Managing grassland for production, the environment and the landscape. Challenges at the farm and the landscape level

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Abstract

Grasslands are increasingly considered not only for their contribution to livestock production but also in their various functions with respect to the environment and the landscape. There is an accumulation of scientific evidence about the environmental functions of grasslands, such as their role in the conservation of biodiversity, in the regulation of physical and chemical fluxes in ecosystems, and the mitigation of pollution. Their role in the maintenance of landscapes of value is also important for reasons of landscape amenity and cultural heritage.

To introduce the challenges these functions bring for grassland management to both science and practice, a description of the benefits currently expected from grasslands and their role in agri-environmental and landscape public policies is given. The current scientific understanding of grassland dynamics in relation to management is then briefly addressed. An analysis of the changes occurring in grassland management practice and research in reference to the whole farm and the landscape is then provided. The diversity of grasslands and their spatial arrangement within a farm and the landscape appear from this analysis as two emergent factors of major importance in the search for sustainable development of livestock farms and the environment. The practical consequences on both livestock farmer practice and the direction of animal production research are discussed.

Keywords: Grassland; Landscape; Livestock farming systems; Farm management; Environment; Multifunctional agriculture

1. Introduction

Over a long period, permanent grasslands were mainly considered as a limiting factor for the development of more efficient livestock production systems. They are currently regarded as a land use to enhance and a resource to preserve, following the increasing recognition of their many services to the environment and society. In the two last decades, policy-driven changes in the management of intensive grassland have strongly influenced the direction of the agricultural sciences. There has also been an increased interest into grassland types widely neglected in the past, in particular “semi-natural grasslands”. According to various authors (e.g., Critchley et al., 2004; Picon-Cochard et al., 2004), this phrase is used either as a synonym for species-rich grasslands, or to de-
scribe grasslands subjected to a restricted range of management practice, not involving the regular use of inorganic fertilisers, herbicides or cultivation. It is used also to address grasslands maintained for conservation purpose (Bruinenberg et al., 2002). But despite a number of research studies and literature reviews from a variety of perspectives have been made to enhance understanding of grassland functions, the integrated understanding required to support grassland management for multifunctionality remains weak. Existing syntheses, and the knowledge and insights on which they are based, appear as “snapshot(s) of a changing scene” (Grice and Hodgkinson, 2002, quoted by Milne, 2003). An additional challenge of importance in the animal production sciences results from the spreading awareness of the need to consider grassland management in reference to systems beyond the grassland system itself, at the whole farm and the landscape level. This is the rationale for the general perspective of the Livestock Production Science special issue that this paper is part. Considering grassland management in reference to the farm and the landscape requires firstly building a comprehensive view of the diverse services they are expected to provide. The first section of the paper is devoted to a broad outlook of the current condition of European grasslands and the multiple pressures for change in their management. When considering grassland management at large scales and systems, a basic requirement is to build an understanding of the way the non-production functions conflict or can be in synergy with production at the field level. The second section of the paper is devoted to an insight into the relationship between their species composition, production and management, which appears as the core knowledge required for assessing the relationships between productive and non-productive functions. Due to the hazardous character of the enterprise within the current state of the art, the broad integrated view of grassland dynamics proposed is mainly based on a regional case study. It follows from consecutive interdisciplinary research and development projects the author has been involved in, aimed at supporting sustainable livestock farming development in the Pyrenees Mountains of France. The third section of the paper considers grassland management at the farm and the landscape level.

The term “grassland” is used in the paper to describe the variety of vegetation communities mainly or exclusively composed of herbaceous plants and used for grazing and/or mowing in livestock production systems. This approach is inspired by the literature in grassland ecology and nature conservation sciences, where the phrase “semi-natural grasslands” is commonly applied to all types of European unploughed grasslands, the qualifying “semi-natural” referring to the role of man in their establishment and species composition (see for instance Poschlod and WallisDe Vries, 2002). It reflects their main origin in the felling of primeval forests in prehistoric times and their establishment from different types of land use practice, the establishment of sown species at various times in history and the effect of management, such as grazing or mowing, on their composition. This choice follows also from the basic idea that grounds the views developed in the paper, namely that the move of grassland management towards multifunctionality calls for the adoption of a framework in which grasslands, whatever their species composition or intensity in use, are considered as a continuum.

2. Current condition of permanent grassland area in Europe and pressures for change

2.1. Grassland area and its past change

According to Eurostat (Poiret, 2004), permanent grassland occupied 44.6 million ha in 1995 in the 15 countries of European Community before enlargement, which represents 35% of their utilised agricultural land (UAA). Grassland occupies also a significant percentage of UAA in the countries of Central and Eastern Europe. It ranged for instance in 2000 from 15% and 19% for Hungary and Poland, respectively, up to 65% for the mountainous and wooded Slovenia (Habe et al., 2001; Gibon et al., 2003).

Despite this relative importance, grassland area experienced a huge reduction during the 20th century all over Europe. In Sweden for example, mown grasslands have almost ceased to exist during the period, whereas semi-natural grasslands used for grazing have become reduced by 90% (Kiviniemi and Eriksson, 1999). Most of the changes have occurred during the
last fifty years. The replacement of permanent grassland with more productive forage crops has been a major objective in agricultural development after World War II, and the ploughing up of permanent grassland in lowlands and hills is indeed as one of the most significant changes in agricultural land use since the 1960s (Poiret, 2004 op.cit.). European Community (EC) statistics report a 12% decrease in the area of permanent grassland in the 9 countries of the EC in the 20 year period between 1975 and 1995, i.e., a loss over 4 million hectares of permanent grassland. France alone lost 2.4 million hectares of grassland during the period. The greatest impact has been on land used for rearing herbivores (cattle and sheep) in the plains. High-yielding fodder crops increased in these areas, thus reducing the amount of land needed for grazing animals. The ploughing-up of grassland was accentuated by the decrease in stock rearing after the implementation of milk quotas (Poiret, 2004, op.cit.). Permanent grasslands were maintained as a major agricultural land use only in regions where harsh natural conditions hindered their ploughing up (mainly mountain and karst areas, and wetlands), and in some lowland and upland areas with an oceanic climate in Western Europe which specialised in intensive dairy or meat production. Their area nevertheless experienced in all cases some reduction and their management an array of changes.

Both the general reduction in grassland area and the changes in management practice had significantly negative impacts on the environment in Europe.

2.2. Environmental effects of past changes in grassland area and management

Evidence of the detrimental effects of the ploughing-up of permanent grassland on the environment has accumulated over the last decades. The destruction of the complex grassland ecosystems is an important feature in the ecological impacts of arable intensification in Europe in the short and long term, because of the important role these ecosystems play in many natural processes (e.g., Stoate et al., 2001). They contribute to the carbon sequestration, to the regulation of nutrient cycles, to soil quality and structural stability, to the water cycle balance and flood limitation, and they have an important value in biodiversity maintenance.

Past changes in grassland use and management brought along environmental problems where grassland areas were maintained. In lowland areas, where they received abundant organic and mineral fertilizers for intensive livestock production, this intensification contributed to water and soil pollution (Tamminga, 1996) and biodiversity loss (Atkinson and Watson, 1996). In harsh environments, where the main process has been agricultural abandonment, their encroachment with shrubs and trees contributes to increased fire risks, and loss of landscape amenity and biodiversity (MacDonald et al., 2000; Moreira et al., 2001). According to nature conservationists the twentieth century has seen a dramatic decline in the flora and fauna species richness of grassland, caused mainly by the massive reduction in their traditional use, especially during the 1950s–1980s period characterised by either intensification and ploughing out or abandonment and reforestation (Pikala, 2000; Poschlod and WallisDe Vries, 2002).

Changes in the landscape elements associated with the past development of grassland systems also occasioned detrimental impacts on the environment. All over Europe, farmers have reshaped grassland areas and modified their traditional boundaries. The impact of these processes on the environment and the landscape is increasingly recognised as important. In particular, the removal or grubbing of hedgerows contributed to the suppression of corridor habitats, which are important for the maintenance of biodiversity (Burel et al., 2004).

2.3. The growing importance of landscape considerations in science and society

Agricultural landscapes have been for a long time considered as the visual outcomes from the interaction between agriculture, natural resources and the environment. They are increasingly regarded by society and science as complex systems supporting a variety of functions of environmental or social benefit, and there is a growing awareness of the need to care for their change (Vos and Meekes, 1999). These new conceptions are commonly reflected in the landscape sciences in the phrase “landscape multifunctionality”, an important research effort being put into the sustainable development of landscapes worldwide (e.g., Helming, 2003). The approaches remain currently
diverse. A fair idea of the challenges that grassland management for landscape multifunctionality will raise in the future can be get from a glimpse into the variety in landscape concepts on which they are based. These have been described in the following categories (Brandt and Vejre, 2003):

– **Multifunctional landscapes as an expression of the many different functions of the “natural landscape”**. This approach is typical of the ecological sciences, and linked to natural ecosystems. It focuses on the fact that a “natural landscape” simultaneously regulates the local circulation of matter and energy in time and space, and acts as a habitat for many different organisms (Pickett and Cadenasso, 1995). The structure of the landscape and the natural functions influence each other.

– **Multifunctional landscapes as society’s material-ecological links between different types of land use and related land covers**. This approach is more engaged with the landscape from an anthropocentric point of view. It focuses on landscape aspects of the production of material or spiritual values for human beings. The society material-ecological links can be of mutual benefit (for example agroforestry) or conflicting (for example intensive agriculture versus preservation of ground water resources).

– **Multifunctional landscapes as the policy scene for problems related to competing and complementary types of land use**. Different types of social science are engaged in this approach. The understanding concentrates on the economical issues of mutual benefits between land use types, on the diseconomies due to different possibilities of marketing, on the legal problems linked to forms of ownership of land and land resources, and the types of regulation of land use conflicts that arise from multiple use of landscape (e.g., Primdahl, 1999; Penker and Wytrzens, 2005).

– **Multifunctional landscapes as a theatre for aesthetics, social communication and conflicts and cultural interpretation**. This approach, primarily based on the architectural and landscape planning tradition, arises also out of the social sciences as well as culture and art. Grasslands and the associated landscape components, especially hedgerows, are given a special importance in this approach, since they are components of importance in landscape aesthetics valuation. As they were a traditional land use in many places, they constitute also an important feature in the maintenance of cultural heritage (Antrop, 2004).

– **Multifunctional landscapes as all-encompassing systems**. This approach tries to integrate all the other aspects into a common frame from holistic system studies (for example Antrop, 2000; Naveh, 2001). The current state of the art in the operational linking of the landscape structure and diversity with the degree of multifunctionality is currently weak. Most of the approaches proposed deal mainly with conceptual frameworks addressing their roots in the complex relationship between social and natural systems (e.g., Gomez-Sal et al., 2003), or again the difficulties raised by the requirements of interdisciplinary research (Fry, 2001). Well-founded approaches and methods for linkage are scarce and address the question on a partial basis only (Bosshard, 1997; Dramstad et al., 2001; Gulinck et al., 2001; Brandt et al., 2002). Brandt and Vejre (2003, op.cit.) consider their development as “a new research task that will be addressed in the coming decade”. Nevertheless, as a result, landscape functions and values, which are no longer considered to be by-products of bio-physical conditions and land management regimes, are interpreted as “conscious societal demands towards the landscape supplier or producer — namely in particular the local farmer” (Wascher, 2003).

2.4. *A tentative overview of the expected functions of grassland and the consequences for their management*

The roles that, as permanent vegetation covers, grasslands play in the regulation of biochemical fluxes in ecosystems, comparable to some extent to the important ones of forests, lead to focus being placed on the enhancement of their area in the farmland, and their spatial arrangement within the landscape and the watershed, in order to maximise their efficiency as a sink for carbon and nitrogen, and a regulating factor in the circulation of water, the fixation of soils and the filtering of pollutants (e.g., Desjardins et al., 2001). The importance of grasslands in biodiversity conservation brings up additional specific objectives with
respect to their management practice. The ecological sciences have invested much effort in the study of the habitat requirements of a wide range of flora and fauna species related to grasslands. Despite integrated approach for conservation management remains a problematic issue because of some conflicting requirements between species and scales (WallisDe Vries et al., 2002), it has resulted in recommendations for grassland management which include generally reduced fertilizer and pesticide application, and also target sward characteristics at given periods in the year (e.g., Di Giulio et al., 2001; Watkinson and Ormerod, 2001). The pattern of land cover at the landscape level appear also as an important factor in the conservation of habitats (Burel and Baudry, 1995; Waldhardt et al., 2004), the enhancement of the semi-natural grassland area and the recreation of landscape heterogeneity being often considered as the key to restoring or sustaining biodiversity (Benton et al., 2003). In intensive livestock production areas, the reduction of fertilizer application (nitrogen and phosphorus) constitutes a way of increasing the grassland conservation value whilst at the same time it reduces the environmental impact on water and air (e.g., Watson and Foy, 2001; Vickery et al., 2001; Dennis, 2003; Nevens and Rehuel, 2003; Zechmeister et al., 2003). In harsh environments where there is encroachment with shrubs and trees, the mitigation of fire risks and nature conservation objectives contribute to joint objectives with respect to the maintenance of grassland area, their spatial arrangement within the landscape, and the periods and intensity of their use (Caraveli, 2000; WallisDe Vries et al., 2002 op. cit.).

2.4.1. The search for landscape benefit

It is difficult to judge what the importance of societal objectives with respect to the control of landscape change and the impact on grassland management will be in the future. Various research and development initiatives, in particular the important OECD effort into the assessment of agricultural landscape change, and the current emergence of landscape policies at European Union and other countries (see Section 2.5. of the paper), support the idea that landscape management and planning will become an increasingly important feature in rural development, in reference to the environmental and the other recognised landscape functions.

The societal interest in recreation and the cultural values attached to landscape, such as aesthetics and natural heritage (Naveh, 1998), may lead to specific objectives with respect to the restoration of grassland areas and their spatial arrangement within the landscape (Bender et al., 2005). Landscape patchiness and heterogeneity, which depend upon spatial arrangement of the landscape elements, as well as the nature of these elements, such as carefully managed hedges, are increasingly recognised as important factors not only in the ecosystem functions but also in the appreciation of the landscape aesthetics and stewardship. Natural heritage conservation objectives lead additionally to attempts to restore “traditional” grassland management practices (Norderhaug et al., 2000; Antrop, 2004 op.cit.).

2.4.2. New expectations with respect to grassland ecosystem services in animal production

New conceptions of grasslands and their role follow also from changes in societal views of livestock production, and from recent animal research advances. The search for reducing agricultural surpluses led the EU to promote livestock production extensification and a decrease in stocking rates on grasslands. The new societal and consumer concerns for animal welfare and healthy and natural animal production practice contributed to upgrade the interest in alternative livestock systems to intensive production, such as organic livestock production, which are regarded also to favour biodiversity maintenance (Hermansen and Zervas, 2004), and can help matching production efficiency and the control of nutrient flows (Steinshamn et al., in press). The value of species-rich grasslands is also reinforced by the increased interest of consumers in site-specific and origin-labelled products, and the growing scientific evidence of the role of local grassland flora on various sensory characteristics of both cheese and meat products, such as colour and flavour (Coulon et al., 2004; and Priolo et al., 2001 for cheese and meat, respectively).

2.5. The changes in public agricultural policy in relation to the approach to grasslands and their management

The series of reforms in European public policy since the beginning of the 1990s play an important
role in the promotion of the restoration of grassland area and the application of changes in their management.

2.5.1. The extensification and agri-environmental policy in the 1990s

Incentives for extensification of livestock production encouraged changes in management with reductions in stocking rate and fertilizer application, and the CAP 1992 agri-environmental regulation (EC/2078/1992) promoted agricultural practice compatible with environment protection and conservation of nature and landscape. The design and implementation of the resulting national agri-environmental schemes (AES) modified deeply the direction of grassland system development at the EU countries. The most important changes were in (i) the regulations and incentives to limit grassland fertilizer application and modify manure management, in order to reduce nutrient losses and mitigate soil and water pollution, and (ii) the delineation of sensitive areas, with incentive measures for the maintenance of biodiversity and landscape (increase in grassland area, enhancement of species-rich grasslands and control of encroachment, for example). The proportion of agricultural land under agri-environmental agreements in the European regions provides a fair idea of the acceptance of farmland management for objectives other than production at the end of the 1990s. Approximately one in every seven farmers in the European Union were participating in some form of agri-environment scheme, covering an area of more than 20% of the EU farmland (European Union, 1998a).

2.5.2. The recent reforms of agriculture and rural development policies

The policy pressure for the delivery of environmental and other public goods by agriculture has steadily increased. Cross compliance is now being included in EU agricultural regulations. In both the Rural Development Regulations introduced with Agenda 2000 and the Second Pillar of the 2003 CAP reform, the promotion of agri-environment schemes is a compulsory element of the rural development programmes of the member states, requiring voluntary commitment of farmers in the management of the environment and the landscape (EU, 2002). The CAP reform strengthens the connection between agricultural policy and a new approach to rural development, in which the landscape is also given special emphasis. It aims explicitly at “preparing farmers for qualitative reorientation of production, to the application of production practices compatible with the maintenance and enhancement of the landscape, the protection of the environment, hygiene standards and animal welfare and acquisition of the skills needed to enable them to manage an economically viable farm” (Article 9 in EC/1257/1999, EU, 1998b).

2.5.3. The emergence of landscape policy

The growing awareness worldwide of the need to care for landscapes has resulted in recent years in the adoption of a specific landscape policy in various EU and non-EU countries. At the European Landscape Convention (Council of Europe, 2000), which defines the landscape policy framework at EU level, the landscape is said to “(have) an important public interest role in the cultural, ecological, environmental and social fields, and (to constitute) a resource favourable to economic activity. (… It contributes) to the formation of local cultures and is a basic component of the European natural and cultural heritage, contributing to human well-being and consolidation of the European identity”. The convention considers “landscape protection, management and planning (…) as a societal requirement that can contribute to job creation, in urban areas and in the countryside, in degraded areas as well as in areas of high quality, in areas recognised as being of outstanding beauty as well as everyday areas”. Such a view, which grounds most of the national landscape policies, contributes also to reinforcing landscape issues for grassland management.

2.5.4. The development of systems and tools for monitoring environment and landscape change

Due to the societal and political changes in progress, there is effort being expended into the development of reliable sets of indicators for monitoring environmental and landscape change (cf. particularly OECD, 2001), and practical instruments for environmental impact assessment (EIA) at the farm level (e.g., Haas et al. (2001); van der Werf and Petit (2002), Braband et al. (2003); Halberg et al., this volume). Such systems and tools meet a variety of objectives, from the documentation and assessment
of the general changes under progress, to the assessment and evaluation of the programmes and schemes implemented, and the control of farmer compliance with prescriptions. They can be used also for tuning financial support to farmers, in order to stimulate more efficiently the adoption of desired change in management (e.g., the EcoPoints method in Austria, van der Werf and Petit, 2002 op.cit.). The ex post and ex ante assessment of the efficiency of the changes applied with respect to their environmental and landscape objectives is an important rationale for the EIA development: up to now, the design of prescribed changes in grassland management practice for non-production objectives relies mainly upon expert opinion, due to the lack of consolidated scientific knowledge in the area.

3. The agro-ecological basis of grassland management for multifunctionality

The investigation of the relationships between grassland production and non-production functions has produced research studies and literature reviews on a wide array of new issues:

– the short-and long-term changes in grassland species composition and production according to management to elicit the impacts of reduced fertilizer application on animal nutrition and N balance (Peyraud and Astigarraga, 1998) and/or the possibilities to sustain species-rich vegetation (e.g., Hulme et al., 1999; Barthram et al., 2002; Marriott et al., 2003);
– the role of pasture vegetation, management practices and grazing behaviour on vegetation and faunal diversity on both marginal and intensive livestock production areas in relation to biodiversity conservation (Rook and Tallowin, 2003; Rook et al., 2004);
– the spatial organisation and the dynamics of plant–animal grazing interactions at a variety of scales to support the manipulation of grazed landscapes to balance diversity, heterogeneity and agricultural performance (Parsons et al., 2001; Parsons and Dumont, 2003);
– the production and feeding value of species-rich grasslands in support to their integration in livestock production (Daccord, 1991; Wilman and Riley, 1993; Bruinenberg et al., 2002).

Research advances emphasis increasingly the importance of grassland heterogeneity in management for multifunctionality and, at the same time, the many gaps in knowledge that currently hamper the integrated understanding of grassland dynamics. They bring out, however, a growing evidence that species-rich grasslands can be not only of benefit for the environment but also suitable for production (Donath et al., 2004); they could “even (be) of practical use in ruminant nutrition systems (…) in intensive livestock production” (Bruinenberg et al., 2002 op.cit.). An outstanding general result of recent grassland research in agricultural science is the large convergence in current thinking about the pathways for further progress in understanding and implementation (Milne, 2003): (i) the general adoption of a view of grasslands and their management as complex ecosystems driven by human activities, (ii) the need to undertake research in multidisciplinary teams and to develop a variety of research methods from the monitoring of change to computer modelling, (iii) for their address at a variety of scales, and (iv) a search for strategies for integrating farmer knowledge with scientific knowledge (e.g., Millar and Curtis, 1999).

3.1. An insight into the relationships between grass production and grassland species composition

The challenges raised by grassland management for multifunctionality at the farm and the landscape level cannot however be appraised without a broad general understanding of the agro-ecological basis of grassland dynamics. The solution adopted in the paper is to use a regional case study for proposing a simple overview of two among the major questions for multifunctional grassland management namely (i) the relationship between grass production and grassland species composition and (ii) the species composition change in relation to grassland management. The views presented follow from a study of Pyrenean grasslands run by an INRA-SAD Toulouse interdisciplinary research group from 1976 to 1998, within a series of R and D projects in support of the sustainable development of local livestock farming. Grassland dynamics over a wide range of vegetation communi-
ties and management practices were analysed from a set of field observations and experiments in two valleys (Couserans and Luchonnais; grassland altitudes from 500 m to 1350 m a.s.l.). Most of the illustrations presented in the paper are taken from the resulting regional guidebook for grassland agro-ecological assessment and management practice support (Gibon, 1997; Duru et al., 1998).

Pyrenean grasslands, which range from "intensive" meadow grasslands to "extensive" dual-purpose and pasture grasslands, present a wide variety in species composition. The average number of species at a field scale is 31 and 38, respectively in the two valleys, the total number of species in the grassland area in each valley being 130 and 217 species, respectively (Gibon et al., 2004). The grassland diversity organises into five main categories of intensiveness using an assessment method developed by Balent (1991). An indication of their respective species composition and productivity is given in Table 1.

The variation in their grass production appears to fit a general scheme over the range of local grasslands as illustrated for first growth cycle in Fig. 1.

The more intensive the grassland and its management, the higher are the growth rates at the beginning of the growth cycle and the greater the standing

Table 1
An overview of the variety in Pyrenean grasslands (adapted from Gibon, 1997)

<table>
<thead>
<tr>
<th>Dominant species</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 Lolium Perenne, Trifolium repens, Dactylis glomerata, Plantago lanceolata, Poa trivialis, Taraxacum officinalis...</td>
<td>Very intensive grassland with very nutrient-rich soil, abundant fertilizer application and very intensive use. Potential annual crop yield: &gt;12 t DM/ha/year</td>
</tr>
<tr>
<td>Type 2 Dactylis glomerata, Trifolium repens, Trifolium pratense, Agrostis capillaris, Plantago lanceolata, Holcus lanatus, Poa pratensis, Taraxacum officinalis...</td>
<td>Typical fertile grassland with intensive fertilizer application and use. Potential annual crop yield: &gt;10,5–12 t DM/ha/year</td>
</tr>
<tr>
<td>Type 3 Dactylis glomerata, Agrostis capillaris, Stellaria graminea, Taraxacum officinalis, Plantago lanceolata, Trifolium repens...</td>
<td>Medium type grassland with moderate fertilizer application. Potential annual crop yield: 6,5–10, 5 t DM/ha/year</td>
</tr>
<tr>
<td>Type 4 Festuca rubra, Agrostis capillaris, Cynosorus cristatus, Lotus corniculatus, Sanguisorba minor...</td>
<td>Extensive grasslands with little or no fertilizer application. Potential annual crop yield: 4–6, 5 t DM/ha/year</td>
</tr>
<tr>
<td>Type 5 Festuca rubra, Brachypodium pinnatum, Origanum vulgare, Thymus serpyllum, Genista tinctoria, shrubs...</td>
<td>Very extensive grasslands at the stage before encroachment with shrubs and trees. Potential annual crop: &lt;4 t DM/ha/year</td>
</tr>
</tbody>
</table>

![Fig. 1. Schematised dynamics of grass production according to grassland types during first growth cycle in the Pyrenees (adapted from Gibon, 1997; Duru et al., 1998). Legend: non-limiting plant nutrition conditions; ---: grassland type 2; ------: grassland type 4 (see Table 1 for detail).]
herbage peak obtained, but also the earlier is the maximum reached in the season and the more rapid is the following decrease in the quantity of the standing crop (Fig. 1a). The nitrogen contents of the herbage are on average higher in the intensive than the extensive grasslands (Fig. 1c), as expected from literature (e.g., Craine et al., 2002). However, the large difference observed at the beginning of the season reduces over the growth cycle and then disappears. The organic matter (OM) digestibility of the herbage, which is much higher at the beginning of the growth cycle in intensive than extensive grasslands, has a higher rate of decrease, which leads to an opposite situation late in the growth cycle (Fig. 1b). As illustrated in Fig. 1d and e., such phenomena follow for a large part from differences in the physiology and the composition of the various species, in plant architecture as well as development patterns (see Poorter and Remkes, 1990; Duru, 1997; Craine et al., 2002 op.cit.). This leads to a wide diversity in grass production patterns over time and composition at a similar stage of maturity, in relation to, among others, the proportion of leaves and stems and the dynamics of senescence that relies on the length of the leaf lifespan and turn-over. Observed variation in OM digestibility follows from differences in the composition of the plant tissues. The lignin and cellulose contents, which vary among species at a similar maturity stage, exhibit also differences in their dynamics of change over time (see for instance Wilman and Riley, 1993 op. cit.; Bruinenberg et al., 2002 op.cit.).

Variations observed locally in grass production according to grassland species-composition can therefore be regarded as part of a continuum encompassing from the most extensive grasslands to the most intensive ones, in relation to their species composition.

3.2. An insight into grassland species composition and dynamics according to management practice

In many regions, human activity appears to have a much greater impact on species richness than do biophysical factors (e.g., McIntyre et al. (2003) in Australia). High-diversity grasslands are usually associated with traditional extensive farming systems (e.g., Bignal and McCracken, 2000). Elevated soil

Fig. 2. Determining factors of plant species assemblages (adapted from Balent et al., 1999).
phosphorus contents following long-lasting intensive management appear as an important factor in the reduction in their species richness and a difficulty for restoration as well (Critchley et al., 2002). Despite the current lack of integrated understanding of the general relationships between vegetation composition change and management practice, general patterns of grassland species composition can be appraised from the integrative framework provided by the species assemblage theory (Diamond, 1975) currently developing in grassland ecology (Eriksson and Eriksson, 1998), as illustrated below from the Pyrenees case study. According to this theory, the local variety of plant species assemblages in grassland vegetation communities is encompassed into a local-specific pool of plant species, inherited from the local natural environment and the land use history (Fig. 2). At the field level, habitat factors, such as soil characteristics and landscape fragmentation, and management factors, including fertilizer application and regimes of defoliation, act together as an environmental filter that determines the actual possibility for the species in the pool to be part of the species assemblage observed. The taxonomic diversity of grassland communities has, therefore, strong linkages with their ecological and functional diversity (Balent et al., 1999).

The variations of Pyrenean grassland community composition according to management practice have been investigated and modelled by Balent (1991). Within the range of soil conditions at the valleys studied, the composition of the plant species association depends closely on the grassland management practice, the major driving factors being the soil nutrients contents following from past and current fertilizer practice and the intensity of the biomass removal applied through grazing and mowing practice (Fig. 3). The impacts of changes in management practice (intensity of grassland use or fertilizer application), which were hypothetised from this empirical model, have been verified from diachronic studies over 20 years (Balent and Alard, submitted for publication). They follow the general framework illustrated in the Fig. 3.

At any stage in the succession, when the management practice applied is in balance with vegetation composition and edaphic conditions, in particular when fertilizer application and biomass offtake allow a balance between vegetation uptake and nutrient content of the soil, the vegetation composition is “stable”. It remains unchanged over time, with only small fluctuations around an equilibrium composition. At a given intensity of use, when the management includes insufficient application of fertilizer with respect to biomass offtake intensity, a depletion of soil nutrients occurs, grass production decreases over years, and the vegetation composition moves towards one of the less productive communities in the succession. Conversely, high application rates of fertilizer with regard to the equilibrium described above leads to an increase in soil nutrient content and supply, and consequently in grass production, and the vegetation composition moves towards one of the more productive grasslands in the succession. A decrease in intensity of use without a
change in plant nutrition conditions generates en-croachment by shrubs and trees. Therefore it can be considered that, within a given vegetation succession, a new equilibrium can be reached between vegetation composition and management practice following a change in management. This equilibrium will determine the “final” grassland value for production and non-production functions. Such a reference framework supports an understanding of how changes in local management practice through modifying fertilizer application and intensity of grassland use can contribute to a new equilibrium being reached (Gibon, 1997 op.cit.). Whilst it is of limited value for management decision-making at the whole-farm level during the period when changes are applied, it contributes a useful support for designing farm management scenarios at the time horizon at which the new balance will establish (Gibon et al., 1999a).

4. Grassland management in reference to the whole farm and the landscape level

4.1. Ongoing changes in the approach of grassland management in animal production sciences

Despite assessments of agri-environmental schemes (AES) regulating grassland management and fertiliser use at European level resulted in an acknowledgement of their global beneficial impact on practice improvement and protection effects (e.g., Primdahl et al., 2003), reviews covering in a range of local schemes over Europe (see also Kleijn and Sutherland, 2003), as well as local AES assessments, also questioned their environmental effectiveness and/or the impacts of the management changes prescribed on farm economics. From assessments of AES implemented on Dutch dairy farms for control of nutrient flows, Berensten and Tiessink (2003) and Westhoek et al. (2004) stressed the negative impacts of an accumulation of contradictory schemes on effectiveness in achieving environmental objectives and on farm economics. They recommended an improved integration of measures, and to leave more room for farmer choice in the achievement of the desired changes. From an assessment of AES for biodiversity conservation in UK lowland grasslands, Critchley et al. (2004) recommended a greater use of site-specific targets and prescriptions making use of traditional farmer knowledge. In a study of the AES targeted at mountain landscape protection in France, Dobremez and Perret (1998) pointed out the need to take account of the whole-farm level when designing practice prescriptions at a field scale, in order to improve the compatibility between environmental objectives and the modes of adaptation of farm management strategies. From an assessment of the relationships between grassland species richness and management in Austrian meadows, Zechmeister et al. (2003) considered that it was necessary for increasing the effectiveness of biodiversity conservation that AES provide farmers with clearly defined recommendations, and increased financial incentives to mitigate their negative impacts on farm economics. In biodiversity conservation, McCracken and Bignal (1998) considered that the “intimate and complex interactions with the annual farming cycle (…) many species have” call for a detailed understanding of how each particular farming system functions and how species reliant upon that system integrate with it.

Such examples illustrate the basic difficulties currently met in the design of AES for grassland multi-functionality: namely (i) the existence of conflicting objectives, often at different scales, which calls for an integrated understanding of how grassland systems function at the various scales concerned (Milne, 2002) and (ii) the complexity of the problems, with possible feed-backs and side-effects due to the many interactions involved between ecological processes and grassland management at the whole-farm level. The evidence of the limitations of recommendations that do not rely on a detailed understanding of how each particular farming system functions and integrates with the ecological processes is accumulating, and at the same time the awareness of the need to consider whole farm management when assessing the agri-environmental effectiveness of grassland management practice is growing. The move from a production-oriented to a sustainability approach to livestock systems, referring to short- and long-term ecological, economical and social objectives, pushed forwards a systems view of livestock farming (Gibon et al., 1999b). This view, which emerged primarily with respect to the important difficulties of livestock farming development in harsh environment areas, has spread over other grassland-based systems in Europe since the 1990s (Dent et al., 1996; Gibon et al., 1996).
patory research with farmers and cooperation with a variety of disciplines support advances towards a holistic approach to livestock farming development of interest for the assessment of the challenges of grassland management for multifunctionality. The notions of “farmer strategy” (or “family-farm type”) and “farming style”, developed respectively in French farming system research and Dutch sociology (cf. Béranger and Vissac, 1994; van der Ploeg, 1994) stress the major role of farm household values and objectives in the farm management decision-making and in farmers’ attitudes towards innovation (see also Gasson and Errington, 1993). These notions are currently applied in developing an understanding of the diversity of livestock farmer decision-making, and are increasingly used for assessing the economical and/or environmental impacts of change in grassland use in reference to farmer management practices at various scales, the whole farm, the landscape and the watershed (e.g., Gafsi and Brossier, 1997; Steyaert et al., 1997; Oenema et al., 1998; Gibon, 1999; Rougoor et al., 1999; Versteegen and Huirne, 2001; Ondersteijn et al., 2002, 2003; Duru and Hubert, 2003; de Koeijer et al., 2003).

The recognition of the adaptative character and hierarchical nature of such systems that incorporate strategic, tactical and operational decision rules led to the adoption of process-oriented approaches in farm management studies (Gibon et al., 1988) and event-driven models for the simulation of farm operation (Sorensen and Kristensen, 1992). Such notions are currently used in the development of decision support models based on scenario simulation to assist policy makers, managers and planners in assessing the best ways to develop farming systems and explore future impacts of management/policy decisions at various scales (e.g., Oglethorpe and O’Callaghan, 1995; Oglethorpe et al., 1995; Herrero et al., 1999; Cros et al., 2001; Cassell et al., 2002; Herve et al., 2002; Pacini et al., 2004).

4.2. An insight into the current understanding of grassland management at whole farm level in reference to grassland heterogeneity and the farmland spatial organisation

The development of the understanding of the spatio–temporal organisation of grassland systems at real-life farms supports the assessment of the challenges of managing grassland for multifunctionality. The agri-environment and landscape policy pressures for change on grassland management may lead to the variation in grassland vegetation composition and productivity among grassland fields at the individual farm scale, and bring in spatial and temporal prescriptions and restrictions for their use within a year. The general challenges that are raised at the farm level are illustrated here from the results of a set of regional studies of cattle and sheep livestock farms in France. They rely on a spatially-explicit approach to grassland management in relation to the variety of grassland resources of heterogeneous production value. The methods applied consist in farm monitoring or survey designs fitting into the general framework reported by Béranger and Vissac (1994 op.cit.), the building of generalised models of the farm operation year-round being a core element in the assessment of the farm management (Theau and Gibon, 1993; Fleury et al., 1996; Girard and Hubert, 1996).

These studies showed that grassland management in systems relying on heterogeneous grassland resources consists in a large set of strategic, tactical and operational decision rules, nested into a complex hierarchical system (Gibon et al., 1989; Girard et al., 1996). At the highest level in the hierarchy, it includes a provisional year-round strategic spatio–temporal planning that associates (i) the attribution to each field in the farm of a sequence of grazing/cutting and fertilizer application operations over the year on the one hand, and (ii) the spatio–temporal organisation of the grazing and harvesting practice over the fields within a sequence of well-defined consecutive management periods in the year on the other hand. Some common general principles appear to ground farmers’ strategic and tactical decisions in grassland management in the study areas considered.

The year-round sequence of grazing/cutting operations of each field is arranged in reference to the specific functions the farmer has for the particular field in the grassland system. In their decision rules for the allocation of the functions and sequences to the various fields, farmers take an account of both field-related and management period-related factors (Girard et al., 1996, op.cit.). They consider grass growth patterns, according to the grassland field condition (and also in pastoral systems the patterns of use of the
commons), but they rely also on a variety of additional issues, such as the strategic and tactical options for the organisation of hay and silage harvesting at the farm level (Viviani-Rossi et al., 1992), the options for the arrangement of the herd into functional grazing groups in the different periods in the grazing season (Ingrand and Dedieu, 1996), and the objectives and constraints in the use of labour resources throughout the year (Dedieu et al., 1997). As a result, the use of each field depends not only on its intrinsic constraints and production value but also on the overall heterogeneity of the set of grasslands fields on the farm (Gibon et al., 1989 op. cit.), and their spatial arrangement within the farmland and in the landscape (Morlon and Benoît, 1990). Their specific agronomical constraints (e.g., slope, humidity, soil depth, etc.), their accessibility to vehicles, but also geographical characteristics such as their distance from the farmstead/barns appear as general factors influencing their use in the various regions studied. Farmers preferentially use the more remote fields as a grazing area for replacement ewe lambs/heifers, or again for ewes/cows in the periods when they are barren or in early pregnancy. They generally use the fields close to the barns as a first grazing area when turning out to pasture in the spring, a period when there is close inspection of the herd. Their allocation of herd grazing groups to each field, which depends on decision rules with respect to herd reproduction, fattening and sale patterns, etc., also takes account of other factors, such as, for example, the respective size of the fields and the geographical proximity the ones have with the others (Josien et al., 1994).

These studies showed also that in extensive livestock systems farmers’ management includes a variety of strategic, tactical and operational decision rules aimed at coping with climatic uncertainty, such as the attribution of buffer functions to some fields, the manipulation of animal body reserves, or the manipulation of the times of animal sales and cullings (e.g., Gibon and Duru, 1987). The nature of the decision rules applied has a major influence on the efficiency of grassland management at farm level, as shown from computer simulation in the French Pyrenees (Charpenteau et al., 1983), and verified from experiments in the Massif Central of France (Louault et al., 1998). It is noticeable that mountain farmers with traditional management consider grassland heterogeneity as a facilitating factor for coping efficiently with climatic uncertainty (Gibon et al., 1989 op. cit.). Tradition-based grassland management does not optimise production or non-production functions at the individual field or animal, but the overall efficiency of the system at the farm level (e.g., Gibon, 1994; Santucci et al., 1994). The attitude of “traditional” farmers to innovation depends, therefore, on their assessment of its provisional impact on the balance of their grassland system, in which they consider the many inter-relationships between a variety of factors and processes. Adoption can be quick when it appears them there is no risk of a negative impact, as illustrated by the rapid uptake of round bales by farmers in the Pyrenees. Nevertheless, when they consider undergoing substantial changes, such as a significant increase in farm size, a change in herd production orientation or the fertilizer or harvesting policy, farmers can have difficulty in anticipating the overall impacts on the farm operation and the long-term effects on their grasslands. Since they consider such anticipation as essential for sound strategic decision-making, decision-support tools can provide them support in the assessment of scenarios for change (Gibon et al., 1989 op. cit.).

The inclusion in management practice of changes designed from the “outside” for environment or landscape benefit appears challenging with respect to both smooth inclusion in management practice and the achievement of expected non-production benefits. To improve the process, new systems experiments have been conducted and new models built (e.g., for grass-based intensive dairy production, Delaby and Peyraud, 2003; Ferris et al., 2003; Pulido and Leaver, 2003; Herrmann et al., 2004; for sheep and beef production: Brelurut et al., 1998; Laws et al., 2000), in addition to the effort invested in cooperation with various disciplines for developing an integrated understanding of grasslands dynamics (cf. Section 3 of the paper). The problem appears all the more difficult when there is reliance on developing practical prescriptions at the field or farm scale which tamper the spatio–temporal organisation of the grassland system. Therefore, the development of spatially-explicit models linking management and grassland system operation at the farm level, and their incorporation into decision-support tools, appear important in providing sound support in decision-making by farmers and to aid research on rural land use.

Decision support tools developed at the Macaulay
Institute in the UK, which address respectively tactical and strategic decision-making at the farm level (HILLPLAN and LADSS), provide examples of model developments that rely on the integration of a Geographical Information System (GIS) and progress in the modelling of soil, plant and animal processes within grazing systems (Milne and Sibbald, 1998).

The development of such models within participatory approaches in close cooperation with farmers appears of potential important benefit also for the scientific progress towards integrated understanding of grassland dynamics. On-farm case study experience shows that the common analysis between farmers and researchers of grassland management at the whole farm allow efficiently the identification of empirical knowledge of grassland dynamics and animal–vegetation interactions, so that researchers can then attempt to understand them better (e.g., Meuret and Dumont, 2000). Such approaches can be of particular benefit when involving farmers who have maintained a tradition-based management, the "sophisticated ecological rationality underlying their practice" (Walker and Sinclair, 1998) being increasingly acknowledged.

4.3. An insight into current approaches to grassland management at the landscape level

The growing emphasis public decision makers give to management and planning at the whole landscape makes it increasingly place for the negotiation of rural development options and the societal control of their practical application (Wiggering et al., 2003). Consequently, a wide array of methods for the projective and prospective assessment of impacts of change in agricultural land-use on landscape development is being investigated. They aim at anticipating the visual impacts of change (Lange and Bishop, 2001), supporting landscape development (Blaschke, 2002), or designing landscape-planning devices for an active control of landscape development (e.g., Dolman et al., 2001). An important scientific effort is devoted to incorporating models of land use change with GIS at various geographical scales for exploring scenarios for the future, making use of a wide range of scientific and/or expert knowledge (Bosshard, 1997; Maleczewski, 2004). The modelling approaches range from multiple goal linear programming systems, built for simulating and optimising scenarios (e.g., Zander and Kachele, 1999; Verburg et al., 2002), to multi-agent systems developed in close cooperation with local landscape stakeholders (e.g., “companion modelling”, Etienne et al., 2003). Such multi-agent systems allow the simulation of the individual strategies of land managers as well as the negotiation between land use stakeholders, and their evolution over time in reference to land use and cover change (Parker et al., 2003; Bousquet and Le Page, 2004). They appear increasingly as powerful tools for supporting negotiation between land-use stakeholders, policy-makers, managers and planners in the search for sustainable management of the natural resource at the landscape scale. At the same time, the awareness of the important role of the farm structures and farm management on landscape dynamics, not present in the first AES of the early 1990s, has widely spread (e.g., Mecus et al., 1990; Deffontaines et al., 1995; Meyer-Aurich et al., 1998; Smeding and Joenje, 1999; Kristensen et al., 2004; Thenail and Baudry, 2004). In the practice, it is therefore foreseeable that in the future landscape considerations will increasingly lead farmers to take part actively in local discussion groups that will consider landscape management or planning with the help of such tools. In the scientific area, both the development of the conceptual models of land use change and their implementation in tools for supporting the exploration of scenarios result in a growing investment in the development of interdisciplinary research between a wide range of disciplines in the natural and social sciences. This is to be regarded as falling into the worldwide research effort into the understanding of the “global change” and the investigation of the conditions for sustainable relationship between natural and social systems (e.g., Holling et al., 1998; Walker et al., 2002; Berkes et al., 2003; Lambin et al., 2003). Agricultural sciences were absent from the first developments in the area, but increasingly they are participating in the effort to bridge ecological and socio-economical systems (e.g., Fresco et al., 1994; Bouma et al., 1998; Zander and Kachele, 1999; Kropff et al., 2001; Veldkamp and Lambin, 2001; Verburg et al., 2002; Klocking et al., 2003; Munier
5. Conclusion

The changes under way in grassland management resulting from the environment and landscape objectives that society desires constitute an important challenge for both animal production practice and science. They not only could modify the direction of the development of the livestock farming systems, especially those that are intensive, but also could bring about an important change in the fundamentals of farmer practice in land management. The novelty is that the new societal and policy pressures directly address their land use strategy as far as their day-to-day practice in grassland management of each field of the farm. The aim of the paper has been to attempt to expose the new challenges it raises for sustainable management of livestock farming. In the scientific realm, the change results into a move from the idea of grassland as a resource for animal production to grassland as a complex agro-ecosystem to be managed at a variety of scales for multifunctionality. The change requires a large change in scientific thinking and research orientation in the animal production sciences. It requires a greater adoption of a systems approach, and cooperation with not only ecological sciences and economics, but also with social sciences. It also leads to develop an interest in using farmers’ knowledge of the interrelationships between grassland dynamics and management to make progress in the integrated understanding required for sustainable grassland management. Another aspect of importance in the changes under progress is the modification in the respective roles of science and policy in technological development of grassland management. In the past, political decisions followed on from progress in scientific knowledge in the development of grassland management prescriptions. Now, this has changed, induced by the societal shift towards a sustainable development paradigm. The awareness of the necessary move towards problem-oriented research and the importance of cooperation with stakeholders and policy-makers is developing in many scientific disciplines, as illustrated for instance by the evolution in the current thinking in landscape ecology. This appears increasingly as the way for sustaining scientific progress and at the same time participating efficiently in the wider effort to meet challenges induced by the search of balanced relationships between society and environment in the short and long term.

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