consumers), the real opportunities are perhaps more limited. In fact, while markets should continue to progress for a number of years, and the opportunities to bypass traditional types of commercialisation develop, it is concerning that the absence of favourable policy measures constrains the development of BA.

Economic constraints

The expansion of the market for organic products is at risk of remaining limited in the medium term due to issues of consumers purchasing power and/or decisions made by consumers in favour of either other types of expenditure (communication and leisure products, travel, housing), or food products that are easy and rapid to prepare. If organic agriculture products are sold at an increased price due to their quality in order to compensate farmers for their lower production, the actual price is in fact quite variable and can be seriously reduced when produce becomes abundant or in some distribution circuits. Finally, the disparity in such higher prices between different countries negates free market competition, even within Europe. Other factors likely to enter into consideration over the longer term include: competition with land required for non-food production (biofuels…), the greater workload necessary, the delocalisation of a proportion of production to countries with lower labour costs, divergences in different schools of thought within organic agriculture, investments by supermarkets into organic agriculture which could, for reasons of public image, be counter productive.

Technical constraints

Organic agriculture requires considerable technical expertise, often more so than conventional agriculture.

For example, for fertilisation, it is based in theory on a system of polyculture – animal husbandry. However, 60% of BA farms do not have any animals. The integration of legumes into cropping rotations becomes essential, but the technical expertise is often lacking. One of the most important questions is, of course, the establishment of reliable methods for the control of pest species. In BA, this management is based on a global approach using a range of environmentally friendly techniques. The demand from producers for rapidly implementable and effective protection solutions can lead to researchers favouring phytosanitary products approved for BA.

After considerable research and development there exist reliable control methods available to farmers (the use of nets to limit attacks on apples from codling moth, new alternative products such as pyrethrum against the leafhopper involved in grapevine yellows…), but numerous pathogens which cannot be controlled through the simple application of a product remain. For example, almost thirty substances have been tested against lettuce downy mildew without any of them offering any real protection.

Research concerning the development of indirect protection methods has made significant progress. For example, the control of microclimatic conditions through the correct use of tunnels greatly reduces attacks by spider mites (Tetranychidae), and the burial of leaves of trees suffering apple scab leads to decreases of up to 80% in the presence of ascospores. Similarly, initial results on the role of functional diversity show considerable promise in improving the control of codling moth and pests of tomatoes.

Research addressing global approaches to cropping systems has allowed progress in the development of integrated methods of management. This work has refocused attention on some agronomic approaches that have fallen somewhat into disuse. For example, the importance of rotations in managing attacks of the nematode *Meloidogyne*, or the relationships between nitrogen fertilisation and attacks of aphids on apple trees have been rediscovered. Research on the effects of managing the areas around field is also relevant here (see the appendix table for this chapter). Some interesting examples are found in countries where organic agriculture is more developed than in France: for example, in Switzerland, where 2% of vineyards are using organic agriculture (and 98% use integrated management, based on the directives of the OILB), the majority of vines have intervening rows sown with multi-species mixes (containing flowering plants) adapted to limit competition for water. Farmers receive payments when this sowing is carried out in concordance with a set of standards. Similarly for fruit production (3,5% using BA, the remainder using integrated management), almost all orchards are managed using strips sown with flowering plants, not in the rows between trees (due to effects of voles), but around field margins. In vineyards, as for orchards, it has been shown and it is recognised by farmers that such sown strips act to reduce pressure from pest species and thus the number of necessary chemical treatments (synthetic in integrated management, organic for organic agriculture, for example rotenone), but the effectiveness of this is not complete.

The lack of plant varieties specifically selected for use in the context of organic agriculture is a major problem. Disease resistance and the efficient use of nutrients are the key points that are less important in selection for conventional agricultural species than for BA, even though changes are now occurring. For arboriculture, the varieties of fruit trees available today are in general poorly adapted to low levels of agricultural inputs or to the conditions of organic agriculture. To rectify this situation and to better exploit existing species, a network of semi-extensive orchards was formed in 2001 to evaluate the characteristics of old apple and pear varieties and to study their responses to new methods of agricultural management such as BA or the use of low inputs. The relevance of such a "professional" network with the aim of assessing varietal characteristics has been acknowledged and should develop further in the future, through links with official organisations such as INRA or the permanent technical committee for selection (CTPS).

Beyond the lack of technical expertise and of adapted varieties, one of the main reasons for the slow development of BA is the aversion of farmers to risk. In organic agriculture, the fluctuations in production from year to year are greater than in conventional agriculture. Finally, some standards are difficult to adhere to due to farm activity planning constraints: the control of weeds without herbicides demands an important investment in time for the monitoring of fields, and also for the control itself, often based on mechanical removal. In conventional agriculture, this occurs in particular during autumn (harvests), during spring (sowing, treatment applications) and at the beginning of summer (grain harvest) when workload is highest. For organic agriculture, workload remains high throughout the summer. These results can be a constraint if a farmer wishes to develop a secondary activity / occupation either on or off the farm. Other studies have shown the increase of workload in organic agriculture, with a wide range of variability, from 7 to 75%.

Economic performance

A large amount of research has been assessing the economic performance of cropping systems using organic agriculture compared to conventional systems, but it is very difficult to synthesise these results. In reality, farmers experience and knowledge is greater for conventional production systems that for innovative cropping systems.

Any comparisons between systems are thus likely to be influenced by the lower technical capabilities of farmers using innovative systems. Conversely, innovative systems are usually adopted by a category of farmers who are curious about new cropping practices and who often wish to show the superiority of the new system. Such farmers are often very technically competent, which again poses problems of the validity of comparisons with routine systems. Additionally, the level of economic performance also strongly depends on the soil and climatic conditions under which the comparison is carried out. Another important element to be taken into account is aversion to risk. Numerous studies only compare the results of different modes of production over a short period. However, farmers are generally interested in the reliability of results over the medium and long-term. This aspect should be taken into account in any comparisons of performance, and also to explain the high rates of return of farmers to conventional agriculture. Finally, extra costs due to the requirement for greater manpower are rarely taken into account in these studies.

The viability of BA farms has also been the subject of a large number of studies. The results have been extremely variable: considerably higher profitability of BA farms when savings due to reduced inputs are coupled with higher prices (dairy farms in Quebec); lower revenue, despite a greater profitability per cow, due to the smaller size of farms (milk production in New England); comparable revenue, even though producers using BA have greater technical performance (lowland areas in the Netherlands); comparable revenue but a greater dependence on agricultural aid (sheep farms in the Massif central)… Farms using organic agriculture can also have overall higher profitability than conventional or integrated systems, while also having higher performance on the quasi totality of indicators of environmental impact, including impacts on biodiversity (farms in Tuscany).

The adoption of organic agriculture is often linked to the dynamics of farmer groups. Government policies could assist such changes, with particular understanding and flexibility during the establishment stage, which varies greatly between farms. This stage requires a farmer not only to understand and implement new techniques, but also to develop new commercial and professional networks which result in their personal evolution. Finally, the diversity of types of organic agriculture should be recognised, beyond the dichotomy of organic agriculture through the substitution of inputs (an exchange of synthesised products for "natural" ones) and organic agriculture through the reconstruction of a new production system with changes to farm infrastructure. In fact there exist a whole range of practices and innovations that should be recognised, valued and used.

3.8. Associating technical changes and social dynamics

The integration of biodiversity into agriculture cannot simply be considered as a change of practices: for any integration to be sustainable, considerable research has shown the importance of the integration of biodiversity into the professional ethics of farmers.

In general, for questions concerning biodiversity as for environmental questions in general, institutions request farmers to change their practices through the proposition of implementable technical solutions or a list of standards and requirements carrying financial compensations. The changes are conceived and are assessed essentially as a modification of agricultural practices. Such a conception of the integration of practices favourable for biodiversity can be considered as belonging to a linear model of innovation. In this model of the diffusion of techniques, the techniques are produced by research, they are prescribed by institutions concerned with agricultural development and today by environmental protection, and are then adopted, with more or less delay, by farmers. This model of change is somewhat restrictive and only partially reflects the diversity of ways in which change occurs.

Making reference to management models, another representation of changes in relationships between biodiversity and agriculture is proposed (see figure). Regardless of the type of farmer or farm, of the type of project or management focussing on biodiversity, it appears that those projects that have succeeded both from the environmental and agricultural points of view have involved multiple types of change:

- Changes in farmers' understanding in the areas of species ecology and natural sciences, or improved knowledge by environmental managers in the areas of how farms function and of agricultural activity in general. Not only do the different stakeholders involved in a project learn from each other, but together they produce new knowledge;

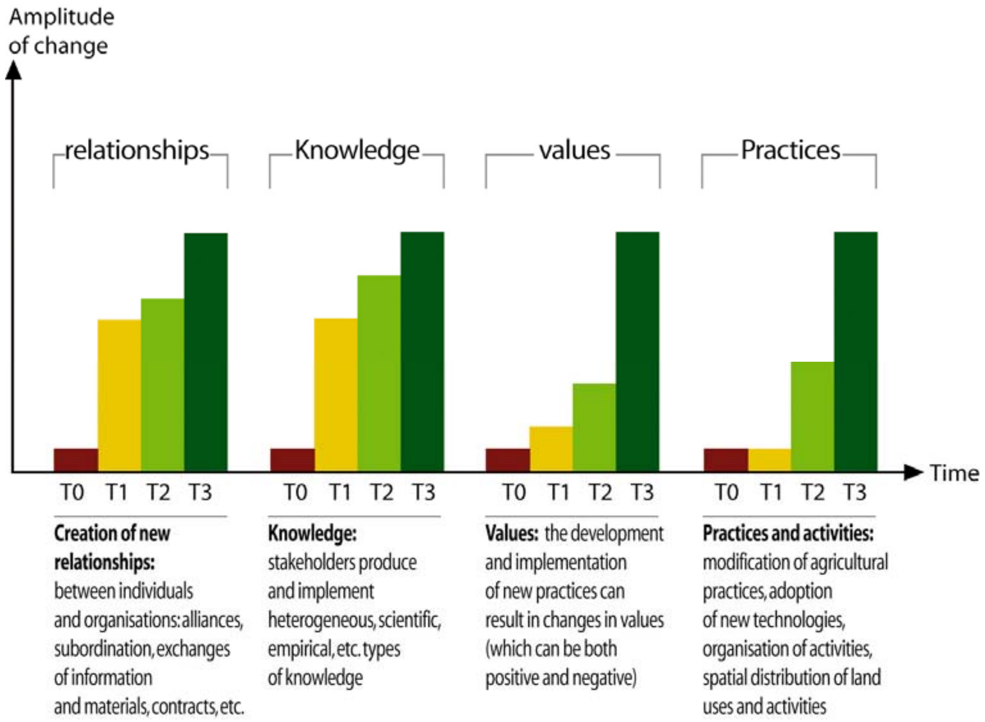
- Changes in values. The development and implementation of new practices and activities can result in changes in values (judgement references). Having contact with environmental activists and professionals can change farmers' understanding of their profession, and conversely environmental stakeholders can question and integrate into their values new dimensions linked to development;

- Changes in relationships. Nothing can progress without the establishment and especially the maintenance over the lifetime of a project, of new relationships between stakeholders who have previously had little opportunity to work together. While working together to develop a technical solution to an environmental problem, the types of understanding implemented and developed differs between stakeholders (farmers, politicians, environmentalists, scientists from different domains) and with the types of relationships that are formed (subordination and hierarchy, partnership, alliance, conflict, *etc.*).

- Changes in agricultural practices (of course!) and their organisation and integration into farming systems.

The integration of biodiversity into agricultural development is thus a situation of change that has many different facets. It is a communal and progressive project, where it is important to not only focus on the conditions required for the participation of farmers and for the adaptation of agricultural practices, but also on the overall organisation of changes.

Biodiversity and agriculture: the different dimensions of technical changes



This figure represents a trajectory that is the most frequently encountered one in successful projects from both environmental and agricultural points of view: relationships and understanding begin to change before values, with practices being modified afterwards. There exist however a diversity of possible trajectories: in particular, in some cases practices begin to change earlier, but such changes are often not sustained. The time scales required can be very variable, with some projects resulting in major changes in practices within a year, while others can take three to four years to reach the same stage (after Fleury et al., 2006).

3.9. Summary and conclusions

Possibilities for biodiversity restoration exist in numerous agricultural areas (see chapter 1), depending on the adoption of appropriate practices and types of management. It is entirely possible to use the beneficial effects of biodiversity in the context of agricultural production (see chapter 2). In this *a priori* favourable framework, four points need to be highlighted:

- To ensure that this integration of biodiversity is sustainable, three types of factors that determine the behaviour of farmers need to be taken into account: the psychological or social constraints, too often neglected, the level of technical knowledge required and the aversion to risk, and economic factors (markets, upstream and downstream supply chain pressures, profitability of the "clean" solutions proposed, impacts on the organisation of farm activities).

- Public policies have an important role to play to promote such changes, both in terms of financial aid to help overcome various constraints and in defining biodiversity objectives. Communal actions play an important role. They should be encouraged as firstly, they can make the adoption of new practices easier, and secondly, only such actions can ultimately result in significant impacts at the landscape scale. The process of "land reallotment" (aménagement foncier) is an example of a collective process conducted in tandem with public policies for the restructuring of landscapes.

- The implementation of these new methods of production requires the acquisition of new techniques and knowledge that often entails further innovation and development. For example, in the case of integrated protection, a number of technical solutions exist, but the information necessary for their adoption in a large range of climatic, soil type and productivity contexts is lacking.

- For organic agriculture, the effects on biodiversity are only likely to be significantly positive in the case of a complete restructuring of the production system. This should include improvements and management methods that explicitly take into account biodiversity both for the ecosystem services that it provides and for species conservation. Organic agriculture is often promoted, and justly so, for its ecological benefits, but as we have described in chapter 1, there are limits to this approach for biodiversity preservation (limits that depend strongly on the regional and landscape contexts). In addition, amongst the current standards and regulations for organic agriculture, measures that explicitly address biodiversity are almost inexistent. Consequently, conversion from conventional to organic agriculture is unlikely to result in major biodiversity benefits if it remains simply at the stage of the substitution of synthetic inputs for natural ones.

Conversion to organic agriculture is a difficult process which requires considerable and sustained technical and financial inputs, for which subsidies and assistance are not always available (or of limited duration), which can be an important constraint on its adoption. Other constraints on the conversion to organic agriculture include market uncertainties and uncertainties in information transfer from experimental trials to real farm situations. Regulations concerning the development and sale of seeds may also be a barrier to the selection of varieties useable in organic agriculture. It is also necessary to carry out global assessments of organic agriculture not only in terms of direct revenue, but also taking into account environmental effects, including effects on soil fertility, on health, etc. In this context the role of local collective dynamics is essential, and this should be supported at all scales (local, national…) by government policies.

Transformations of production methods will most likely require arbitration, with some possible tensions being generated including:

- Tensions between economic and environmental requirements: the high current prices for a whole range of agricultural products is pushing farmers to target high yields, which is in conflict with aims such as reductions in the use of pesticides;

- Tensions between the aims of individual farms and those of the wider region: for example, the specialisation in some regions of the majority of farms in a limited number of crops (or in the most profitable varieties) creates regions in which the development of high populations of pests which attack these crops or varieties is favoured;

- Tensions between different production methods in the same region, linked to difficulties stemming from the co-existence in the same area of varieties, species and cropping systems with different requirements / objectives (typically: genetically modified and non-genetically modified production).

At the local scale, the integration of biodiversity into agriculture cannot be considered simply in terms of changes in agricultural practices: for such an integration to be sustained over the long-term, biodiversity must have a meaning for farmers and must become part of their professional ethics. Such deeper changes must be developed through communal and progressive projects, where the focus must be broader than simply the conditions required for the participation of farmers and the technical aspects of required adaptations in agricultural practices.

At the national scale, the implementation of new production systems favouring biodiversity will not develop in a significant manner without the concerted involvement of farmers, upstream and downstream businesses, research and development, government organisations and consumers. Agricultural education must integrate into its basic programs the concepts of integrated production and studies of the environmental impacts of agricultural practices. Cooperatives and also agricultural development agents who sell seeds and phytosanitary products need to also participate in reductions in pesticide use through the establishment of less intensive, but still profitable, production methods. These stakeholders have an important role to play in the promotion of resistant varieties, of diverse mixes of species and varieties, and to encourage farmers to place integrated production methods at the centre of their production strategies. Biodiversity in countries exporting animal feed also needs to be taken into account. The risk that national or European policies lead to practices or products that have negative consequences for biodiversity being exported to countries with less stringent environmental regulations needs to be avoided.

Research perspectives

The farmer on his farm and the farmers in a region are important foci where public policies, advanced techniques, the economic context and the taking into account of effects on biodiversity all meet.

Observations and modelling

It is necessary to develop research investigating the diversity of responses of farmers to environmental and biodiversity policies, not only in terms of adoption but also in terms of modifications of practices. In particular it will be necessary to assure the coupling of economic, agronomic and ecological observations. This implies an understanding of how the different forms of biodiversity are produced and change under different systems of production (including systems of organic agriculture), by studying drivers of these changes such as agricultural practices and the management of semi-natural elements. Consequently there is a need to model, from observations, the ways in which these practices act on biodiversity, and also the reasons for the adoption (or rejection) of these practices, as well as the decision systems in which they are placed. It is from such information that the levers of action, at different scales and from technical, economic and social fields will emerge[1].

It is necessary to carry out this research over large enough regions in order to take into account the landscape dimension. This research also requires research teams that have the capability to carry out long-term observations and experiments to assess the spatial and temporal scales of response to changes in practices. The observational systems put in place (Zones ateliers, environment research observatories) should be developed and reinforced with these objectives in mind.

Experiments

The adoption of innovation by farmers requires, as we have stated, the acquisition of new references and new knowledge. Consequently research and development faces major challenges. The development of solutions useable in the real world sometimes requires a long time (for example the use of wasps of the genus *Trichogramma* for biological control). It is also necessary to offer a range of varieties adapted to low input cropping systems. Finally, issues of farmer education are crucial.

One of the major problems posed by changes in practices is also taking into account the transition phases between different production methods. This point is essential: it explains, for example, the numerous cases of re-conversion from organic to conventional agriculture. Finally, questions of work organisation and of labour availability are very important. In general, agricultural systems that are more environmentally sensitive and favourable for biodiversity require greater time investment, an aspect that is only very rarely taken into account in most research.

Coupling experimental and observational approaches allows feedbacks between the integration of new knowledge and new challenges as a function of changing political objectives.

[1] This is convergent with the report by INRA's commission on innovative agricultural systems (SAI): "*the internalisation of environmental, sanitary and ethical dimensions in agricultural systems*" is of course already in progress, but, by increasing, could lead to reconsideration of basic principles of current agriculture (using pesticides and veterinary products, autonomy for decisions of farmers within a given region, specialisation of farms and region, abandonment of least productive land...). This internalisation can take a diversity of forms: revisiting intensive systems; low input systems, zero-pesticide systems; systems aiming primarily to produce environmental goods; organisation of land tenure and landscaping of interstitial areas (hedgerows, grassy strips, 'refuge' areas…); reconstruction of social, ecological and economic links between cropped areas, grasslands, rangelands and forest… This construction needs to be supported by a substantial work on redefining criteria for performance assessment, as well as on a tight linkage between research on innovating systems and research on public policies that are to favour them. This will entail tight coordination between actions at the scales of the plot, of the herd, of the farm and of the territory. A delicate question will be to make these evolutions compatible with the control of production costs and the securing of farmers' income, in the context of climate change. To reach these objectives, work in progress on the conception of farming systems will need to be strongly linked with work in ecology, environmental sciences, epidemiology and public economics.

Appendix: Examples of agricultural techniques or developments of agricultural areas favourable for biodiversity for which the acceptability to farmers has been studied (sometimes only marginally). The list is therefore not an exhaustive list of possible practices or developments.

Choice of techniques, developments or systems	**Desired objectives** (for biodiversity / environment and agronomy)	**Reported successes**	**Major constraints identified**	**Relevant approaches for adoption** (techniques to be encouraged, policy measures, initiatives and support...)
Modifications of the local landscape context of fields				
Establishment of grassy strips along the margins of wheat fields (Belgium)	Maintenance of aphid populations at levels where their incidence in economic terms is acceptable through the promotion of their natural enemies	Resolves the spring asynchrony between parasitoids and aphids (through the early development of alternative non-damaging aphid hosts); a simple technique to establish. Also favourable for numerous other beneficial species and as a refuge for game	The maintenance of the grassy strips + a loss of revenue from the non cultivated field area + concerns as regards the possibility of the strips being a reservoir for weed species	Payments to farmers if they establish grassy strips within their crops to compensate for losses due to the lack of production from the grassy areas Using the grassy strips for biological control gives them an economic value and could deprive farmers of their payments: → change the current legislation to allow a more effective generalisation of their use
The establishment of a bocage landscape in Brittany at the regional scale of a community of communes	Primary objective = protection of water quality + habitat for flora and fauna (increasing the continuity of a network of hedgerows)		Choice of species made primarily on the basis of water quality maintenance, but also wood production and biodiversity (exotic tree species are also used)	Measure proposed by the region and managed by the community of communes; a participative initiative, with the incentive being payment for the plants and technical support for their establishment
Establishment of multi-species hedgerows along the margins of orchards (south-eastern France, mostly by farmers using organic agriculture)	A physical role as a wind-break and in limiting the unwanted dispersal of phytosanitary products + favouring populations of natural enemies of pest species that can be tolerated in relatively high abundances (for example pear psylla), with the aim of reducing the number of treatments Refuge value for game and a variety of other groups (rare plants, birds, small mammals…)	Few studies of the benefits in terms of protection, except for lower populations of psylla in environments with a diversity of trees (benefits include 0-1 treatments leading to successful pest control instead of normally 2 to 3 not always efficient treatments); delays over the long-term in the appearance of resistance to the few molecules effective for the treatment of this pest In Finland: more rapid repopulation by predatory spiders after perturbations (treatment applications) when tree and shrub species rich in beneficial spider faunas border the orchard	Benefits limited by intensive methods of protection used in the orchard (e.g. against codling moth) Reductions in the numbers of applied treatments not always verified as thresholds for intervention are often very low (zero risk taking) and / or controls necessary to estimate the degree of infestation Depending on the planted species, risks of negative effects (various pest species or quarantined organisms favoured) Costs of establishment of the hedgerows	Limited knowledge of the community of species to establish / impact of hedgerows on the productive area: however a more favourable situation in the south-east where wind makes hedgerows desirable Little precise knowledge as to the best network of hedgerows / the connectivity between them and other natural elements of the landscape for the most effective connectivity Some financial aid (for example in the Drome region) covering establishment costs Possible supplementary production (wooden posts, fruit…) although often anecdotal
Promotion of heterogeneity at the scale of agricultural landscapes				
Establishment of fallows favourable for wild animals	Promote the abundance of game and biodiversity in general		Populations of butterflies significantly inferior to those in long-term fallows or permanent grasslands	Contracts proposed by hunters federations with financial payments
Establishment of multiple flowering fallows on farms (Switzerland)	Increase the diversity of vegetation cover on farms, to favour the diversity of flora and fauna.	Contributes to the preservation of the flora, however mostly a major increase in fauna richness (arthropods, in particular	Only partial success if the fallows border busy roads (high animal mortality); soils that are too rich, wet, compacted or peaty	A tool at the scale of the farm / landscape Have available sufficient capacity to establish and maintain some 30-50 hectares / year

	The fallow must remain in place for 4-6 years; with establishment offset in time so as to result in fallows of varying ages being present on the farm.	butterflies and beetles) Correlations with the abundance of some bird species characteristic of open agricultural landscapes	Risks of re-sprouting of unwanted plants in the following crop; better to sow a cereal crop instead	Provision of seed mixes (20-40 indigenous annual and bi-annual species + buckwheat which serves as ground cover, via the research station Agroscope) Information can be obtained from local agricultural advisory bodies
Management of a proportion of the surface area of a farm under a contract of ecological compensation (SCE) (Switzerland)	Maintain and develop biodiversity by using at least 3.5% of specially adapted crops or cover at least 7% of the area of the farm with ecological compensation surfaces (SCE = extensive permanent grasslands, grassy strips, hedgerows, fallows…)	In plains: a promotion of general biodiversity (higher numbers of plant and arthropod species) + contribution to the stabilisation of populations of species dependant on extensively managed agricultural areas In mountains: contribution to the maintenance of traditional agricultural activities and areas / landscapes still rich in biodiversity	Ecological constraints (in intensively managed regions few plant and animal species can benefit from the ecological compensation areas) Sociological constraints (considerable effort must be expended on educating farmers and convincing them of the utility of the measures); also a question of time required for a change of attitudes	Freedom of choice amongst 16 different types of SCE; 8 of these types attract additional financial compensation Integrate into the eco-conditionality a base of available surfaces for biodiversity. Using this base, supplementary programs of the type of regional MAE could increase the effectiveness of the SCE
Promotion of diverse rotations on farms (Switzerland)	Prevention of pests and diseases + soil protection Requires at least 4 different crops per year (with each occupying at least 10% of the area under rotation)	The measurements have not yet been assessed for biodiversity; but show a strong correlation between floristic and faunal diversity in the crops	Primarily short-term economic constraints	Include eco-conditionality as a basic constraint
Increasing the surface area of grasslands managed in a non-intensive manner				
Reductions in the use of mineral or organic fertilisers in grasslands	Restoration of floristic richness, especially that of oligotrophic species (species of high conservation value); flow on effects for the preservation of animal species (birds, insects) and on soil microflora	Good success in terms of biodiversity in situations where the initial soil fertility is low or decreases quickly after the cessation of fertilisation (which does not correspond to the majority of observed cases)	↘ in the quantity of fodder produced; ↘ in the quality of fodder for animals of high productive potential (dairy cattle): this effect varies depending on the manner in which quality is characterised; many grassland soils are fairly rich (particularly in P), and the slow ↘ in mineral concentrations can greatly slow biodiversity restoration	Compensatory payments for the decreases in fodder quantity (and in quality for high production dairy cows); Agro-environmental measures (MAE) have an obligation of positive effects on biodiversity, but with the expectation that this will not be rapid (minimum 5 to 10 years); A total cessation of fertilisation is preferable to low amounts (e.g. 30U) (often of the same order of magnitude than atmospheric fertilisation or organic fertilisation, often not taken into account) It is better to have a part of the farm completely unfertilised than to have lower rates of fertilisation over the whole farm, which also simplifies the workload for the farmer
Reduction in grassland stocking rates	Restoration of floristic and faunal richness (in particular of insects) through the creation of a more heterogeneous vegetation cover	A maintenance of the performance of individual animals is generally observed, but there is also a decrease in the number of animals able to be supported per hectare	↘ in the quantity of fodder used (increases in refusal); ↘ in fodder quality for animals of high production potential (e.g. dairy cows) An overly great reduction in stocking rates can result in a situation close to that of abandonment, unfavourable for biodiversity	Importance of the presentation and dissemination of the results of the trials proving that it is possible to graze differently than only using intensive systems
Adoption of a late first mowing in grasslands	Restoration of sexually reproducing plant species; restoration of habitat for animal species associated with such		↘ of the quantity if fodder produced; ↘ in the quality of fodder for animals of high production potential	Compensatory payments for the decreases in fodder quantity (and of quality in systems of dairy cattle of high production potential); Agri-environmental measures have the obligation of a result in terms of biodiversity; delays in the date of first mowing generally

	plant species (e.g.: insect pollinators) or such a vegetation structure (e.g.: nesting birds)			also result in a reduction in fertilisation, cumulating the beneficial effects on biodiversity
Increasing within field plant diversity				
Modern agroforestry	Increase the total productivity of a field (biomass) by combining trees and crops while creating benefits for the environment and biodiversity	Traditional agroforestry systems (dehesas, traditional orchards…) known for their landscape and biodiversity value; but modern agro-forestry is at the experimental stage (innovative farmers): environmental effects well established – reductions in nitrates, less erosion, less research for biodiversity	Regulations and agricultural payments poorly adapted to such systems; long-term investment required from farmers; many management methods still poorly developed	Promotion is necessary for these systems and to pressure for change in financial aid regulations (such that agro-forestry is not penalised in comparison to conventional monoculture agriculture), research
Establishment of flowering strips in the inter-rows of orchards (Switzerland)	Increase aphid predating faunal assemblages	↑ aphid predating faunal assemblages (Beetles, Heteroptera, Chrysoperla), ↑ abundance of spiders whose webs trap many aphids (migration flights) Can be equally effective against psylla and lepidopterans	Management of vegetation cover (establishment, mowing), choice of useable species (local adaptations, perenniality of the mixture…); while a positive effect on pest control is observed, lower productivity or other negative effects are also encountered The same experiment conducted in Germany gave contradictory results (hypothesis: flowering too late due to the northerly location)	The farmer should be able to obtain compensation for potential losses in the form of an increased price at harvest In Switzerland, this technique is commonly used against the rosy apple aphid Ecological compensatory surfaces with flowering fallows need to ≥3.5% of the farm surface area to achieve certification
Use of seed mixes of flowering herbs and grasses in orchards and limited application of specific insecticides	Maintenance of spider populations	Increases in spider abundance and species richness South-eastern France: benefits from the soil covered with vegetation as compared to bare soil for the control of pear psylla	Use of specific insecticides which do not always succeed in dealing with all of the problems	Inter-row plant establishment commonly used in the Czech Republic
Use of particular varieties				
Use of cereal varieties resistant to aphids (USA)	Control of aphid populations without insecticide	Significant decrease in the growth of aphid populations	Differences in wheat quality	A program of varietal selection needs of be established
Use of corn varieties resistant to aphids (Belgium)	Limit the use of pesticides and energy inputs in cropping	Significant decrease in aphid populations in the field and presence of numerous beneficial species	Effects on the third trophic level, less aphid predators on the most resistant plants	Introduce the use of resistant plants into a larger program of integrated control Organisation of a warning system for corn crops in Belgium
Use of ancient wheat varieties for use in low input production systems (France)	An integrated strategy targeting lower productivity than in conventional strategies and limiting agricultural inputs (lower sowing densities, no nitrogen addition at tillering, no growth regulators and a reduced number of fungicide treatments)	A network of trials in highly varied geographic and agronomic contexts showed that this strategy can be profitable. The integrated strategy is viable in 70 to 85% of cases	The profits obtained are highly variable depending on the year	The economic result is highly sensitive to the price of wheat (analysis carried out for a wheat price of 100 €/t)

Biological control through innondative releases				
Releases of Trichogramma over more than 80.000 ha of corn in France (20% of the area of this crop in France)	Control of the European corn borer in France	Satisfactory control of the corn borer, rate of parasitism greater than 70%	The techniques required many years of research before arriving at the stage of technical feasibility	Requires that farmers provide technical information regarding results; greater success is possible through the constant amelioration of the technique and adaptation to farmers needs (e.g. simplified application in the field through reductions in the number of release points and release periods)
Releases of aphid parasitoids in cereals (Belgium)	The control of aphids by parasitoids	Technical feasibility demonstrated	The study is currently at the trial stage Limiting factor = costs of production of the parasitoids	Challenge = the industrial production of the parasitoids at a price acceptable to farmers Combining techniques of habitat management + releases and the use of resistant plants would allow reductions in costs, but would further increase the technical requirements
Limitation of pesticide use in the context of integrated fruit production (PFI)				
Control of codling moth in apples using mating disruption (France)	Reduction in the number of applied chemical treatments, management of insecticide resistance	Significant results in fields infested with low densities of codling moth coupled with good monitoring	Insufficient effectiveness of the dispersers if the pest pressure is too high and / or if immigration of fecund females requires complementary treatments	Technical assistance is necessary. It is possible to combine this type of treatment with an application of granulosis virus (microbiological control) for example, 6 or 7 applications at the rate of one every 10 days
Use of thresholds of intervention in the context of integrated fruit production (PFI) (France)	Reductions in pesticide residues in fruit after harvesting, consideration of both the quality of the product and environmental protection	Pear psylla: reduction by 50% of phytosanitary treatments through the application of an economic threshold taking into account the effectiveness of natural predators of psylla (*Anthocoris*)	Consumers have ambiguous concepts of quality (desire for both visual unmarked fruits + an absence of residues) For French orchardists: constraints = economic handicap = technical constraints of required standards Duration of control in the orchard Useful for pests that can be tolerated at high population densities (e.g. pear psylla, mites in apples)	Link together the quality of the product and that of the environment, pay the farmers for their role in environmental and biodiversity protection Development of integrated fruit production at the European level and the development of quality labelling; however, difficulties in moving to more ecological production methods for orchardists (objectives centred on the volume of production and on markets). Facilitate the adoption of technical innovations in fruit production

4. Biodiversity of agricultural areas and government policy

The preceding chapters have shown that biodiversity can provide services to agriculture, notably in the agronomic context, and have described the opportunities for adaptation to better reconcile the objectives of agricultural production and biodiversity preservation. Potential modifications of agricultural practices used on the farm and for the management of semi-natural elements present in a region have been presented. The analysis has also shown that constraints to the adoption of such options result from the additional costs imposed and potential profitability losses at the farm level.

In this context, this chapter presents the main public policies and laws used in the European Union (EU) and more specifically in France, for biodiversity protection; the advantages and problems associated with these measures are described, and on this basis suggestions for improvements in policies are made. This exercise is particularly difficult as it is not possible to easily attach monetary values to biodiversity, and then to quantify the costs associated with its destruction and/or the benefits associated with its preservation. This issue also results in difficulties in taking biodiversity into account in the legal context.

4.1. The legal and economic "status" of biodiversity

4.1.1. Biodiversity and the law

Developing legislation for the protection of biological diversity is confronted by two major difficulties, and one specific to agriculture

A multidimensional concept

Numerous legal cases have highlighted that biological diversity is a concept whose protection is difficult to implement due to the fact that it requires a systems approach to the environment including policies for the protection of specific natural areas and species, but also policies for the prevention of negative impacts on biodiversity overall. Biodiversity protection implies actions at a wide range of scales from the local to the global, a long-term perspective (at the scale of multiple generations) and the integration of the variability of ecosystems over time. With all of these complications, the authors have concluded that the protection of ecosystems is a "challenge" for the law, and that biodiversity is most realistically considered through its constitutive elements (environments, species).

Specific laws – Environmental law

A large number of legal cases have emphasised that the effectiveness of biodiversity protection depends on the legal status afforded to biodiversity, and its place in the hierarchy of values and interests protected by the law. In general, the lack of recognition of a specific legal status for natural resources leads to the consideration of the elements of the environment, and more specifically elements of biodiversity, as "objects" in the legal sense, and thus subject to laws of ownership. This absence of a specific status has the consequence that while the environment is subject to a series of specific laws (environmental law), it does not have sufficiently adequate status to be fully considered in the traditional legal context, whether this be international, European or national. Consequently, conflict between environmental law and other bodies of law are inevitable. Sometimes such conflicts are accommodated for under law. This is the case for example, in situations where environmental damage is considered legitimate under various measures for the protection of the environment. For example, the destruction of species or habitats in a Natura 2000 site is only authorised for reasons of overwhelming public interest. However, most often, regulations for the resolution of any conflicts between environmental protection and other interests either do not exist, or do not have mechanisms in place to allow their application. This conclusion is applicable, to a large extent, to the protection of biodiversity at the three scales of international, European or French law. Under French law, numerous lawyers have concluded that under the present system, audits of costs versus benefits preceding an activity or project are rarely favourable to environmental protection.

A late application to agriculture

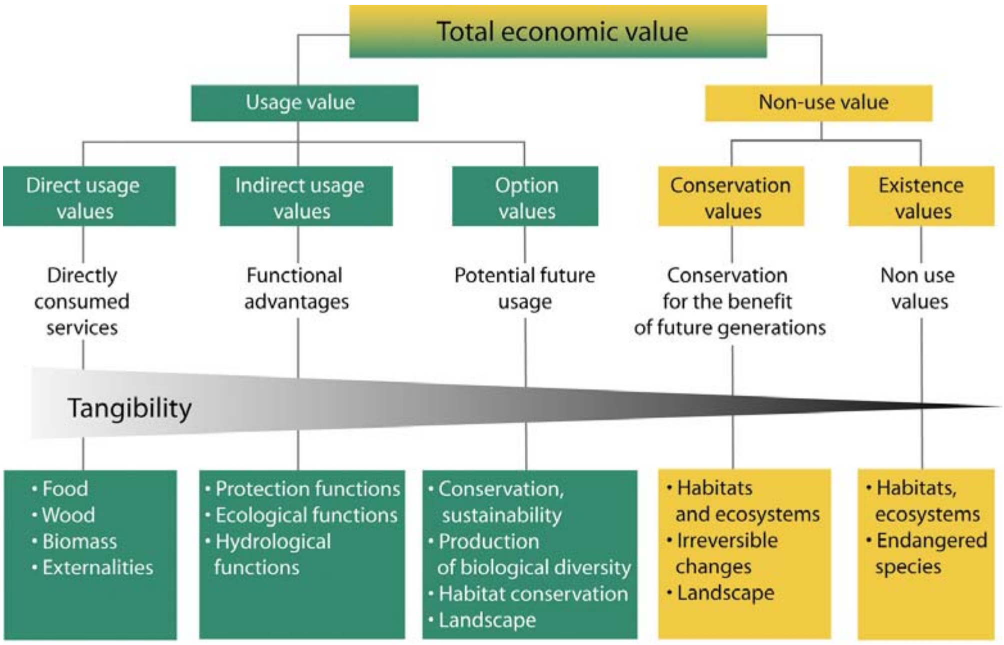
The conclusion regarding the limited effectiveness of environmental law also applies, in general, in the case of agriculture. In addition to the explanations presented above, this is largely due to the delayed recognition of environmental damage due to agriculture as compared to that of industry, mostly due to the more diffuse nature of pollutants deriving from agricultural activities and the fact that it is more difficult to determine the precise source of any emissions and to identify the contributions of individual farms. In addition, the application of European and national agricultural policies, which for a long time have targeted primarily production objectives, has led to the development of a body of agricultural law which largely ignores environmental concerns. Finally, the application of environmental law to agriculture has often taken the form of incentive programs rather than regulation, in contrast to general legal principles often applied in environmental law (in particular, the principle of prevention and the principle of polluter pays).

4.1.2. Biodiversity and economics

The value of biodiversity

To a large extent, the problems surrounding the integration of biodiversity into the legal structure result from the difficulties in associating a value with biodiversity. Biodiversity encompasses the variety of living organisms and their interactions at three levels; genetic diversity, species diversity and the diversity of ecosystems. Biodiversity is the result of dynamic interactions between ecosystems, which are themselves the result of more local interactions between humans, animals, plants and microorganisms. The factors motivating a private decision, or a political decision, at a local scale are not the same as those which would motivate a collective decision adopted, or which should be adopted, at the scale of the planet. This divergence in the factors explicitly taken into account poses a major problem as it is usually through the management of biodiversity components at the local scale that the future of planetary biodiversity is decided.

The figure presented below illustrates the difficulty in measuring the total economic value (TEV) of biodiversity. This TEV is classically divided into two categories, the usage value (left part of the figure) and the non-use value (right part of the figure). Usage value consists of direct usage values (agricultural production, tourism attractions…), indirect usage values (ecosystem function, pollination…) and option values (price ascribed to biodiversity and its preservation in the context of a potential future use). As for non-use values, this regroups conservation values (conservation of biodiversity for the benefit of future generations) and existence values (value ascribed to biodiversity for the reason that it exists); non-use values are tightly linked with considerations of justice, morals and equity and to concepts such as "the rights of nature" or the "rights of future generations", etc. Even though economists have developed methods to quantify at least some aspects of the TEV of biodiversity, this huge range of possible values illustrates that the task is not easy. The difficulties in this type of evaluation of the value of biodiversity and of its various components have been encountered in, for example, in the preparation of the *Millennium Ecosystem Assessment* (MEA).



Source : Centre for strategic analysis, February 2008

Economic justifications for biodiversity protection policies

It is not because it is difficult, or even impossible, to measure the TEV of biodiversity that biodiversity does not have a value. And it is because biodiversity has a value, but that this is not reflected in a market price, that the theory of public sector economics justifies and legitimises interventions by the state, through public sector policies for the preservation of biodiversity. The reasoning behind this can be presented as follows. Biodiversity is a public resource in the sense that all economic agents can benefit from it without the possibility, in most cases, of one agent appropriating it to the exclusion of others. However, as a market does not exist, and therefore neither does a price for biodiversity, biodiversity is not taken into account, or only partially, in the economic calculations of private agents such as, for example, farmers. In the absence of a price, biodiversity is consequently available for use at a higher level than desirable. There is consequently justification and legitimacy for the intervention through public policy regulation in order to, in a sense, restore an appropriate level of use for biodiversity. This simple form of reasoning does not, of course, determine the acceptable level of use of biodiversity, which supposes that it is possible to attribute a value to biodiversity. Neither does it provide a mechanism for determining the optimal type of intervention. In practice, a range of different measures can be used to obtain the same result in terms of the preservation of biodiversity: regulation, increased taxes for practices unfavourable for biodiversity and/or payments for favourable practices, etc. The choice between these different possible measures is based on criteria such as the simplicity of implementation, administrative costs, respect of principles such as the user - pays and its corollary, supplier - beneficiary, etc.

4.2. The context of public policy actions for the protection of biodiversity

The Convention of Biological Diversity (CBD) of June 1992 is the first international text devoted to the principle of biodiversity preservation (this text has the status of a treaty for those countries having ratified it). Its first article fixes its objectives, these being "the conservation of genetic diversity, the sustainable use of its elements and the just and fair division of the benefits stemming from the exploitation of genetic resources, notably through satisfactory access to genetic resources and an appropriate transfer of relevant techniques, taking into account all of the patents on these resources and techniques, through adequate financing". Every two years, and most recently in May 2008 in Bonn (Germany), the countries that have ratified the convention meet at a conference called the conference of parties, to assess the measures undertaken in the context of the CBD, and if necessary, adopt new measures.

At the level of the European Union, the community strategy in favour of biological diversity, established in 1998, defines the framework within which the policies and the community level measures designed to satisfy its obligations under the CBD (COM(1998) 42 final) are developed. This strategy is articulated around four main themes: the conservation and sustainable use of biological diversity; the division of benefits resulting from the exploitation of genetic resources; research, identification and surveillance of the exchange of information; and education, training and public education. This framework defines the areas of intervention for each area and its objectives: for agriculture these being the reinforcement of the conservation of genetic resources having a value for food production; the promotion of good agricultural practices allowing the preservation of genetic diversity and pollution reduction, notably by linking agricultural financial aid to the respect of ecological criteria; the reinforcement of agri-environmental measures; the promotion of commercial policies favourable for biological diversity; etc.

For each domain there is an associated action plan; for agriculture, the action plan in favour of biological diversity in agriculture of the 27 March 2001 (COM(2001) 162 final) defines the priorities and identifies the community level measures, in particular those of the common agricultural policy (CAP), that contribute to this aim. In general, several recent changes to the CAP, for example the cross-compliance (conditionality) of direct payments (referred to as the first pillar of the CAP) on the respect of certain criteria, in particular environmental, or the reinforcement of agri-environmental measures and policies of rural development (the second pillar of the CAP) are steered in this direction. The action plan relative to agriculture is complemented by specific texts concerned with, in particular, phytosanitary products[1], organic agriculture[2] and genetic resources in agriculture[3].

Finally, on the 22 May 2006, the European Commission presented a document entitled "Halting biodiversity losses by 2010 and beyond – preserving ecosystem services for human wellbeing" (COM(2006) 216 final). This publication "analyses the adequacy of the response of the European Union to date" in terms of biodiversity preservation. While important progress has been made and the rates of biodiversity loss have shown the first signs of slowing down, the Commission concluded that the pace and scale of implementation of the European Union strategy in favour of biological diversity and its associated action plans has been insufficient. The commission re-affirmed that the objectives defined in 2001 to "halt biodiversity losses [within the European Union] by 2010" (European Council, Goteborg, 15 and 16 June 2001) and to "restore the state of habitats and ecosystems" (COM(2001) 264 final) are still reachable, but with the condition that member states of the Union reinforce their policies focused on these objectives.

1. "Towards a thematic strategy towards sustainable pesticide use" (COM(2002 349 final) and "thematic strategy towards sustainable pesticide use" (COM(2006) 372 final), communications of the European Commission which led to a proposed Directive , on 12 July 2006, establishing a Community action framework to achieve sustainable pesticide use.
2. "European action plan in the area of organic food and agriculture" (COM(2004) 415 final).
3. Regulation (EC) 1590/2004 of the Council establishing a Community programme regarding the conservation, the description, the collection and use of genetic resources in agriculture.

In conjunction with activities at the European scale, the majority of member states have elaborated, or are elaborating national strategies and/or action plans. This is the case in France which defined, in 2004, a national strategy for biodiversity that also sets a goal of halting biodiversity losses by 2010 (in compliance with the commitment agreed to at the Goteborg European Council of 2001) as well as engaging all involved stakeholders; recognising the value of the living world; improving the integration and protection of biodiversity in public policy; and increasing scientific and observational knowledge. As at the community level, the French strategy for the preservation of biodiversity is based around action plans, including an "agriculture" action plan. This is based around five major policies aimed at increasing the integration of biodiversity into French agricultural policies and on-ground practices, these being "promoting the integration of biodiversity by farmers and their partners into regional planning; promoting the generalisation of agricultural practices favourable for biodiversity and ameliorating the negative impacts of other agricultural practices; protecting and reinforcing the diversity of genetic resources available for food and agriculture; carrying out surveys so as to follow changes in biodiversity in rural areas in response to changes in agricultural practices; and reinforcing the awareness and skills of those directly involved in agriculture, agricultural educators, researchers and technical advisors to improve the interrelations between agriculture and biodiversity". In this same context, but also in the context of the national health-environment plan of 2004 and the inter-ministerial plan 2006-2009 for the reduction of pesticide risks, an additional target for pesticides is for "a reduction by 50% of sales of the most dangerous active substances" via actions structured around five axes: "act on the products themselves through improving the conditions of their sale; act on agricultural practices so as to minimise the need for pesticide applications; develop education opportunities for professionals and reinforce the skills and protection of users; improve knowledge and transparency in the area of the health and environmental impacts of pesticides; and evaluate the progress achieved".

4.3. European Community and French actions for the preservation of biodiversity in agriculture

The concrete measures adopted for biodiversity preservation are based on a number of policies. Naturally these include policies for the protection of the environment (water, air, natural areas and protected species, pollution prevention, risk prevention, etc.), but also policies for various sectors such as, for example, agricultural policies. Measures for the protection of biodiversity are thus scattered across a wide and diverse range of bodies of law. In this assessment, we have made the choice of presenting only the main measures for the protection of biodiversity in agriculture, these being agri-environmental measures (today called agri-environmental payments) of the "rural development" section of the CAP, the Natura 2000 directive, the cross-compliance (conditionality) of direct revenue and market assistance, and finally methods of certification. This choice should not obscure the fact that the preservation of biodiversity is addressed in parallel by other measures, notably those which relate to financial law, rural law, laws relating to water and to phytosanitary products.

4.3.1. Agri-environmental measures (MAE)

Agri-environmental measures in the European Union

The integration of environmental objectives and concerns into the common agricultural policy has been increasing gradually. It was a facultative option in 1985 (article 19 of the regulation EEC 797/85); before becoming a specific obligatory regulation in 1992 (Regulation EEC 2078/92 concerning the methods of agricultural production compatible with environmental protection and the management of natural areas). A further assertion of the importance of rural development and the second pillar of the CAP (with the first pillar being the policy of market and revenue assistance) occurred during the Agenda 2000 reform process with the definition of Regulations for Rural Development (RDR) grouping 22 measures, including measures benefiting less favoured areas and areas subject to environmental constraints, as well as agri-environmental measures, with all of these measures conforming to the structural and assistance measures of the CAP (Regulation CE 1257/1999). Finally, during the reform of the CAP of June 2003, the scope of agri-environmental measures and the cross-compliance (conditionality) of financial aid from the first pillar of the CAP on various criteria, including environmental criteria, was extended. At the level of the European Community, this increase in environmental legislation has been accompanied by increases in the budgets allocated and in the agricultural surface areas and the number of farms concerned, however without accompanying increases in the resources allocated to measures of the first pillar of the CAP.

Agri-environmental measures in France

In France, the first applications of article 19 of the regulation CEE 797/85 date from 1989, and target in particular the protection of sensitive biotopes. During the reform of the CAP in 1992, France reorganised the operations of "article 19" henceforth called Local Agri-Environmental Operations (OLAE) and targeted two categories of rural areas with particular environmental sensitivities, on the one hand zones with rare and endangered biotopes, and on the other hand extensively managed areas that were threatened with or had already experienced agricultural abandonment. Two new forms of MAE were established including the national "payment for the maintenance of extensive husbandry systems (Prime au Maintien des Systèmes d'Elevage Extensif)" (PMSEE) better known under its simplified name of "payments for grass (prime à l'herbe)", and various regional measures such as the measure for "conversion to organic agriculture". From the double point of view of the surface areas concerned and the financial resources allocated, the PMSEE was the larger scheme; due to the expectation that significant positive outcomes in terms of biodiversity preservation would stem from the maintenance of grassland areas.

In 1999, the law of agricultural orientation (LOA) introduced the principle of agricultural multifunctionality as well as a new type of contract, the regional exploitation contract (Contrat Territorial d'Exploitation) (CTE), which recognises the economic, social and environmental functions of farms. In 2002 the CTE was replaced by the sustainable agriculture contract (Contrat d'Agriculture Durable) (CAD) with a greater focus on agri-environmental objectives; nevertheless, even though MAE's could be joined outside of the CAD, this measure was quickly abandoned in 2007. The CTE, and then the CAD, were themselves placed in a larger context, the national rural development plan (Plan de Développement Rural National) (PDRN) 2000-2006, corresponding to the establishment in France of the RDR at the level of the European Community in 1999. Within this overall plan, the MAE's themselves would be revised. Consequently, the PMSEE became the Agri-Environmental Herbage Payment (Prime Herbagère Agri-Environnementale) (PHAE) in 2003, with this measure itself, initially termed PHAE 1, being replaced in 2007 by the PHAE 2 with the establishment of a new rural development plan (Plan de Développement Rural Hexagonal) (PDRH) 2007-2013. In summary, these changes over time correspond to increasing environmental requirements: with farmers benefiting from assistance under the terms of the PHAE 2 having the obligation of at least 20% of the area covered by the PHAE 2 comprising of fixed elements favourable for biodiversity (hedgerows, tree windbreaks, isolated trees, marshes, humid permanent grasslands, areas in a Natura 2000 area, canals, ponds, watercourses, etc.).

From this presentation of the implementation of agri-environmental measures in France, the most obvious feature has been the gradual increases both in terms of surface areas concerned and of budget allocation. Even though these many changes, both at the French and European levels, aim to improve the effectiveness of measures by correcting the main inefficiencies and problems of previous measures, their complexity and the temporal variability, as well as that of the broader plans within which they are placed, is apparent, together with their primarily regional scale application (the OLAE or the CAD), and the essentially vertical application of measures to the industry (the CTE). This complexity and instability do not facilitate the assessment of the effects of the measures, and are constraints on the maintenance over time of the expected effects of the measures, the familiarisation with the measures by stakeholders, and the capitalising on the lessons learnt and gradual improvement of the legislative tools (in contrast to what has been possible to achieve in other member states, both at the national and regional levels, for example in Germany in the context of the MEKA program implemented in Bade-Wurttemberg).

Legal analysis of agri-environmental measures as contracts

The legislative tool for the implementation of MAE's, in France, as in the other member states, is the contract. A legal analysis of the contract as a tool for environmental protection in general, and of biodiversity in particular, reveals both advantages and drawbacks.

Lawyers consider that the contract is a less effective tool for the protection of the environment than regulation, primarily because of its voluntary nature which makes the implementation of the policies with which the contract is concerned, dependent on the consent of the involved stakeholders. The achievement of regional objectives and implementation in certain types of areas can be compromised by the refusal of some farmers to become involved; in which case, the effectiveness of the objective in its entirety may be compromised. The voluntary nature of a contract leads to two major consequences: on the one hand, it makes it very difficult to make any programme permanent (even if it is possible, for example as for rural rentals, to set up long-term contracts); and on the other hand, the exclusivity of the contract legally obliges only the parties involved. Agri-environmental contracts thus limit the ability of third parties to access information and influence the measures used, offer weaker legal guaranties (relative to regulatory legislation) to the extent that third parties are not able to act in regards to those activities that may represent a threat for the conservation of an area (CJCE, C-255/93, 5 October 1994), and can be compromised by private contracts to which a farmer subscribes, for example supply contracts or other integrated contracts with either upstream or downstream businesses.

In terms of advantages, lawyers have observed that the imposition of penalties in the case of the non-respect of the engagements agreed to in the context of the contract through the non-payment of the farmer are simpler to implement than administrative or legal penalties associated with contraventions of regulations; even though both of these methods may have the same difficulties in terms of controls. In general, an advantage of environmental contracts compared to legislative regulation is that it contributes to the increasing consciousness amongst farmers of "environmental issues" and consequently, allows progress in "environmental consciousness" in the agricultural sector. Contracts are considered to favour the involvement of stakeholders and increase their stake in the process, two factors that lead to a better adherence to regulations. In this sense, the contract is often viewed as a complement to legislative measures, or as a "preparation" for future regulations and/or a means to go further than the existing legislative structures (taking into account that the obligations within the contract should be distinct from legal requirements).

Since the reform of the CAP in 2003 and the regulation (CE) 1698/2005, member states have been obliged to conduct a public consultation during the development phase of any MAE; they are also obliged to continually assess each MAE. It is also henceforth possible to resort to bids to attribute payments, with the aim of improving the ratio of the costs versus the effectiveness of measures; an analysis of the literature does not allow any unambiguous conclusions as to the effectiveness of this strategy (see boxed section below).

The attribution of agri-environmental contracts via bidding

Agri-environmental contracts in general, and more specifically MAE's, can / could be granted on the basis of bidding mechanisms. Government bodies could thus acquire benefits for the environment while farmers would compete for the payments that they wished to receive by offering in return the provision of environmental conservation efforts and ecosystem services, similar to a the process of a government tender. Such bids can be implemented either under budgetary constraints (the contracts are awarded to the best offers until the budget is exhausted) or under objective constraints (for example, a minimum number of hectares under contract). Such mechanisms of bidding for agri-environmental contracts have been used in England, Australia and the United States of America. The results of these schemes have been limited. One identified limit has been that the bidding system generated high administration costs, both at the level of the administrator and that of the farmer, and in particular when constraints regarding spatial continuity were involved.

The impact of agri-environmental measures on biodiversity

The ecological assessment of MAE application in France has been very poorly developed. An analysis of the results in a number of European Union member states and Switzerland shows that the results have not been overwhelmingly positive. Of the 59 studies included for that assessment, 31 showed a positive impact on biodiversity while almost as many (28) showed that there was either no effect, or mixed effects (see the adjoining table). This result raises two closely linked questions: firstly, that of the adequacy of the correspondence between the objectives of the scheme and the requirements of its component contracts or regulations; and secondly, that of the effective implementation of the scheme's requirements. The first problem is often linked to gaps in scientific knowledge as to the biological processes that the government administration is aiming to reverse or, in contrast, favour; but a poor correspondence between a scheme's requirements and the desired objectives can also result from unpredictable biological, economic or social dynamics. In addition, the effectiveness of such schemes can also be limited by an overly short duration of contracts relative to the response times of ecosystems, as well as the involvement of insufficient surface areas, or surface areas too dispersed in space.

	Number of studies	Positive effects of MAE	No effects or mixed effects
Ireland	2	0	2
Netherlands	8	2	6
France	1	0	1
Germany	5	2	3
Sweden	2	1	1
Spain	5	2	3
England	12	6	6
Switzerland	24	18	6

Assessment in 8 European countries (7 belonging to the European Union and Switzerland) of the impacts of MAE on biodiversity (species richness, composition of species groups)

Ecological and economic effectiveness of MAE's

Since payments for MAE schemes are based on the fulfilment of a set of technical obligations and not on obligations of results in environmental terms, their effectiveness depends primarily on five factors: the causality between the specified practices and the environmental impacts, the location of the areas under contract, the proportion of farms under contract in the area of interest, the respect of the requirements of the scheme by contracted parties, and the duration of the practices, either with or without the renewal of the contract.

Regarding the first point, the spatial and temporal variation of causation needs to be taken into account as well as the effects of scales and thresholds for areas larger than the agricultural plot and/or farm (even when they are well understood these non-linear phenomena are rarely taken into account). For the second point, the most efficient solution, already adopted in some countries / regions and for some schemes, is the restriction of eligibility to those areas considered of primary interest. This solution is not without problems, especially in terms of the acceptability to farmers, who may perceive such restrictions as a form of discrimination in the accessibility of budgetary resources and their distribution. For the proportion of land under contract, this is in itself a function of numerous parameters (per hectare payments relative to the additional costs and losses of profit due to adherence to the requirements of the scheme, duration of the contract, flexibility of scheme requirements, degree of choice in the areas of land to place under contract, methods of control, penalties and renegotiation, etc.). Within this list, it is worth highlighting an often neglected factor, the lack of acknowledgement of the transaction cost even though this can amount to up to 35% of the payment (20% on average, with a high variability ranging between 5 and

35%). In fact, the theory of transaction costs states that the amount of a transaction cost will increase with the specialisation of the product, that is with the increasing difficulty of using the resources deployed in the transaction concerned for other purposes. This result explains, at least in part, why the best paid schemes, and thus usually the most constraining but also very often the most ambitious in terms of expected environmental results – which is in particular the case of MAE’s targeting biodiversity protection – have also the lowest rates of contractualisation[4]. Increasing compliance controls is a source of additional costs which is potentially recoverable, at least in part, by increasing the financial penalties that are currently considered insufficient to be truly dissuasive; however such a change risks to increase "bureaucratic inflation" and dissatisfaction amongst farmers. An alternative solution is perhaps through greater efforts in farmer education in the issues of environmental protection, and through better information and more efficient technical assistance. It has been observed that farmers can sometimes go beyond the requirements of the terms of engagement in their contracts; for example farmers in the Northern French Alps have profoundly changed the technical organisation of their farms and integrated biodiversity as a major element of their farm management, even though they were only contractually committed over small areas of land and for low levels of payments. Finally, for the fifth point, the duration of favourable practices depends mostly on their profitability, both overall and relative to alternative practices, with the profitability of various types of practices subject to modification by changes in public policies.

4.3.2. The Natura 2000 scheme

The Natura 2000 scheme is a central element of European Community policies for the protection of biodiversity. Natura 2000 consists of a network of natural areas within which animal and plant species, as well as their habitats, are to be protected. This network, which today covers more than 20% of the surface area of the Community (the 15 original member states), is composed of sites designated for the conservation of certain species of birds, in application of the "Bird Directive" of 1979 (the special protection zones or ZPS), and of sites for the conservation of natural environments and other species, in application of the "Habitats" Directive of 1992 (the special conservation zones or ZSC)[5]. At the EU level, ZPS target the conservation of more than 180 species and sub-species of birds and ZCS the preservation of more than 250 types of habitats, 200 species of animal and 430 plant species. Human activities, and in particular agricultural activities, are not excluded from these protected areas; in fact the "Habitats Directive recognises that conservation should take into account "economic, social, cultural and regional contexts" and adds that the protection of "biodiversity can, in some cases, require the maintenance, and even encouragement, of human activities"; exercising such activities need "only" be compatible with the objective of the conservation of the flora and fauna of the habitats. Natura 2000 areas are designated by the European Commission, on the basis of nominations by member states.

Natura 2000 in France

In France, the responsibility for the identification of sites is vested, since 1995, in the regional scientific councils for natural heritage (Conseils Scientifiques Régionaux du Patrimoine Naturel) (CSRPN) comprising of expert naturalists. The proposals, compiled at the national scale, are presented, since the beginning of 1996, to the national council for the protection of nature (Conseil National de Protection de la Nature) (CNPN) for validation. In April 1996, the so called “group of nine” composed of agricultural, hunting, fishing and forestry representatives contested the delegation of the designation of sites only to scientists. "Monitoring committees" were then established at the national, regional and departmental levels with representatives from the "group of nine", environmental associations and local government representatives. These committees secured assurances that proposals for Natura 2000 areas would be presented before the municipal councils of the communes involved. For each site, it was decided that, in consultation with local stakeholders, a document of objectives (DOCOB) would be developed identifying the objectives in terms of conservation, and the expected participation of the various local stakeholders in their accomplishment. These guarantees in terms of the recognition of human activities carried out within Natura 2000 areas allowed the re-launching of the process. In 1999, more than 1000 sites were communicated to the European Union; and it was also in 1999 that the process of the development of the DOCOB’s was established.

The development of a DOCOB is based on a desire to associate all of the stakeholders concerned by the designation of a Natura 2000 area in a forum in which debates and exchanges are possible, with the aim of defining, through consultation and negotiation, the appropriate management practices for each site that are accepted, or at least are acceptable, to the stakeholders. The development of a DOCOB is delegated to local institutions, termed operators, who have the task of establishing the baseline ecological, economic and social information for the site, to define the conservation objectives and to propose the measures to be put in place by the various local stakeholders in order to attain them. The identity of these operators is variable, local administrative structures (regional natural parks, communities of communes…), environmental associations (in particular the regional conservatories of natural areas) forestry administrations (national forestry office, regional centres of forest property), etc. Their operation is placed under the supervision of a direction committee (Comité

4. the lesser rate of contracting for the most ambitious MAE's can also result from an insufficient evaluation of compensation per se and/or of an over-evaluation, at least relative, of payments under less ambitious MAE's.

5. More precisely, it is the "Habitats Directive" 22 May 1992 which defines the structure of the Natura 2000 network. This directive concerns both the ZSC classed under the "Habitats Directive" and the ZPS classed under the "Birds Directive".

de Pilotage) (COPIL), initially presided over by the prefect of a department, but today by an elected representative, and consisting of representatives of the activities and interests involved in the site's conservation. The composition of the COPIL reflects this wide range of concerned parties: local government structures represent one third of members; followed by representatives of other administrations, agriculture, environmental associations, hunting and fishing associations, etc. At the beginning of 2005, more than 300 DOCOB had been validated by the COPIL and about 550 DOCOB were in the process of being developed; almost one third of French communes were involved; multiple thousands of local political representatives and representatives of local interest groups had been involved in the COPIL process; and many tens of thousands of citizens had taken part in the processes of consultation, dialogue and negotiation and the development of proposed management plans. This process has allowed greater appreciation and sense of ownership of the challenges involved in the preservation of biodiversity by stakeholders, with variable degrees of involvement and debate between sites depending on their particular characteristics (size of the area, diversity of activities present, etc.). It should be highlighted that, in order to confirm and recognise the central role of local administrations in the development of a DOCOB: the law of the 23rd February 2005 concerning the development of rural regions (Développement des Territoires Ruraux) (DTR) delegated to local government the function of being the managing body for all of the Natura 2000 sites and reserved the presidency of the COPIL's for a local elected representative.

In April 2007, 1334 ZSC sites had been communicated to the European Union in the context of the Habitats Directive and 369 ZPS sites in the context of the Bird Directive. In total, this represents 6.8 million hectares, or 12.4% of the area of the French territory: 41% of this area corresponds to agricultural lands, 39% to forests and 13% to heathlands and open environments. At the same date 587 DOCOB had been validated and were considered as being "operational".

Tools for the protection of biodiversity within Natura 2000 sites

In general, measures for the conservation of flora, fauna and habitats in Natura 2000 sites are carried out in the context of Natura 2000 best practices[6], contracts or through the application of legislative, regulatory and administrative tools, especially those dealing with national parks, natural reserves, biotopes, special sites (sites classés) or the nature police. French lawyers have noted that French legislation has not created any specific biodiversity protection measures applicable to Natura 2000 sites, nor has it chosen any particular tools or legislation to use amongst the existing legal arsenal. The Natura 2000 scheme is thus an example of the implementation of a plurality of legal tools (tax exemptions, contracts, zoning regulations, etc.).

The use of contracts is favoured for the management of Natura 2000 sites and for the implementation of conservation or restoration operations in these areas. Two types of contracts are used in priority: MAE contracts for agricultural areas and Natura 2000 contracts for non-agricultural areas. As of the end of 2006, 3100 "MAE" contracts had been signed with farmers and more than 600 Natura 2000 contracts with local administrations, land owners, regional natural areas conservancies, various associations, etc. As of this date, the financial resources allocated to Natura 2000 contracts amounted to 17 million Euros; the amounts allocated to "MAE" contracts on sites located in Natura 2000 zones are not available, but the previous section made reference to the low financial allocations for "MAE" contracts overall, both within and outside of Natura 2000 areas. In other words, while the first DOCOB were validated at the beginning of 2002, very low financial resources were made available for this process[7]: this limited financial investment has two negative consequences. Not only does it limit the surface area under contract, but it also disrupts the positive dynamics created by the participative process of the development of the DOCOB's. Scientists have shown that this has resulted in the risk of de-motivating stakeholders, and even increasing their mistrust and caution when dealing with the public sector.

The inadequacies of MAE's identified previously apply equally in the specific case of MAE's applied to agricultural land within Natura 2000 sites; with in particular the problem that the MEA are individual contracts whereas the Natura 2000 scheme is, by essence, a regional approach (by environment) leading naturally to recommendations for regional management. The particular factors that can pose problems include those aspects relating to the surface areas under contract, their location, their fragmentation, etc. More generally, the greatest problem stems from the possible conflicts between the objectives of the two main stakeholder groups, that of private sector actors such as farmers, and that of public sector actors such as local administrations. A similar issue arises from the fact that MAE contracts are based on the obligation to implement certain practices while the European Union requires member states to implement monitoring programs based on results, i.e., an obligation of results. Legal cases concerning the use of contracts as the method for the implementation of environmental policies are based, in the case of Natura 2000, on the judicial precedents of the European Court of Justice, for example the decision of the "Marais Poitevin" of the 25th November 1999 (C-96/98) which considered that contracts resulting from the

6. "The Natura 2000 standards for a given site, established by the law relative to DTR comprises of a list of commitments which contributes to reach the conservation or restoration objectives of natural habitats and species defined in the DOCOB [of the site under consideration]…" (Article R. 414-12, code for the environment). These commitments are not subsidised; however the contractor can be exempted from the tax on un-built land.

7. This weakness is not particular to France: some member states have communicated to Brussels lists of sites covering a greater percentage of their territory (for example, close to 23% for Spain); however, the procedures for the establishment of management plans, generally less participative than in France, the instruments used for this and the financial resources potentially available / drawn on are considered insufficient.

application of MAE's did not offer sufficient environmental protection as required under the Bird Directive due to their "voluntary and purely indicative nature".

High Natural Value agriculture (HNV)

HNV agriculture refers to both agricultural areas of HNV and to agricultural systems of HNV.

In the context of the IRENA scheme (in French, an indicator for the monitoring of the integration of agri-environmental concerns into agricultural policies) initiated in 2002, a definition of agricultural areas of HNV was proposed at the European Community level: these areas correspond to "areas where agriculture is the dominant land use (generally the dominant practice) and where this agriculture favours or is associated with either a large diversity of species and habitats, or the presence of species whose conservation is considered a priority at the European / national / regional levels, or both". As regards HNV agricultural systems, this refers to systems using low inputs and to farms on which feed for grazing animals is derived from semi-natural vegetation. These two concepts are not equivalent, with the first corresponding to a static approach, and the second to a dynamic one. As HNV agricultural areas and HNV agricultural systems have been identified with the aid of indicators, these indicators can / could be used to monitor changes, in particular those relating to resources, such as biodiversity, in the areas concerned. In this perspective, it should be remembered that in the context of the second axis (environmental and landscape improvement) of the rural development policy 2007-2013, the European Union targeted three priority areas, these being biodiversity, the preservation and development of HNV agricultural and forestry systems and traditional agricultural landscapes, and water and climate change.

4.3.3. The cross-compliance (conditionality) of direct payments of the first pillar of the common agricultural policy

The principle by which European Community farmers must respect the requirements of environmental protection in order to receive direct payments and market support assistance (first pillar direct payments) was introduced during the Agenda 2000 reform process in 1999. This concept termed cross-compliance or eco-conditionality was expanded during the reform of the CAP in June 2003 with the integration of aspects relating to public health, animal and plant health and animal welfare concerns; from which stems the current form of cross-conditionality which goes well beyond only environmental aspects, even though these remain central.

The three aspects of cross-compliance

The first aspect of cross-compliance consists of 19 European Community directives and regulations pertaining to three main areas, these being, the environment (5 texts), public health, and animal and plant health (food safety) (11 texts) and animal welfare (3 texts)[8]. The five texts relating to the environment are the 1979 directive on the conservation of wild birds, the 1980 directive on the protection of sub-surface water from pollution by dangerous substances, the 1986 directive on the protection of the environment, and in particular soils, during the use of sewage sludge, the 1991 directive concerning the protection of water from pollution from agriculturally derived nitrates, and the 1992 directive on the conservation of natural habitats as well as wild plants and animals.

The second aspect of cross-compliance is based on the maintenance of Good Agricultural and Environmental Conditions GAEC, aimed at maintaining four basic objectives: protecting soils from erosion; maintaining the levels of soil organic matter; maintaining soil structure; and assuring a minimal level of farm management (Regulation (CE) 1782/2003). While the first aspect of cross-compliance is obligatory, each member state has the possibility of defining, from a range of EU options, the GAEC to be applied. France has chosen to define its national GAEC via five measures: the first measure obliges farmers receiving payments from the first pillar to establish a minimal surface area of an environmental vegetation cover, more specifically this measure requires 3% of the surface area sown with cereals, oil seed crops, pulse crops, flax and hemp, including land set-aside under the obligatory policy setting aside some portion of eligible land, to have an environmental cover (established in preference along watercourses and with no fertiliser or pesticides applications); the second measure obliges farmers to not burn crop residues; the third measure encourages a diversity of rotations and requires farmers (who wish to receive first pillar direct payments) to put in place at least three different crops in their rotations, or at least two different families of crops; the fourth measure obliges farmers irrigating crops to possess a declaration / authorisation for the water extractions and an appropriate method of evaluating / determining the volumes extracted; finally, the fifth measure requires a minimal level of farm management in order to prevent the establishment of undesirable weeds and the development of shrubs / scrub.

The first two aspects of cross-compliance apply to the entire area of a farm receiving direct assistance from the first pillar. The third aspect is concerned specifically with permanent grasslands and is defined at the aggregated

8. Only some articles among these 19 texts are part of conditionality.

scale of the country or region. It requires that the surface area of permanent grasslands be "maintained", or more precisely that the reference ratio between the surface area (national or regional) of permanent grasslands and the total agricultural surface area is maintained within a limit of decreases of 10%.

First analyses

Cross-compliance was only implemented in 2005, and then in a gradual fashion (the three texts relative to animal welfare where only integrated into the cross-compliance scheme in 2007). It is thus too early to draw any scientifically robust conclusions as to its effects (ecological, agronomic, economic…), and in particular in terms of effects on biodiversity conservation even if it is possible to suggest that some of the regulations (in particular, the first three measures of the BCAE and the maintenance of permanent grasslands – with the proviso that member states do not use the freedom to decrease their area by 10%) should have positive effects on biodiversity, at least in comparison to a situation in which cross-compliance is not applied. In this context, the example of the implementation of the conditionality of financial assistance in Switzerland could be used to modify, if necessary, the French cross-compliance scheme in a way so as improve biodiversity maintenance (see the boxed section below).

For the first aspect, it should be mentioned that cross compliance, while it does not modify the legal nature of regulatory requirements, has the potential to induce farmers to better respect them: it is often less easy to refuse a financial aid, especially when this is significant in terms of total farm revenue, than to take the risk of potential legal penalties. In the case of the non-respect of the regulatory requirements of the first aspect of cross-compliance the farmer risks reductions in his first pillar direct financial payments, or even their suppression. The amount of this reduction depends on the seriousness, the scale and the persistence of the contraventions committed (5% maximum in the case of negligence, with the possibility of a reduction of this penalty to only a warning without a reduction in payments, 15% maximum in the case of repeated negligence, 15% minimum in the case of an intentional contravention rising up to 100%). Cross-compliance has resulted in a significant effort in terms of the communication of the applicable regulations. While there are positive aspects to cross-compliance, as noted above, lawyers have observed that the mechanisms of compliance control for cross-compliance are virtually the same as those used for regulation. The motivation to respect regulatory requirements is greater with increasing probabilities of control, where penalties are systematic and rapidly applied (which relates also to the mechanisms for the control of penalties), and that the situations in which penalties are reduced are rare, limited and transparent.

For the second aspect, lawyers have noted that cross-compliance schemes can be useful even when applied to criteria that are otherwise not considered as being constraining. In fact, cross-compliance transforms these criteria into contractual obligations where a payment is expected by the farmer for the respect of these obligations. The weaknesses of using contracts as the tool for biodiversity protection presented earlier are less marked in the case of the BCAE. Firstly, the access to public assistance modifies the perception of the contract by the farmer: it is not easy to accept a reduction in a payment that has already been attributed. Secondly, the long term nature of the assistance is assured as legally, there is nothing to prevent the continuation of the payments without a time limit.

The conditionality of agricultural aid in Switzerland and its impacts on biodiversity

Obligatory eco-conditionality for direct agricultural payments was established in Switzerland in 1998 in the form of the required ecological services (Prestations Ecologiques Requises) (PER). This eco-conditionality requires producers to maintain a part of their land as ecological compensation surfaces (Surfaces de Compensation Ecologique) (SCE) with a primary objective being the preservation and development of biodiversity: at minimum, 3.5% of land under special crops, and 7% of the useful agricultural surface of the farm should be used for SCE. Currently 88% of Swiss farmers representing 97% of the total useful agricultural surface are respecting this eco-conditionality; with 13.6% of the total Swiss useful agricultural surface being covered by SCE. Controls are very frequent with 33% of farmers being controlled each year.

An assessment of the SCE scheme in 2005 in terms of the objectives of the preservation and development of biodiversity was globally positive: the minimal requirement of an increased biodiversity in areas of SCE as compared to control areas was satisfied (and this for all of the different types of SCE, 16 in total); nevertheless, the effectiveness of the scheme in terms of the protection, and if possible increases in the populations, of the most threatened animal and plant species is considerably lower (by itself the eco-conditionality scheme is not sufficient for the protection of endangered species).

From the economical point of view, cross-compliance is without doubt the source of additional costs for farmers, and these costs rise as the criteria to be adopted become more demanding and require changes to agricultural practices. To these direct compliance costs should also be added transaction costs; It is however too early to provide a scientifically robust evaluation of the impact of the cross-compliance scheme for direct financial payments from the first pillar of the CAP on these two types of costs.

4.3.4. Certification

Also termed "modes of value-adding" for agricultural products, French law defines official labels for the identification, the quality or the origin[9] (red label, controlled terms of origin, protected geographic indications, guaranteed traditional specialities, and organic agriculture), value-adding labels ('mountain product' labels, 'made on the farm' or 'product of the farm' labels, etc.) and the processes for the certification of products. There also exist other collective forms of labelling and differentiation, for example the labelling of farms or farm products as being produced through sustainable agriculture (agriculture raisonnée) or according to the requirements of integrated fruit production. The producers adhering to such a collective labelling scheme must comply with the corresponding requirements, the additional costs linked to the adherence to these requirements being compensated or over-compensated for, at least in theory, through a higher product price. The contractual requirements for these collective schemes can include the obligation to respect some "good" cropping and animal husbandry practices and to maintain some regional practices such that positive outcomes for biodiversity could be anticipated. It is nevertheless difficult in the context of the absence of precise and robust scientific information to draw any further conclusions in the context of this assessment. The boxed section below presents the case of the Beaufort cheese controlled term of origin (AOC), which, due to the fact its production is based on extensive and diverse grazing systems, has potentially favourable effects from the point of view of biodiversity. It is also possible and interesting to consider the specific case of organic agriculture (Agriculture Biologique - AB in French), in the light of its requirements which specify certain production methods with potential consequences for relationships between agriculture and biodiversity.

The difficulties of the AOC "Beaufort Cheese"

The production of numerous AOC cheeses is based on production systems using low intensity management, or even extensive, grasslands; this is the case for, in particular, the AOC cheeses from mountain regions (Beaufort, Comté, Munster…). In these systems, the grassland flora is rich and diverse, characteristics recognised and valued by the farmers (appetising feed and hay, flexibility in grassland use, characteristic taste of cheeses; see chapter 2). In addition the landscapes of the corresponding regions are shaped and maintained by these grazing activities.

The AOC "Beaufort cheese" is based on a very strict list of requirements aimed at maximising the use of local resources and limiting agricultural intensification. In spite of these AOC requirements, grazing practices in this area are changing in manners unfavourable for biodiversity. Increases in the baseline rations for dairy cows have led to losses of grassland floristic diversity; decreases in the number of farms and increases in their size with resulting increased workloads having the consequence of increasing land use heterogeneity, with in particular an over-use of flat areas and an under-use of slopes.

Conscious of the risks these changes could create in the long term, the managers of the AOC were heavily involved in a collective CTE called "Beaufort Cheese" from its launching in 1999. For stakeholders involved in cheese production, the CTE coupled with the AOC label was a means for increasing the recognition of environmental and landscape management as a function of agriculture. This dynamic was slowed down by the suppression of the CTE and CAD schemes. It has nevertheless continued in the context of local partnerships with the communes involved, and groups of communes and environmental managers. Expectations for the effects of the new MAE are very high.

After two decades of increases, the revenues of milk producers in the Beaufort area have begun to stagnate; this is occurring in a context of increases in the base price of milk, which has reduced the differential between milk prices sourced from the AOC area and from non-AOC areas. This situation has led some farmers within the area to request decreases in the restrictiveness of the criteria and requirements of the label so as to reduce additional costs and allow greater competitiveness with other milk producers. More generally, this example illustrates the difficulty of trying to market a high quality product while the price of the "standard" product is rising.

Organic agriculture

Organic agriculture is subject to specific European Union regulations applicable by all member states, together with supplementary national regulations (national regulations will be abrogated from the 1st January 2009 and replaced by the European Council regulations of the 28th June 2007). By prohibiting the use of chemically synthesised products (phytosanitary products and fertilisers), at the risk of significant decreases in productivity, organic agricultural production reduces the pressures of toxins on the environment and implies the adoption of agricultural practices favourable for biodiversity. It is primarily due to these factors that the development of organic agriculture has been encouraged. For example, the minister in charge of agriculture has stated that "organic agriculture is of major interest for environmental protection and can be considered as a tool to respond to the objectives of water protection and the maintenance of biodiversity due to the limitations in the agricultural

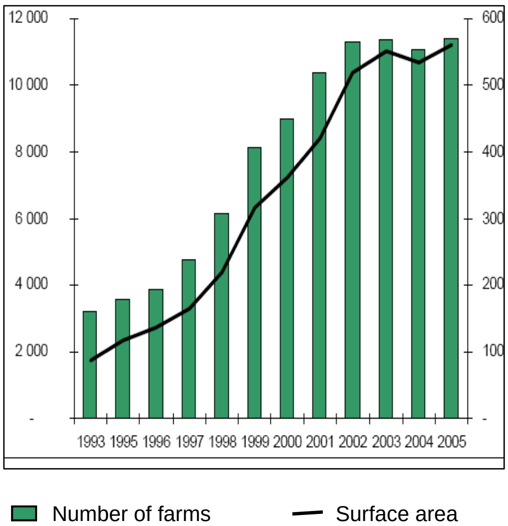
9. The official terminology could be confusing since in the case of organic agriculture for instance, the production method is also certified.

practices used". Nevertheless, chapters 1 and 3 of this current assessment have shown that the positive effects of organic agriculture depend on the landscape context.

A study based on 76 cases compared the effects of organic agriculture versus conventional agriculture on biodiversity. This study found a wide range of taxa, including birds, mammals, invertebrates and plants, were favoured by organic agriculture by manifesting greater species richness and / or greater abundances. Another study, carried out in cereal cropping systems in the United Kingdom, concluded that organic agriculture resulted in a greater biodiversity than conventional agriculture, with nevertheless differences in responses between taxa: in particular a greater positive response of plants than invertebrates, birds and bats. Finally, a third study based on 66 cases also concluded that organic production systems had a positive impact on invertebrate and bird biodiversity (again relative to conventional agriculture).

In 2005, 11 400 French farms (including farms in the process of conversion) used organic agriculture; they represented close to 560 000 hectares, or 2.0% of the French useful agricultural surface. These figures are far removed from the multi-year plan for the development of organic agriculture launched in 1997 which aimed for some 25 000 farms and 1 million hectares by 2005. In reality, after a period of strong growth at the end of the last decade, the development of organic agriculture has stagnated since 2002 (see graphic). The causes of this slowdown are numerous, and difficult to place in a hierarchy on the basis of existing scientific information: technical difficulties, poorly adapted methods for the evaluation of inputs, insufficient varietal selection, insufficient research effort coupled with the complexity of research and development programmes for organic agriculture, unmet needs for farmer assistance, unmet needs for farmer and technical advisor training, insufficient governmental financial incentives both in absolute and relative terms (i.e. in comparison with assistance and revenue that could be expected if the farm was managed under conventional agriculture), etc.

In France, organic agriculture was officially recognised in 1981. During the conversion phase (period between the date of the adoption of the organic production mode and the moment that it becomes possible to commercialise products under the organic agriculture certification), farmers receive conversion assistance: until 1999 in the context of the MAE, and then under the broader scale schemes of the CTE and the CAD. Organic agriculture has also been the beneficiary of numerous other development plans, with the latest being "Organic agriculture objective 2012" introduced in September 2007, which is based around five types of actions: research, development and education; industry restructure; promotion of the consumption of organic agriculture products; regulation; and improving the conversion and sustainability of organic agriculture farms. In particular, this plan includes the continuation of tax credits for farms for which at least 40% of revenues are derived from products that are certified organic agriculture and which do not (or no longer) receive assistance from a CTE or a CAD. These measures are in conformity with the conclusions of the Grenelle summit of the Environment which recommended that for organic agriculture (conclusions of the round tables of the 24-26 October 2007), the demand for organic products should be stimulated by encouraging their consumption in collective restaurants and canteens (a target of 20% by 2012) and, simultaneously, the production and surface area managed under organic agriculture should be increased, preferably around water catchment zones (targets of 6% by 2010, 15% by 2013 and 20% by 2020). In contrast to other European member states, France does not grant assistance for the maintenance of practices corresponding to the requirements of organic agriculture. The 2007 plan does however include the possibility of "measures of targeted assistance for the maintenance of collective, regional and contractual actions reinforcing the structure of the organic agriculture industry". Even though scientific evidence is limited, it is possible to suggest that one of the causes of the slowdown in the development of organic agriculture since 2002 is due to distortions induced by the fact that French producers do not have the benefit of assistance for the maintenance of organic agriculture systems, while a number of their competitors do benefit from such assistance (granted in the context of MAE's).



Organic agriculture in France: changes in the surface area (millions ha) and numbers of farms (source: Agence Bio, 2006)

4.4. Effectiveness of existing schemes and new mechanisms of action

Despite an increasing integration of the environment and more specifically of biodiversity into European Union and French agricultural policies, this assessment has shown that, in general, overall integration remains moderate, the policy measures used have numerous limitations and that opportunities for improvement exist.

Before presenting suggestions for possible improvements, one point merits further discussion, this being the coherence of government policies.

4.4.1. The coherence of government policy – a necessary factor

The table below shows clearly that direct agricultural payments to French farmers in the context of the first pillar of the common agricultural policy (payments and market support) are not comparable to those granted in the context of the rural development policies of the second pillar of the CAP (11 billion versus 1,5 billion). The figures illustrate the point, already made, of the relatively low funding allocated to rural development which, it should be remembered, does not only cover environmental aspects, but also aspects such as promotion of the quality of agricultural products and regional development.

The process of the reform of the common agricultural policy underway since 1992 can be characterised by two major directions; firstly, decreases in assistance based on price support and its replacement by direct payments more and more decoupled from the type and amount of products produced (the process of "decoupling" subsidies from particular crops); and secondly, the gradual transfer of financial resources from the first pillar (direct payments and market support) towards the second pillar and its primarily environmental and regional development priorities[10]. The relatively small magnitude of this transfer should be recognised even if it is difficult to estimate what the "optimal" distribution of funding between the two pillars should be, particularly due to the difficulty of measuring the value of the environment and its services.

	Area (millions ha)	% of the country	% of the French UAS	Payments (billion Euros)*
First pillar (direct payments and market support)				**11**
(cross-compliance)	13	24%	40%	6.6
set-aside	1.2	2.2%	4%	na
Second pillar (rural development)				**1.51**
Total MAE	6.9	12.7%	30%	0.6
organic agriculture	0.6	1.1%	2%	na
grassland maintenance (prime à l'herbe)	3.2	5.8%	10%	0.21
Natura 2000 (1705 sites)	6.8	12.4%	10%	0.002
Regional natural parks (45 parks)	7	12.7%	10%	na

* Direct payments in the context of agricultural policies; na: not available

The analyses of economic data shows that in terms of governmental assistance the adoption of environmental measures can sometimes be in contradiction with measures for production assistance. For example, a farmer may not be able to adopt a MAE favourable for biodiversity "simply" because the adoption of this measures would force the farmer to renounce all or some part of other direct payments targeting other objectives[11]: this is the case, for example, if the MAE constrains the farmer to reduce the number of animals per unit of surface area whereas another type of assistance would provide higher payments with increasing numbers of animals; in this context, the decoupling of direct payments and market support is advantageous as it removes the link between first pillar payments and the choice of products produced and production methods.

4.4.2. Measuring biodiversity and its value

Legal methods can be used to create a better framework for taking into account and protecting biodiversity values. The establishment of a system of environmental responsibility, as for example that instituted by the European directive 2004/35/CE concerning the prevention and restoration of environmental damage, allows for the actor responsible for damage to biodiversity being obliged to repair it. In order to facilitate the evaluation of any environmental damage and the measures necessary for restoration, this directive takes into account environmental damage affecting "the functions provided by a natural resource that benefit another resource or the public".

10. Let us recall in addition the simultaneous move towards conditionality of aids from the first pillar on the respect of regulations of good agricultural and environmental practices, a move which some summarise as a "greening of the first pillar".
11. For a presentation of other factors determining non adoption, see the above section dedicated to MAE.

The obligation to repair damage inflicted on biodiversity can also be applied in a pre-emptive fashion, prior to any environmental degradation, via for example compensation mechanisms. Very simply, such compensation obliges the proponent of a project that is going to result in environmental degradation to compensate for such degradation via the creation and management of an equivalent natural area. This principle of pre-emptive compensation is applied in a number of countries, for example the United States, in the context of "*conservation banks*" which target the protection of wetland areas, or "*mitigation banks*" which target the protection of species and their habitats. In France, such compensation, even though possible since 1976, has not really been employed other than in the context of the Natura 2000 network[12]. These mechanisms allow the association of a "given" value with biodiversity and to integrate the costs of its degradation, via its replacement, into public and private decision making. The effectiveness of such compensation schemes depends greatly on the degree of monitoring and control carried out by public institutions in charge of their administration. These schemes also have a number of potential risks: discrimination between those who are able, or not, to "buy biodiversity"; a spatial segregation between compensation (protected) areas and areas to be compensated for (degraded), etc.

In general, literature reviews show the need for better ways of measuring, taking into account and valuing ecosystem services beyond the relationship between the destruction of biodiversity and its compensation "alone".

4.4.3. Better understanding biodiversity and its relationship with agriculture

It has been shown that the absence of clear information regarding biodiversity impacts is a constraint for the widespread adoption of practices favourable to biodiversity (see chapter 3). The establishment of systems for the monitoring of the environmental and agronomic performance of agricultural practices imposed by this, or that, environmental scheme is necessary, but can be very costly (see boxed section below). In this context, the experiences of other countries or regions (Baden-Wurttemberg in Germany, the Netherlands, Switzerland…) can be instructive; in general these show that systems facilitating the evaluation of policy measures and of collective learning and assessment by stakeholders, lead to increases in the acceptability of the measures to stakeholders and to in turn improve the technical specifications of the imposed practices. Significant efforts in the areas of information, its collection and maintenance are thus useful for the continued definition and development of public policies for the preservation of biodiversity, the monitoring of their effects and of their improvement.

Information and monitoring

Observations and monitoring protocols of the component elements of biodiversity (populations, species, etc.) are often limited in scale, scope and of insufficient duration. Numerous factors explain this situation:
- the costs of collecting such information is high as biodiversity consists of multiple parameters, is spatially distributed and its measurement requires highly specialised skills;
- the collection of information is most often carried out by amateur "naturalists" motivated by conservation or by users of biodiversity (hunters, fishermen, etc.);
- the measurement of changes in biodiversity and their interpretation is difficult and subject to many sources of error.

4.4.4. Better regulating relationships between agriculture and biodiversity

Regionally based environmental governance

The relevant regional scales for the management of biodiversity should be defined as a function of the spatial scales and levels of biological organisation identified in the three preceding chapters of this assessment. Constructing forms of environmental governance at appropriate regional scales is not an easy task, and such a process would result in considerable human and financial costs (direct costs and transaction costs) which, hopefully, would decline after the start-up phase. The experience of the Natura 2000 network in France (with increasing involvement of regional administrations and positive impacts stemming from this involvement) suggests that the decentralisation / regionalisation of governance facilitates the sense of ownership of actions by stakeholders, and consequently their engagement, as well as allowing, through the application of the principle of subsidiarity (devolution of governance to the smallest, lowest or least centralised competent authority), increases in the coherence between desired objectives and implemented actions.

12. Let us mention nevertheless the recent initiative by the Caisse des Dépôts et Consignation (CDC) through the creation of its branch "CDC Biodiversity" based on the principle of compensation; more specifically, the two objectives of this branch are, on one hand to ecologically manage land that generates "biodiversity units", which can be sold to public or private agents, who carry out projects liable to damage the environment, and on the other hand to propose an offer for services in order to help businesses in compensating damage themselves.

Defining acceptable risks

This point can be illustrated by taking the example of phytosanitary products. Chapters 1 and 2 of this assessment have clearly shown that these products can have an impact on biodiversity. Their commercialisation and conditions of use are the subject of a regulatory and legislative framework, both at the level of the European Union and nationally, which aims to identity, assess and reduce the risks that these products present for human health, and that of "non target" plant and animal species. This framework still has considerable room for improvement as illustrated by the proposition for European community regulation (COM(2006) 388 final) and various other proposed plans of action relating to the use of phytosanitary products; the objectives of which are, in particular, a better understanding of the potential effects of these products on the different components of the environment (water, air, soil) and on biodiversity; the substitution of the most dangerous products by other less dangerous ones; and improvements in the conditions of the use and distribution of these products.

A major challenge linked to the use of phytosanitary products is that of defining levels of "acceptable risks", which requires democratic and transparent decision making processes, and the definition of criteria for the acceptability of risks that explicitly takes into account the value of biodiversity.

Developing innovations favouring biodiversity

The development of production systems more favourable for the environment in general, and more specifically for biodiversity, often requires the development, adoption and dissemination of innovations, relating in particular to agricultural inputs and technical improvements in the area of “innovative agricultural systems". It also requires the involvement of all of the stakeholders: agricultural producers, upstream and downstream processing industries, advisory bodies, research and research and development organisations, etc. In this context, due to a lack of funding from the market and private organisations, governmental policies of innovation assistance could be helpful, at least in a transient manner, to stimulate the development of innovations concerning agricultural inputs (seeds, fertilisers, pesticides…) as well as for agricultural practices and production systems (such as for the support of "sunrise industries"). Government policies of additional taxation of the main factors responsible for negative impacts on biodiversity could also be useful; such policies present a double advantage: in a static manner by reducing the use of these factors and thus reducing the impacts on biodiversity; and from a dynamic point of view by stimulating the development of research and innovation targeting reductions in the use of these, now more expensive, factors (via the theory of induced technical progress): of course, these two advantages need to be balanced with the additional costs imposed on agricultural production and reductions in farmers revenue. More generally, the aim would be to develop government policies (initiatives and regulations[13]) and methods of governance allowing the development and dissemination of win-win agricultural systems, favourable both from the environmental and economic points of view.

13. From this standpoint, it would probably be necessary to analyse criteria for authorisation of commercialisation of pesticides, by taking into account the stakes, in particular in the long term, of biodiversity conservation and of ecosystem services that it can provide.

Conclusions

An assessment based on identifying beneficial synergies between agriculture and biodiversity

The interest being currently shown in biodiversity is becoming more and more focussed on its role in the functioning of ecosystems, and in particular human-dominated ecosystems, and on the ecosystem services that biodiversity provides for human society. In this context, the relationships between agriculture and biodiversity can be addressed from three types of perspectives:

- A perspective that emphasises the protection of, and exclusion of agriculture from, high ecological value environments, and which proposes a spatial specialisation of land uses, with agriculture being able to intensify its production, with lower levels of protection for biodiversity, in those areas that it exploits. This perspective operates on the assumption that there exists an antagonism between biodiversity and agriculture, and that neither can develop other than in separate areas.

- A perspective that emphasises the conservation of biodiversity in agricultural areas and which seeks to promote agricultural practices which limit negative impacts on biodiversity and which are acceptable to farmers. This perspective aims to manage the coexistence of agriculture and biodiversity through negotiating compromises between the objectives of agricultural production and the preservation of biodiversity.

- A perspective based on the better integration of biodiversity into agricultural production systems which attempts to, not only limit the impacts of agriculture on biodiversity, but also to better utilise the possible benefits of biodiversity for production activities. This third approach which associates both protection and utilitarian views of biodiversity is based on the assumption that synergies existing between biodiversity and agriculture can be exploited and encouraged. In this case, the benefits that biodiversity can provide to farmers can contribute to their motivation to implement agricultural practices favourable for biodiversity.

This present interdisciplinary scientific assessment has synthesised and analysed the available scientific knowledge in the light of these three perspectives and in accordance with the terms of reference defined by the ministries of agriculture and ecology. This assessment has taken into account the diverse dimensions of biodiversity, its intrinsic value, the services that it provides in the functioning of ecosystems, and more generally, its aesthetic and cultural values. It has been particularly concerned with biodiversity associated with agricultural activities, whose persistence or disappearance is closely linked with agriculture and which at the same time constitutes a source of ecosystem functions which could be maintained and utilised to develop more sustainable agricultural systems.

1. The effects of agriculture on biodiversity

A close historical relationship between agriculture and biodiversity

Biodiversity and agriculture are indivisibly linked in Western European countries due to the large surface area occupied by agriculture, and the historical role of agriculture in the evolution of biodiversity in these areas. In France, for example, agricultural areas represent the majority of the country's surface area (60%). Historically, the positive effects of agriculture on biodiversity in Europe have been linked to the diversification of landscapes, and especially the creation and maintenance of open areas hosting high biodiversity levels. The issue today is focused on the effects of more recent changes in agriculture, and in particular on the negative effects due to the intensification and specialisation of production modes. These changes have resulted in increases in the productivity of cropped areas, via the use of mineral fertilisers and synthetic pesticides, and correspondingly, in the simplification of agricultural landscapes resulting from specialisation on a limited number of production systems and the loss of non-productive areas.

Today, strong and confirmed effects of agriculture on biodiversity

A conclusion of the existence of strong, worldwide effects, both negative and positive, of agriculture on biodiversity has been established at different levels of organisation and at different spatial scales, in the context of, in particular, Europe-wide studies that have investigated the effects of agricultural practices and landscape characteristics on the diversity of a wide range of organisms.

The negative effects at the plot level are linked to an intensification and homogenisation of practices that modify environmental conditions by creating intense and frequent disturbances (fertilisation, pesticide treatments, irrigation and drainage, soil cultivation…). At the landscape scale, the negative effects are linked primarily to landscape homogenisation, in particular due to the major decreases in the area of semi-natural elements (including wooded areas, semi-natural grasslands, hedgerows and field margins) at the interface of agricultural areas, as well as the homogenisation of practices (a decreased diversity of crops both over time and in space, synchronisation of the dates of harvest or mowing…). The environmental conditions imposed by intensive practices have eliminated those species sensitive to disturbance or negatively impacted by nutrient enrichment. Landscape simplification has removed those species completely or partially dependent on semi-natural elements or a diversity of crops or landscape elements. Pest species are favoured by intensive agriculture in homogenous landscapes, whereas beneficial natural enemies of crops pests are favoured in complex landscapes and low intensity agriculture. In general, agricultural intensification and landscape simplification favour common, generalist species.

In contrast, less intensive production modes have generally positive effects on biodiversity, which are largely due to lower intensities of disturbance and the greater heterogeneity of systems generated. Such practices are, in a wide variety of situations, beneficial for species richness. These positive effects are in particular observed in the context of complex landscapes, which in turn play a role as reservoirs for increased biological diversity at the regional scale.

Are compromises required for biodiversity conservation in agricultural areas?

On the basis of the mechanistic explanations provided above, this assessment has identified three major trends which have, over the last few decades, had strong negative impacts on biodiversity. These are the intensification of agricultural practices occurring in numerous regions, the retreat or abandonment of agricultural activities in other areas, and the simplification / homogenisation of landscapes that has occurred particularly in bocage areas. These trends can lead to conflicts between biodiversity and intensive, specialised and simplified agriculture, leading to the search for compromises and mechanisms for the preservation of biodiversity in agricultural areas alongside agriculture. This assessment has shown that landscape complexity plays an essential role in biodiversity conservation in agricultural areas through its capacity to reduce, and even compensate, for the negative effects of intensive production systems. It would thus be possible to propose landscape management methods that would allow the preservation / restoration of biodiversity depending on the intensity of local production systems. It should be emphasised that restoration measures are only possible if the process of biodiversity modification is reversible, high levels of landscape simplification reduce the possibilities for reversibility and the capacity for restoration.

Going beyond these conclusions, this assessment has also shown that it is essential to consider the role played by biodiversity in agricultural systems as a provider of ecological services, and a cause of losses. It is also essential, following the third perspective advocating greater integration presented above, to analyse the possibilities of developing practices to benefit from the possible synergies between biodiversity and agriculture.

2. Integrating biodiversity into the process of agricultural production: benefits and conditions for achievement

Services provided by biodiversity

Biodiversity provides three levels of ecosystem services: those which contribute directly to agricultural revenue (production, product quality); those which contribute to the maintenance of ecosystem functions via biotic regulation (natural enemies of pest species, pollinators…) or via the provision of resources to plants (soil fertility and physical stability…); and those which result in benefits beyond direct agricultural revenue (water quality, climate regulation…).

Production services, plant and animal
The role of biodiversity for these services is important, most particularly in grasslands where the opportunities to benefit from functional complementarities between species, such as associations between grasses and legumes (plant species that can fix atmospheric nitrogen which can benefit other surrounding plants) are marked. The positive effects of functional complementarities between species on production can also be observed in crop rotations, with increased effectiveness in low intensity systems. The botanical diversity of grasslands and rangelands also has a significant effect on stimulating the appetite, and thus the ingestion, of domesticated herbivores. This floristic diversity, or at least the presence of particular species, can also improve the organoleptic characteristics and thus the taste of cheeses. The benefits of these services are already, at least partly, recognised and used by some types of agriculture; and such utilisation could be increased in the context of a greater integration between biodiversity and agriculture.

The services of pollination and pest control by their natural enemies
This analysis has confirmed the benefits to agriculture of the services of pollination and pest control by natural enemies, provided by biodiversity of some key insect groups, for example bees and hoverflies. These insect groups require semi-natural areas for their reproduction and survival, and thus the maintenance of these ecosystem services depends not only on limiting pesticide use, but also on a landscape context in which suitable areas for the maintenance of "source" populations exist (this also includes the adoption of appropriate management techniques for non-productive landscape elements adjoining agricultural areas). These services can, in addition, reduce the costs of agricultural inputs and avoid management failures, such as the development of pesticide resistant organisms.

Services of resource provision for plant populations
These services, which include in particular the maintenance of soil physical stability and fertility – and thus the provision of mineral elements and water to crops, are primarily provided by the biodiversity of soil fauna and microorganisms, but also by that of the flora. As these organisms are highly sensitive to fertilisation and soil cultivation, intensive practices employing these techniques reduce both the level of ecosystem services provided by biodiversity and their agronomic usefulness in intensive contexts. The benefits of these services may be difficult to obtain if they are not accompanied by appropriate, and often innovative, management methods (additions of organic matter, more efficient uses of water resources and nutrients through the use of appropriate varietal choices and adapted practices…).

Services not directly contributing to agricultural revenue
Biodiversity provides essential services outside of agricultural production and revenue in its strict sense, via, for example limiting the pollution of the water table. Some of these services can be /could benefit farmers more directly through a recognition of the role of agriculture in terms of the maintenance of open landscapes corresponding to the desires of citizens, through schemes for the payment of farmers for the maintenance of biodiversity (for example, through compensation mechanisms), etc.

The published results on which this assessment is based have been carried out to test hypotheses in the context of experimental studies developed often without reference to agricultural situations, and are consequently often far removed from real management conditions on farms and in agricultural areas. Nevertheless, it is obvious from the information currently available that a moderate intensification of agriculture, leaving a place for a diversity of key organisms would allow the preservation of important ecosystem services to the benefit of agriculture. At this stage, it is thus necessary to determine to what extent these services are integrated into the practices of farmers, and to analyse the possibilities for a more systematic use of biodiversity for the services that it can provide.

From limiting the negative effects of agriculture on biodiversity to seeking greater integration

Some technical changes seeking to decrease the effects of agriculture on biodiversity and/or benefiting from synergies between agriculture and biodiversity are already operational and have been adopted by a certain number of farmers: cropping systems using low levels of agricultural inputs, no-till methods for soil preparation and crop sowing, selective herbicide use, integrated methods of production, organic agriculture, extensive grassland management, crop diversification, etc. These practices can lead to decreases in productivity and profits relative to conventional methods; nevertheless, these losses are often compensated by the reduced expenditure on consumables involved in agricultural production (energy, fertilisers and pesticides).

In general, the integration of biodiversity and agriculture remains limited, even in the case of technical innovations described above: the adoption of techniques such as no-till soil preparation and crop sowing can be accompanied by increases in the use of pesticides and may not be of sufficient duration to be beneficial; the number of phytosanitary treatments often remains high in systems of integrated fruit production; the positive effects of organic agriculture on biodiversity depends on the characteristics of the surrounding agricultural landscape, etc.

In reality, the implementation of practices to effectively limit the negative impacts of agriculture on biodiversity and to utilise the ecosystem services it offers requires profound modifications of agricultural systems and methods of production (rotations, maintenance of permanent soil cover, significant reductions in pesticide use, etc.). Such modifications need to be accompanied by the appropriate management of agricultural areas at the level of landscapes and regions. In other words, by a systematic approach integrating different levels of organisation of both productive and semi-natural biological systems. In most cases, these modifications impose on farmers a greater degree of technical complexity and a greater workload. In the case of broad-acre cropping, changes in production methods will, in particular, require a major re-structuring of the landscape. These changes depend on the availability of new technical information, which is currently insufficiently developed or not widely available.

Opportunities to better preserve and utilise biodiversity in agricultural areas

Current scientific knowledge makes it possible to propose a number of possibilities to better integrate biodiversity and agriculture depending on the production system and on the regional context; such suggestions include:

- In cereal production regions such as Beauce, Brie, Champagne or Lauragais, the establishment of new semi-natural elements (perennial grass strips, semi-natural grasslands, hedgerows, copses, ponds…), connected with those already in place would be useful. Simultaneously, agricultural practices should move towards integrated production systems limiting the use of fertilisers, pesticides and soil ploughing… The implementation of long and diverse rotations, a more heterogeneous distribution of crops throughout the region, the use of companion cropping, the use of intermediate crops, the use of varietal types less susceptible to disease as well as the targeting of lower levels of production better adapted to the potential of the land appear as key elements to be considered.
- In bocage areas, where the landscape mosaic is complex, it is important to maintain the quality of semi-natural elements, in particular those at the margins of fields (rocky borders and hedgerows) subject to strong pressure from agricultural activities. It is also necessary to re-establish connectivity between semi-natural elements when removals of rocky borders or hedgerows have been too great.

- In areas of intensive grazing dominated by grasslands, such as in some parts of the Jura, the most important measures to allow the preservation and improvement of biodiversity are reductions in the amounts of fertiliser used and changes in management methods, with a reduction in stocking rates, decreases in mowing frequency and delays in the date of the first exploitation of some fields. In general, in regions dominated by permanent grasslands, the major challenges vary depending on the geographical and agricultural context, (i) in the choice of the intensification level for grassland management and fodder production systems in the areas where this is possible (plains, humid foothills, regions with an oceanic climate), and (ii) the choice of production systems, in particular the proportion of permanent grasslands as compared to fodder production systems (such as corn destined for silage) and crops.
- In arboriculture areas, such as in south-western France for example, the primary challenge is the reduction in pesticide use and the development of integrated fruit production systems to preserve and benefit from biodiversity, and also increase the diversity of plant species present through the inclusion of grassy / flowering strips in orchards.
- In mountainous regions in southern and central France, agricultural abandonment can lead to biodiversity losses that can only be avoided through the maintenance of "appropriate agricultural activities" over at least part of this area, while ensuring that a diversity of land uses remains in the region.

In all of these cases, it is not only the agricultural practices, but also the totality of the production systems and the spatial organisation of land uses at the regional scale that needs to be considered.

Conversion to organic agriculture

While the specifications of organic agriculture do not make explicit reference to the preservation of biodiversity, this production mode which excludes the use of synthetic pesticides and fertilisers can be considered as being favourable for biodiversity. After a period of strong growth at the beginning of the last decade, the development of organic agriculture has significantly slowed down in France since 2002, with the surface area under organic agriculture representing 2% of the useful agricultural surface of the country. The causes of this slowdown are multiple, and difficult to place into a hierarchy on the basis of existing scientific knowledge: technical difficulties (difficulties in pest control, in the supply of organic fertilisers, yield fluctuations…), poorly adapted methods for the assessment of inputs, insufficient varietal selection , insufficient research effort coupled with the complexity of research and development programmes for organic agriculture, unmet needs for farmer and technical advisor training, insufficient governmental financial incentives both in absolute and relative terms (i.e., in comparison with assistance and revenue that could be expected if the farm was managed under conventional agriculture), decreased financial rewards due to insufficiently high market prices, etc. Numerous studies in other countries such as the United States, Canada or the Netherlands have however shown economic results similar to, if not greater than, conventional agriculture, at least over the short term.

The integration of biodiversity into agriculture: a requirement for research and education for the entire industry

To be sustainable, the integration of biodiversity as a component of agricultural production should take into account a wide variety of factors and interactions; such an integration must go beyond simply taking into account the technical feasibility of the proposed measures and include economic, psychological, organisational and social factors (the maintenance of agricultural profitability over the medium and long term, integration of the measures into farm organisational schedules, the availability of educational resources and technical information for farmers, etc.).

This assessment has shown that the possibility for agriculture / biodiversity synergies being developed exists; nevertheless, it appears that in numerous situations the adaptations and changes in production methods require choices between agricultural production and the preservation of the environment, between an individual perspective and a regional one, as well as between the various industries / production methods, each with varying objectives, present in a region.

While such opportunities exist, for them to become a reality they will require that intensification occurs in a manner different to that which has occurred up until today. This means an intensification targeted on factors such as "knowledge", "education" and "technical skills", as much as on production factors which currently dominate, i.e., the consumption of intermediate inputs and materials. The factors of "time" and "workload" would also need to become more focussed on the tasks of the management of services, and in particular the direct and indirect management of biodiversity and the services it provides. These profound changes in production systems will require the participation of all stakeholders, farmers primarily, but also all of the upstream and downstream industries, research and development organisations, technical advisors, government organisations, etc.

Conflicts between the intensification of agricultural production and biodiversity depend on the degree of intensification, on the diversity of production methods present and on the landscape context. Finding an "optimal" equilibrium between these three dimensions is an important challenge for the years to come. This current assessment has shown that semi-natural areas within landscapes, whether these occur in the form of ecological corridors or mosaics, are an important factor in these equilibria. The optimal landscape structures to be promoted need to be developed taking into account local ecological and agricultural conditions.

3. Public policy measures: assessment and future opportunities

Translating the protection of biological diversity into the regulations of law and / or government policy is a difficult task. These difficulties stem from the fact that biodiversity is a multi-dimensional concept difficult to define in a simple manner. Its protection is the subject of specific legislation collectively termed "environmental law" which has in general been applied in a partial and delayed manner to agriculture, as compared to, for example, the industrial sector. A large part of these difficulties are due to the difficulties inherent in measuring biodiversity (the diverse components of biodiversity) and subsequently attributing a value to these components. It is because biodiversity does indeed have a value, and that this value is not, or only very partially, reflected in market prices that the theory of public economics justifies and legitimises the intervention of the state through public policies for biodiversity protection.

In reality, numerous policies have been simultaneously implemented for the preservation of biodiversity. Firstly there are environment specific policies (water, air, protected areas and species, pollution and risk prevention…), but also policies concerning specific industry sectors, in particular agriculture. Secondly, there are agri-environmental measures based on voluntary contracts. Thirdly, there is the Natura 2000 scheme, a central element of the European Union policies for the protection of biodiversity, which is a network of areas for the protection of plant and animal species and their habitats – again largely based on contracts, once the areas to be protected have been decided. Fourthly, there is the obligatory cross-compliance / conditionality of direct financial aid and market support from the first pillar of the common agricultural policy, which subjects the payment of this assistance to the respect of regulatory specifications (some of which relate to environmental protection) and the maintenance of agricultural areas in a good environmental and agricultural state. Cross-compliance has only been applied recently as it is an outcome of the reform of the common agricultural policy in June 2003. Fifthly, the regulatory specifications of certification schemes sometimes include measures favourable for the environment in general, and for biodiversity specifically. Within this type of measure, the certification "organic agriculture" which requires a production mode which excludes the use of chemically synthesised products (phytosanitary products and fertilisers), sometimes with negative effects on production, has demonstrated positive effects on biodiversity.

Without entering into too much detail, it is obvious that the various policy measures for the protection of biodiversity have suffered from the complexity of the relationships between agriculture and biodiversity, from insufficient knowledge of these relationships and the mechanisms underlying them, from the temporal and spatial instability of the measures, and from insufficient financial resources, in particular to "counterbalance" the higher assistance paid for the first pillar of the common agricultural policy, etc. In addition, decentralised consultation at the appropriate spatial scale at which questions as to the preservation of biodiversity are most relevant is a key factor in the effectiveness of any environmental policy as it promotes the involvement of and acceptance by, or at least the acceptability to, the various stakeholders involved of the issues, objectives and measures to be implemented. These various factors are also those upon which it is possible to act in order to increase the effectiveness of public policies for the preservation of biodiversity.

4. Research challenges

A fragmentation of scientific communities and disciplinary approaches

Better integrating biodiversity and agriculture implies bringing together around this objective the relevant scientific communities including ecology, agronomy, legal studies, economics and sociology. Each discipline approaches the question with different objectives, views, concepts and methods.

Ecology is focused on the dynamics of species and communities; consequently agriculture provides a good model system for the study of mechanisms which determine the dynamics of biodiversity in human dominated ecosystems. The scientific communities working at the plot and landscape scales rarely work together and studies integrating different levels of organisation are rare. During the 1990's, based on studies of biotic interactions (competition, mutualisms...), a considerable amount of research was carried out on the functional roles of biodiversity, primarily from the perspective of its biological characteristics. Studies investigating the "services provided by biodiversity" are carried out in an academic context, and in general conceived without direct links to plot level practices or landscape structure. These practices and landscape structure are only considered as factors external to the studied systems and used as forcing variables in models. What has only recently become apparent is the necessity to take into account dimensions relating to the management of the system and of biodiversity, in the landscape context, via a broadening of perspectives, moving from the agro-ecosystem to the socio-ecosystem (‘*socio-ecological system’*).

Agronomy has for a long time been focused on investigating the fluxes of materials and energy in the context, for example, of issues of water pollution or irrigation raised by intensive agricultural practices. Until recently, agronomic research rarely integrated biotic interactions as it was generally assumed that phytosanitary products would / should allow the resolution of problems related to biotic constraints (pests, weeds…).

Finally, social sciences approach the relationships between biodiversity and agriculture from the perspective of the economic, legal, social and political values associated with biodiversity. These studies seek to explain how such values can be taken into account in public policy and in understanding the individual behaviours of the various stakeholders.

This fragmentation of scientific communities and of disciplinary approaches explains the difficulties encountered in aggregating the pertinent knowledge from the different areas concerned by the complex question of the relationships between agriculture and biodiversity. Nevertheless, the most recent literature shows positive moves towards greater integration: ecologists have become interested in the agronomic realities of the systems that they are studying; agronomists are taking into account the implications of experimental work quantifying the contribution of agro-biodiversity to ecosystem services; and the areas of economics, legal studies and the social sciences are beginning to integrate into their work results from the biological disciplines.

A call for the scientific community to adapt and respond to the challenges

Whether it is a matter of the different perceptions of biodiversity, landscape functioning, the definition of agro-ecosystem services, or the conditions required for the implementation and acceptability of environmental policies, the questions asked today regarding the links between biodiversity, agriculture and society require interaction between the sciences of ecology, biology, agronomy and the disciplines of economics, legal studies and the social sciences.

The equilibrium between the contributions of these different disciplines depends on the question being addressed. Defining the possible ecosystems services provided by agro-ecosystems for a given geographical and agricultural situation, and the implications in terms of required changes in practices and landscape structure are primarily the domains of agronomy and of the economic and social sciences; however, the mechanisms which determine either the antagonistic or synergetic character of these services and the effects of agricultural practices and landscape structure on these services and the differing components of biodiversity are primarily the domain of ecology and agro-ecology.

If considerable attention is not focused on clarifying the interfaces between the disciplines, and in defining the priorities for each discipline as part of a strategy of cooperative construction, there is a high risk of superficiality, or possibly errors. It is urgent that a detailed analysis is carried out to define the priorities, delineate the shared topics and those particular to each discipline, so as to better define and develop future research. Dialogue between disciplines and co-operative construction are the important concepts in this process.

There exists a double challenge for research, firstly that of a reformulation of research questions and secondly that of the development of new skills. A better understanding and evaluation the effects of agriculture on biodiversity implies increasing our understanding not only of the impacts of production systems, agricultural practices and landscapes as they currently exist, but also the impacts of technical, economic and sociological constraints which determine how and what types of production activities and management of landscapes are actually implemented. Interdisciplinary research fully integrating the agro-ecological perspective with technical, economic, legal and social aspects, from the scale of the farm to that of markets is necessary. Such research could also progress understanding of the relationships between agriculture and biodiversity and, ultimately, identify potential areas of conflict that need to be taken into account to reconcile production objectives and objectives of biodiversity preservation.

Finally, it should be kept in mind that the strategies for the integration of biodiversity into agriculture are based on synergies, choices and trade-offs. In this context, a major challenge is to develop solutions adapted to local situations, whether this is at the scale of the field or landscape structure, while retaining coherence at the regional scale. Researchers are in general not used to addressing questions linked to such regional realities. Another challenge is to use research results as effectively as possible to differentiate between what is currently known and useable in the short term *versus* what should be considered as hypotheses yet to be confirmed and requiring further research. An improved dialogue between science and society will be necessary to define priorities and develop a more realistic evaluation of what scientific knowledge may be useful for developing innovations.

Important research needs

To respond to these challenges the requirements are multiple. Firstly, a scientific understanding of regional processes implies the existence of a network of observation and experimental sites (intensive study sites, observatories of environmental research…) to investigate the benefits of increased biodiversity in cultivated fields and in the landscape at relevant spatial and temporal scales: such networks should be used as meeting points for scientists from the different scientific disciplines, as well as agricultural stakeholders, politicians and wider society.

It would be useful to develop synergies between research, environmental engineering and experimental agriculture through projects associating scientists, agronomists and farmers. The adoption of innovations by farmers requires the acquisition of new technical skills and knowledge: a first challenge is then the development of innovations and making them accessible and available to farmers. A related challenge that is just as important is the recognition and exploitation of innovative practices implemented by farmers in an observational manner by researchers. To achieve these transfers of knowledge, the establishment of opportunities and the means of communication between farmers and scientists to facilitate dialogue and the sharing of experiences are necessary.

Models will play a key role in evaluating and developing scenarios of the manner in which agricultural practices impact on biodiversity, the reasons for the adoption (or the rejection) of practices and considerations upon which they are based. An important issue here is taking into account the temporal dimension of the adoption of innovations and the management of the transition phases between differing production methods. The adoption of such integrated and formalised approaches will make it possible to identify and develop appropriate policy actions, at different scales and in the differing domains of technical developments, economics and the social sciences.

Appendix. Documentation and bibliographic research

Throughout this assessment, the experts analysed a large number of scientific publications, international reports and technical documents. Five INRA information officers provided support for these experts by searching for appropriate documentation from the different sources of information, compiling a body of documentation, providing documents and formatting the list of literature references in the final report.

Principal sources of information used

Web of Science. Produced by Thomson Scientific (ex-ISI), it is "the" reference database for thousands of scientists around the world. The areas covered represent all of the disciplines in the sciences and social sciences allowing searches crossing numerous disciplinary fields as well as publications at the interface of numerous disciplines.

CAB Abstracts. Produced by CABI Publishing (Commonwealth Agricultural Bureau), this database is specialised in the theme of "agriculture" in its largest sense (plant production and crop protection, animal production and veterinary sciences, forestry, food safety, management and conservation of natural resources, rural economics and sociology).

Econlit. Produced by the American Economic Association, this database is specialised in economics and management. It contains journal articles (400 titles), monographs, chapters from collective volumes, workshop proceedings, theses and working papers.

Business Source Premier. Produced by EBSCO Publishing, this database is specialised in the areas of economics, management, business management, finance, and accounting. It gives access to the complete text of general interest journals such as Business Week, Forbes, Fortune, etc., as well as more academic journals such as the Harvard Business Review, Journal of Finance…

Francis. Produced by INIST, this database is specialised in the human and social sciences. It contains journal articles, books, theses, conference proceedings and other reports. French and European documents are given priority.

Working methods

The bibliographic databases were interrogated using complex equations combining several layers of keywords validated by the experts. Numerous rounds of interaction between the information officers and the experts were used to define the key words and refine the searches. For example, for chapter 2, the search equations used combined 292 keywords corresponding to three levels of analysis (groups, agricultural systems, parameters).

Multiple thousands of literature references were provided to the experts in the form of lists in WORD or Endnote. For example, the experts writing chapter two examined a total of 13481 references, of which only 700 were selected for citation in the report.

Some statistics for the references cited in the report

In total, more than 2000 references were selected by the experts and integrated into the report.

The experts primarily used recent publications, with 44% of the references being published in the last 5 years. They also principally cited articles appearing in international scientific journals (78%), in agreement with the definition of the exercise as a scientific assessment. The main scientific journals used were: Agriculture Ecosystems & Environment, Applied Soil Ecology, Aspects of Applied Biology, Biological Conservation, Biological Control, Conservation Biology, Ecology, Ecology Letters, Environmental Entomology, Journal of Applied Ecology, Oecologia.

The experts also made reference to books or book chapters (12%) published by the major scientific editors: Academic Press, British Crop Protection Council, Cambridge University Press, Editions Quae, Marcel Dekker, Quest Environmental, Springer, University of California Press.

The experts also made use of what is referred to as "grey literature" in the form of scientific reports edited by international institutions (OCDE, European Union Commission) (3%), conference proceedings (2%), theses (1%) and articles appearing in technical journals (4%).

It should be noted that for chapter three, the experts analysed a considerable amount of agronomic data published in reports or technical journals or presented at conferences (18%), while for chapters one and two, the experts preferentially compiled articles published in international scientific journals (84%).

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