Agronomy Research **3**(2), 153–164, 2005

Review

Biodiversity in intensive grasslands: Effect of management, improvement and challenges

S. Plantureux[1], A. Peeters[2] and D. McCracken[3]

[1]UMR INPL(ENSAIA)-INRA Agronomie et Environnement Nancy-Colmar,
2 av. de la Forêt de Haye, 54500 Vandoeuvre, France
[2]Laboratoire d'Ecologie des Prairies, Université Catholique de Louvain, Place Croix du Sud,
5 bte 1, B-1348 Louvain-la-Neuve, Belgique
[3]Land Economy Research Group, Scottish Agricultural College, Auchincruive, Ayr KA6 5HW,
United Kingdom

Abstract. Intensified grasslands are usually the dominant type of grassland in many countries in Europe but are generally of poor ecological value. Several management factors may affect biodiversity of these grasslands including fertilisation, grazing and cutting management. Their effects on grassland biodiversity are described in this paper. In most cases, intensive and profitable grass production from semi-natural grasslands appears to be incompatible with maintaining a high level of biodiversity. Two key questions then arise: how to restore biodiversity in intensive grasslands while limiting the technical and economical consequences? How to choose the target species on an objective basis? Some solutions are considered in the paper but it is suggested that 1) new tools (i.e. indicators) are required to evaluate the functions of biodiversity and to achieve biodiversity restoration goals and 2) in the short-term the research priority is to understand and predict biodiversity at the field and farm-scale**.**

Key words: grassland, biodiversity, intensification, improvement, challenge

BIODIVERSITY AND INTENSIVE GRASSLAND: AN EMERGING CONCERN

The Rio Summit in 1992 and the resulting Convention on Biological Diversity, increased global awareness on the importance of sustainable development for wildlife protection. Agriculture is integral to achieving this goal of sustainability, not only because farming practices have the potential to destroy, protect or create biodiversity, but also because agriculture is simultaneously an economic and social activity. In the agricultural context, grasslands have been recognized as potential species-rich habitats composed of various types of plants, animals and micro-organisms.

In most countries of Europe, biodiversity in grasslands is endangered by two opposite trends: intensification of practices and abandonment. Both have led to the reduction of plant species number (Baldock, 1993; Peeters & Janssens, 1998). Within the list of important ecological habitats of the annex I of the European Council Habitat Directive, 65 pastures types are endangered by intensification of farming practices and 26 by extensification (Rook et al., 2004). However, both pressures are not uniformly widespread throughout the continent. In their report for the European Environment

Agency, Petit et al. (1998) pointed out that in western and north-western Europe grasslands have already been greatly intensified in the past, and hence little further losses in biodiversity are now expected. On the other hand, greater reduction in biodiversity caused by intensification will probably occur in the future in the northern part of central and Eastern Europe (from Austria to Estonia). In the Mediterranean countries, as well as in mountains, land abandonment from agriculture will continue to be an important pressure on biodiversity.

The substantial efforts of scientists on grassland biodiversity are relatively recent. In addition, most of the studies have been undertaken in species-rich or "high biological value" grasslands. Consequently, biodiversity of wet, calcareous or alpine grassland, is better known than for intensified grassland dominated by species such as ryegrass (*Lolium perenne* L.), cocksfoot (*Dactylis glomerata* L.) or white clover (*Trifolium repens* L.). Intensified grasslands are usually the dominant type of grassland in lowland regions, representing millions of hectares in Europe, and are frequently the main forage resource for grass-based farming systems. Therefore, restoration of grassland biodiversity at a large scale throughout Europe raises the question of biodiversity recovery in these intensive grasslands.

The aim of the present paper is to present a general overview on: i) the management factors involved in grassland intensification affecting biodiversity, ii) the possible way to restore biodiversity in improved grasslands or arable land and iii) some key questions which can be addressed about research and environmental policy. The term "intensive grassland" will principally be used to indicate high stocking rate, high fertilizer inputs and frequent and early cutting of fodder.

1. Grassland management and biodiversity in intensive conditions

Most studies about grassland biodiversity have concentrated at the field level, or even at lower scales, when the development of landscape ecology has shown that the relevant scale for explaining species dynamics is rather the landscape level (Burel et al., 1998).At the landscape level, grasslands, including those that were intensified, are generally considered as positive for biodiversity. Interesting results were shown in this way by Feodoroff et al. (2005). They compared a gradient of land-use intensification from old-growth forest to mixed landscapes dominated by crops in Morvan Regional Park (Burgundy, France). Local species richness increases from woodland to crop to grassland for these three types of land use, indicating a better biodiversity for grassland. Local species diversity of woods and crops is higher when grasslands are surrounding these land covers. At landscape level, the highest number of species per unit of surface is found in mixed landscapes dominated by grasslands. Maintenance of permanent pastures in a landscape, even if intensified, therefore appears more beneficial for biodiversity than other types of land use. For some populations like fossorial water vole (*Arvicola terrestris scherman* Shaw), regional and local factors have been identified as being important (Giraudoux et al., 1997). The ratio of ploughed land and of permanent grassland to farmland is a key factor, but local practices like sward height management, linked to intensification of grazing, also appear crucial.

At the field level, several management factors may affect biodiversity of grasslands: use of organic and mineral fertilizers, grazing and cutting, drainage and in some cases use of pesticides, anthelmintics, ploughing and reseeding. The most studied effects concern those vascular plants, but all forms of life are influenced by the quality of the habitats. These various factors interact, for example for farmland birds in the UK. Their population decreases were linked to large-scale temporal changes in invertebrate numbers and seed resources (McCracken & Tallowin, 2005).

a) Fertilisation

Fertilizer supplies result in an increase in nutrient availability for plants. In this condition, only a few fast growing plant species can compete for light, eliminating less competitive plants. This results in a decrease in the species richness. On the other hand, in very poor soils, only a few slow-growing species are able to compete for nutrients. Consequently, higher biodiversity is usually observed for intermediate situations (Al Mufti et al., 1977; Grime, 1979) where the competition is lower and where a large number of mesotrophic species can coexist with some oligotrophic and some eutrophic species. However, the question of the determination of threshold levels is very complex because of the variety of soil, climate and type of fertilizer. From different studies, it appears that a significant reduction in plant diversity is generally observed even for fertilizer levels which are very low in comparison to the normal application rates in intensive grasslands. For nitrogen, a reduction of half of the total number of plant species can be observed for fertilisations between 20 and 50 kg $N.ha^{-1}.year^{-1}$. Tallowin (unpublished) observed that the average number of forb species was very low where nitrogen inputs exceeded 75 kg $N.ha^{-1}.year^{-1}$. High forb diversity was only found in grasslands receiving less than 75 kg $N.ha^{-1}.year^{-1}$. The influence of soil available phosphorus on the number of plant species is less known but Peeters et al. (1994) and Janssens et al. (1998) have found a maximum of 10 dicots at values above 50 mg P.kg-1 of dry soil (EDTA-acetate extraction method). The potassium effect on grassland biodiversity seems to be less depressive and high number of plant species may persist with relatively high potassium soil content between 100 and 200 mg K.kg-1 dry soil as demonstrated by Peeters et al. (1994).

Substantial amounts of manure may also influence the species composition of grasslands. Beside the nutrient content of these organic inputs, specific effects are related to the importation of seeds and the smothering of the sward by liquid or solid manure. In intensive grasslands, seed importation concerns a very few species of poor ecological value like broad-leaved dock (*Rumex obtusifolius* L.) or *Umbelliferae* species. The effect of covering a sward by manure is similar to the screen created by litter accumulation. Foster and Gross (1998) showed the negative effect of litter in seedling establishment of new species. A nitrogen fertilisation increased living plant and litter biomass, and reduced plant biodiversity. Litter removal resulted in an increase in species richness, proving the reality of this screen effect.

High fertilizer inputs effects are not limited to plant species as it leads to tremendous changes in chemical, biological and, indirectly, physical status of soil. Grassland soils contain an abundant and diverse micro-organism, micro- and macrofauna community. Intensive management of grassland commonly impacts negatively on the diversity as a whole, but not necessarily on the density of soil fauna (Bardgett & Cook, 1998). Intensification tends to promote low diversity in soil fauna, favouring bacterial-pathways of decomposition and dominated by bacterial-feeding fauna, whereas more extensive systems present a more diverse habitat dominated by a fungal-feeding fauna more persistent than the bacterial-feeding fauna. Moreover, interactions occur between above and belowground diversity, as shown by Benizri & Amiaud (2005). They found decreases in plant biodiversity with increasing nitrogen fertilization treatments in a grassland trial. Similarly, bacteria extracted from rhizosphere of highly fertilized plots showed a lower catabolic ability (Biolog® plates): they were not able to consume as many chemical compounds than bacteria from unfertilized treatment. The authors emphasize that it would be linked to a lower diversity in root rhizodeposit exudates by the plants in the fertilized treatment.

The addition of fertiliser can benefit some grass- or worm-eating birds such as geese and waders. However, in general the use of fertilizer not only reduces the range of potential invertebrate preys in the sward (through a reduction in plant diversity) but the resulting tall and dense vegetation also limits access to food by birds into these swards.

b) Grazing and cutting management

The primary role of grazing animals in grassland biodiversity management is maintenance and enhancement of sward structural heterogeneity, and thus botanical and faunal diversity, by selective defoliation due to dietary choices, treading, nutrient cycling and propagule dispersal (Rook & Tallowin, 2003). These trends may occur in various situations including grazing at low stocking rates in extensive systems (e.g. mixed grass and forb vegetations in highlands), but also in more intensive grasslands. This phenomenon occurs after a few grazing cycles, even when the initial situation is a homogeneous sward (Garcia et al., 2005).

It is now well established that large ruminants are able to enhance plant diversity at low stocking rates, but decrease it at higher rates (Olff & Ritchie, 1998). This could explain apparent contradictions observed in the literature about grazing effects on plant biodiversity. For example, in a global survey of grassland in Lorraine (France), the two main factors explaining plant species richness and related to grazing activity were the stocking rate and the duration of re-growth between grazing periods (Plantureux, 1996). Plant diversity was limited at stocking rates above 1.5 LU.ha-1, and re-growth durations under 35 days. Conversely, in Switzerland the conversion of mown sites in alpine species-rich grasslands to grazing resulted in a loss of plant evenness and biodiversity (Fisher *& Wipf*, 2002). The mean loss reached 10 perennial plant species in 50 years of grazing. The observation scale also influences results, as shown by Balent et al. (1998): in this study, an increase in the stocking rate resulted in a higher heterogeneity and diversity of the sward at a local scale (field), but in a reduction of these parameters for larger areas (territories).

Heavy grazing produces short dense swards that generate little seed resource and offer limited foraging and shelter opportunities for many invertebrates (Morris, 2000). Low stocking rates conversely produce patches of tall rank vegetation and the accumulation of dead vegetation and litter, depressive for plant seed germination, but favourable for invertebrate species like spiders. A great diversity in bird species would be expected in such situations, but, at a very low stocking rate, the density of sward and litter layer means that invertebrates are generally not readily accessible to foraging birds. From this point of view, an intermediate stocking rate seems to be optimal for foraging birds.

Infrequent cutting management has been proved to be highly linked to species biodiversity. For example, Zechmeister et al. (2003) found that the total number of vascular plants and bryophytes of Austrian grasslands decreased from 11.3 to 5.6 per m^2 when the number of cuttings per year increased from 2 to more than 3. When only one cutting was performed, this species richness was 7.1, indicating that a minimum mowing frequency is required to maintain biodiversity. The effect of the number of cuts also appeared to depend on the moisture of the grassland soil.

Agri-environmental policies concerning grasslands have often promoted late harvests in order to preserve flowering plant species, and birds nesting within grassland swards. Intensive grasslands are very far from this situation. In grass silage-making, the harvest occurs very early in the growing season and the number of cuts per year increases compared with hay-making. Few clonal plant species can resist this regime, and the ecological value of these species is low, as underlined by Muller (2002). Multiple cuts per season not only reduces the number of seed heads and flowering plants (and hence the number and type of invertebrates attracted to these swards) but also serves to remove the vegetative food resource for plant-feeding insects (such as sawflies and plant bugs). The encouragement of rapid re-growth of the sward immediately after cutting also means that the period in which these food items are accessible to birds is very short (McCracken & Tallowin, 2005).

An alternative solution to late-cut hay was proposed to find a compromise between quality forage production and biodiversity maintenance in hay fields. It consists of an early cut in the season (e.g. in May for lowlands) and a late cut (e.g. in September) which permits a delay in flowering in the middle of summer. In this case, plant species are able to produce mature seeds at the end of August-beginning of September, when the germination conditions are favourable.

Another alternative to late cutting consists of a late grazing at high stocking rate for a short period at the time when the sward was traditionally cut. This technique allows flowering and seed formation as well as cutting but it is much easier to implement than mechanical cuttings especially if the soil is wet or marshy or located on a steep slope.

c) Water regime

Drainage of the wetter meadows is one of the factors associated with their intensification. The effect of drainage is commonly associated with the influence of an earlier management (grazing, cutting or fertilization or manuring), and an increasing stocking rate, duration of grazing and fertilizers inputs. Typical plant and animal species from wet biotopes thus disappear under the combined action of the drying of grassland soil and intensification of management (Plantureux et al., 1993). In a study comparing grasslands drained for periods ranging from 1 to more than 30 years, it has been demonstrated that dominance of plant species is modified during the growing season following the drainage, and that species disappearance or appearance significantly change after 5 years (Oberlé et al., 1989). Drainage of wet soils improves soil conditions for some invertebrates such as earthworms, but it can also reduce soil penetrability for probing birds and a more vigorous grass growth in spring may reduce access to the soil surface at this critical time for breeding birds (Ausden et al., 2001).

d) Pesticides and other factors

Numerous factors are likely to influence biodiversity in grasslands but few of them really operate in intensive grasslands compared to fertilisation, grazing and cutting management, and water regulation by drainage. This is mainly linked to the huge effect of these management factors, but it may also be recognized that the influence of the other factors has on the whole been studied less. Ploughing and reseeding will not be considered in this paper devoted to intensive permanent grasslands, but it is clear that they significantly modify plant and even other species diversity.

Even in intensive grasslands, pesticides are applied less (frequency and amounts) than in cultivated fields. Most of the pesticides used in permanent grasslands are herbicides controlling forbs and broad-leaved weeds. Farmers generally use such herbicides on grasslands that have already been intensified, and the reduction of plant diversity is thus restricted to a limited number of species of poor ecological value. In addition, insecticides may be directed against soil-dwelling leatherjacket larvae, which although a pest of grassland, can also form an important prey item for a range of farmland birds (McCracken et al., 1995). However, the most widespread use of chemicals is through the application of anthelmintics to control internal parasites of grazing animals, and particular concern has been expressed over the potential insecticide effects of residues excreted in the dung of treated animals. This effect reduces the feeding resources of meadow birds.

2. Improvement of biodiversity in intensive grasslands and arable lands

As intensive management has been proved to impact on species richness of grasslands, alternative solutions are required in order to enhance biodiversity. Three major questions then arise about restoration of plant and animal diversity in permanent grasslands: Which objectives can be defined in term of particular species to be promoted, how farming practices should be applied to obtain the desired goals, and what are the economic consequences of such modifications. To fully answer these questions is quite difficult mainly because of the complexity of the relationships involved, the frequent conflicts between ecological and economical aims, and the relative lack of detailed knowledge on many of the related mechanisms.

Until now, prescriptions for biodiversity restoration have generally been directed at preserving a limited number of selected species (i.e. birds or plants). However, species differ in their requirement of vegetation structures and soil conditions, and hence the management scenarios for grassland biodiversity restoration may therefore differ depending upon the priorities set. The main focus on techniques to restore grassland biodiversity has been directed at vegetation restoration, and less frequently at bird protection. Other species are generally ignored, or the recovery of the ecosystem is assumed to be beneficial to a wide range of species. However, this is not always the case.

Enhancement of biodiversity depends on the initial conditions (i.e. soil seed bank limitation, landscape characteristics such as fragmentation and diversity), and on the ability to change grassland abiotic conditions and management (i.e. soil nutrient content, intensity of management). The duration of agricultural intensification appears to be a key factor for an effective restoration, as shown by many studies on seed-bank in European grasslands (Bakker et al., 1999). The biodiversity of recently intensified grassland is easier to restore. Landscape environment also acts to speed up the recovery in diversity, as animal and plant re-colonization is better when grasslands are surrounded by species-rich areas. In this context, the importance of ditches, hedgerows and others field boundaries have been mentioned by several authors like Smart et al. (2002), Blomqvist et al. (2003) or Aude et al. (2004) namely as a source of seed rain. The relative influence of abiotic conditions and dispersule dynamics is frequently discussed. Studying the re-introduction of *Silaum silaus* L. in intensive grasslands of the Saale river flood plain in Germany, Bischoff (2000) concluded that slow dispersion was the main limiting factor for the re-colonization by this plant species. When seed-bank and plant dispersion are not limiting, the presence of gaps and the sward height created by management is a crucial condition for the germination and growth of this plant species.

The most common means used in diversity restoration includes extensive management, and techniques to overcome biotic and abiotic constraints (Walker et al., 2004). Extensification of management involves the reduction or the cessation of mineral and organic fertilisation, and/or a decrease in the stocking rate and the number of cuttings per year. Over most studies, the effects of the reduction in fertilizer rates have been found to vary greatly between situations. Re-establishing original plant communities frequently takes more than 10 or 20 years, and the final goal is not always reached. Several reasons may explain this phenomenon: initial soil nutrient content may be very high, and if the soil is deep and plant growth and consequently plant nutrient uptake limited by extensification, the reduction of soil fertility is very slow. The floristic recovery is thus generally more efficient if the depletion of nutrients is subsequently accelerated by hay-making. As described previously, biodiversity is significantly reduced at low levels of fertilizer, especially for nitrogen. Atmospheric depositions of nutrients that are increasing are now considered to slow down extensification effects on biodiversity. This could explain the relatively weak differences observed by Haas et al. (2001) in South Germany when they compared the number of plant species in extensified and intensive grassland systems: in organic and extensified grassland, plant species richness was only slightly higher (29.0 and 26.8) compared with the intensively used permanent grasslands (24.7).

It has been demonstrated that mixed management (grazing + cutting) is preferable than grazing or cutting alone, for most plant species (but not for all species) but, as with the reduction in nutrient supply, the results are very variable among studies. In such situations, a late harvest permit of the production of many seeds, and the following grazing period opens gaps in the sward where seeds can germinate. Moreover, grazing for short periods induces an increase in sward heterogeneity that is highly favourable for plant and animal diversity. Although it is well known that different livestock species (e.g. cattle, sheep, goat, horse) have different grazing preferences, the impact of this on plant biodiversity – and evidently on other species – is not yet understood well enough (Rook et al., 2004).

Overcoming abiotic constraints generally involves the depletion of soil nutrient status, but may also require the restoration of the water regime of drained soil. A thorny question is the persistence of non-labile elements like P in soil. The problem is particularly serious in countries like France where huge amounts of P (basic phosphorus slags used for pH elevation) have been added for many years. P accumulates in grassland soils as they are rich in organic matter that easily binds with this element. Several techniques have been proposed to "remove" P from grassland soil: reasonable (whatever is meant by reasonable) N fertilizer application for a few years seems to be a good compromise because it is efficient and has little effect on environment pollution. More drastic techniques have been suggested like deturfing or addition of chemical material that absorbs nutrients or makes them unavailable for plants. The cost of these techniques is usually high and the techniques of soil nutrient depletion are not easily accepted by farmers. When soil pH has been increased for a long time in acid grassland, acidophilic species have disappeared. Application of acid materials has been proved to reduce pH efficiently and restore the initial situations in few years.

If extensification or modification of abiotic constraints are not enough to improve biodiversity, biotic constraints may be solved by the introduction of species (plant species). Oversowing, direct drilling or mechanical disturbance of the sward is suitable in this objective. The results of such experiments are variable and illustrated by an abundant literature (Walker et al., 2004).

In particular, species-rich grassland restoration by re-introduction of plant species is often faster and easier on arable land than on intensified grassland. After sowing, seedlings can easily establish on a bare soil since there is no competition with mature plants. The soil nutrient status is also more favourable on arable land since the organic matter content and thus the mineralization of organic nitrogen are lower.

Finally, economical considerations have to be taken into account in restoration of intensive grasslands. In a recent contribution, Hodgson et al. (2005) have tried to answer the following key question: "How much will it cost to save grassland diversity?" Comparing a very large range of situations, they found a positive exponential relationship between intensification of practices and net returns of grassland production. At the same time, this increase in financial benefit was associated with a decrease in grassland plant diversity, from intermediate to high levels of intensification. In the case of lowland grassland in UK, the total potential number of plant species was divided by 2 (40 to 20) when the estimated economic yield increased from about 500 to 5000 £.ha^{-1}.

CONCLUSIONS

In most cases, intensive grass production from semi-natural grasslands appears to be incompatible with maintaining a high level of biodiversity. Existing but very rare counter-examples can be identified concerning organisms adapted to highly intensified conditions. The key question is thus: how to restore biodiversity in intensive grasslands while limiting the technical and economical consequences? As these negative consequences are mostly unavoidable, financial support or regulations are required, as now proposed by EU and its member States. Two aspects arise about these policies dealing with i) the relative lack of knowledge on grassland biodiversity and ii) the objectives of biodiversity enhancement and its evaluation.

Despite many studies on grassland biodiversity, many aspects still remain unknown. Firstly, it must be noted that the biodiversity of low productive grasslands (fens, marshlands, calcareous swards namely) have been investigated more than lowland and intensive grasslands. As clearly demonstrated by Leps (2004), biodiversity trials failed to address a lot of topics. There are still many species, and even genus and families that are not studied in grassland ecosystems. Landscape and species scales are the main concern of biodiversity research, whereas genetic diversity is completely ignored in grassland studies. Below-ground studies are also rare, as noticed by Bardgett et al. (1998): "research is needed to test the hypothesis that grassland soil biodiversity is positively linked to stability, and to elucidate relationships between productivity, community integrity and functioning of soil biotic communities". Reseachers in grassland biodiversity thus have many questions to address in the future.

As previously mentioned, conservation or restoration of biodiversity are generally oriented on selected species. The choice of these target species is not always ecologically justified, and a more objective basis is therefore required. Biodiversity is not a simple concept, and Noss (1990) described it in a hierarchical approach based on the distinction between composition, structure and function. Biodiversity may also be considered through its ecological, agronomic and heritage functions (Clergué et al., 2005; Maljean & Peeters, 2001). From this point of view, the restoration of functions ensured by biodiversity would be a way to choose the appropriate management of grasslands. This process requires new tools (indicators) to evaluate these functions and to achieve biodiversity restoration goals. In particular, while there is a need for a better understanding of many issues relevant to grassland, there is also a need for the identification of some research topics where fast results can be achieved in the context of intensified grassland. It is suggested that research priorities should be:

- *Restoration of species-rich grassland*: A large-body of past and present studies have been focused on this issue. There is a need for some consolidation of what is now known about this issue before many other new projects in this area can be developed. The majority of future research in this area should be directed at field (rather than small-plot) scale and should focus much more on the practicalities of achieving results at this scale.

- *Maintenance of species-rich grassland*: Although restoration is important, there is no point in increasing the amount of species-rich grasslands if the best management to maintain them is unclear. Many current and previous studies have been directed at cutting regimes and now there is a need for the development of appropriate grazing management techniques. It is essential that the latter involves research at the field-scale so that the implications of livestock grazing behaviour can be taken into account.

- *Semi-improved and improved grassland*. Given that these form the majority of grasslands across Europe, there is a need for a greater consideration of what can be done to enhance their biodiversity value while maintaining a satisfying level of forage production. Practicalities of implementation of management actions dictate that the options for silage fields should be considered separately from those for grazed fields. In silage situations, it will be feasible to consider either margin or whole-field approaches. In grazed situations, the cost of fencing and difficulty of directing any actions solely at the margins dictate that field-scale options should be given priority for those situations. In both situations, greater attention needs to be given to ensuring (a) that the approaches taken address both summer and winter issues for the biodiversity under consideration and (b) that the management implemented makes sense in terms of the phenology of the target organisms. Manipulating vegetation structure has the potential to achieve quicker results than actions to reduce soil nutrient status. Managing grasslands in order to take into consideration the phenology of the target organisms certainly needs some future research. Nevertheless there is a need to direct more attention towards ways of achieving summer and winter issues for the biodiversity, which fit with farming practice. Although landscape-scale issues will be important in grassland situations, it is suggested that in the short-term the research priority is to understand interactions at the field and farm-scale.

REFERENCES

Al Mufti, M.M., Sydes, C.L., Furness, S.B., Grime J.P. & Band J.R. 1977. A quantitative analysis of shoot phenology and dominance in herbaceous vegetation. *Journal of Ecology* **65**, 759–791.

Aude, E., Tybirk, K., Michelsen, A., Ejrnaes, R., Hald, A.B. & Mark S. 2004. Conservation value of the herbaceous vegetation in hedgerows. Does organic farming makes a difference? *Biological conservation* **118**, 467–478.

Ausden, M., Sutherland, W.J. & James, R. 2001. The effects of flooding lowland wetland grassland on soil macroinvertebrate prey of breeding waders. *Journal of Applied Ecology* **38**, 320–338.

Bakker, J.B. & Berendse, F. 1999. Constraints in the restoration of ecological diversity in grassland and heathland communities. *Tree* **14**, 63–68.

Baldock, D. 1993. Possible policy options and their implication for conservation. In Haggar, R.J. & Peel, S. (eds): *Grassland management and nature conservation*. *BGS occasional symposium* **28**, 167–176.

Balent, G., Alard, D., Blanfort, V. & Gibon, A. 1998. Activités de pâturage, paysages et biodiversité. *Annales de Zootechnie* **47**, 419–429.

Bardgett, E.D. & Cook, R. 1998. Functional aspects of soil animal diversity in agricultural grasslands. *Applied Soil Ecology* **10**, 263–276.

Benizri, E. & Amiaud, B. 2005. Relationship between plant and soil microbial communities in fertilized grassland. *Soil Biology and Biochemistry* (in press).

Bischoff, A. 2000. Dispersal and re-establishement of *Silaum Silaus* L. in floodplain grassland. *Basic Applied Ecology* **1**, 125–131

Blomqvist, M.M., Vos, P., Klinkhammer, P.G.L. & Ter Keurs, W.J. 2003. Declining plant species richness of grassland ditch banks – a problem of colonisation or extinction? *Biological conservation* **109**, 391–406.

Burel, F., Baudry, J., Butet, A., Clergeau, P., Delettre, Y., Lecoeur, D., Dubs, F., Morvan, N., Paillat, G., Petit, S., Thenail, C., Brunel, E. & Lefeuvre J.P. 1998. Comparative biodiversity along a gradient of agricultural landscape. *Acta Oecologia* **19**(1), 47–60.

Clergue, B., Amiaud, B., Pervanchon, F., Lasserre-Joulin, F. & Plantureux, S. 2005. Biodiversity function and assessment in agricultural areas. *Agronomy for sustainable development* **25**, 1–15.

Fedoroff, E., Ponge, J.F., Dubs, F., Fernandez-Gonzalez, F. & Lavelle, P. 2005. Small scale-response of plant species to land-use intensification. *Agriculture, Ecosystems and Environment* **105**, 283–290.

Fischer, M. & Wipf S. 2002. Effect of low intensity grazing on the species rich-vegetation of traditionally mown subalpine meadows. *Biological conservation* **104**, 1–11.

Foster, G.L. & Gross, K.L. 1998. Species richness in a successional grassland. Effects of nitrogen enrichment and litter. *Ecology* **79**, 2593–2602.

Garcia, F., Carrère, P., Soussana, J.F. & Baumont, R. 2005. Characterisation by fractal analysis of foraging paths of ewes grazing heterogeneous swards. *Applied Animal Behaviour Science* (in press).

Giraudoux, P., Delattre, P., Habert, M., Quéré, J.P., Deblay, S., Defaut, R., Duhamel, R., Moissenet, M.F., Salvi, D.& Truchetet, D. 1997. Population dynamics of fossorial water vole (Arvicola terrestris scherman): a land use and landscape perspective. *Agriculture, Ecosystems & Environment* **66**(1), 47–60.

Grime, J.P. 1979. Plant strategies and vegetation processes. *John Wiley and sons*. Chichester. 186 pp.

Haas, G., Wetterich, F. & Kopke, U. 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. *Agriculture, Ecosystems and Environment* **83**, 43–53.

Hodgson, J.G et al. (collective paper with 31 co-authors). 2005. How much will it cost to save grassland biodiversity. *Biological conservation* **122,** 263–273.

Janssens, F., Peeters, A., Tallowin, J.R., Bakker, J.P., Bekker, R.M., Fillat, F. & Oomes, M.J.M. 1998. Relationship between soil chemical factors and grassland diversity. *Plant and soil* **202**, 69–78.

Leps, J. 2004. What do the biodiversity experiments tell us about the consequences of plant species losses in the real world ? *Basic and applied ecology* **5,** 529–534.

Maljean, J.F. & Peeters A. 2001. Integrated farming and biodiversity : impacts and political measures. Pan-European Biological and Landscape Diversity Strategy – *High-level Pan-European Conference on Agriculture and Biodiversity : towards integrating biological and landscape diversity for sustainable agriculture in Europe*, Maison de l'Unesco, Paris (France), 5–7 June 2002. Council of Europe, UNEP, STRA-CO/AGRI (2001) 27: 28 p.

McCracken, D.I., Foster, G.N. & Kelly, A.(1995). Factors affecting the size of leatherjacket (Diptera : tipulidae) populations in pastures in the west of Scotland. *Applied Soil Ecology* **2**, 203–213.

McCracken, D.I. & Tallowin, J.R. 2005. Swards and structure : the interactions between farming practices bird food resources in lowland grasslands. *Ibis* (in press).

Morris, M.G., 2000. The effects of structure and its dynamics on the ecology and conservation of arthropods in british grasslands. *Biology Conservation* **95,**129–142.

Muller, S. 2002. Appropriate agricultural management practices required to ensure conservation and biodiversity of environmentally sensitive grassland sites designated under Natura 2000. *Agriculture, Ecosystems and Environment* **89**, 261–266.

Noss, R.F. 1990. Indicators for monitoring biodiversity, a hierachical approach. *Conservation Biology* **4**,355–364.

Oberle, S., Plantureux, S., Bonischot, R. & Guckert, A. 1989. Relations entre facteur hydrique, drainage et évolution de la flore des prairies permanentes. *XVI° international grassland congress*, Nice, France, pp. 29–30.

Olff, H. & Ritchie, M.E. 1998. Effects of herbivores on grassland plant diversity. *Trends in Ecology and Evolution* **13**(7), 261–165.

Peeters, A., Janssens, F. & Decamps, C. 1994. Importance of soil phosphorus on botanical diversity. *Proc of the XVth general meeting of the European Grassland Federation*, pp.171–174.

Peeters, A. & Janssens F. 1998. Species-rich grassland: diagnostic, restoration and use in intensive livestock production systems. *Proceedings of the European Grassland Federation Symposium*, Hungary, pp. 375–393.

Petit, S., Wyatt B., Firbank, L., Howard, D., Bunce, R.G.H., Hill, M.O., Swetnam ,R.D., Bull, K.R., Morton, D., Cooper, J. & Foppen, R.P.B. 1998. MIRABEL – Models for integrated review and assessment of biodiversity in European landscapes. *Report by ITE (NERC), IBN-DLO and NINA to the European Environment Agency Topic Centre on Nature Conservation*, Paris.

Plantureux, S., Bonischot, R. & Guckert, A. 1993. Classification, vegetation dynamics and forage production of permanent pastures in Lorraine. *European Journal of Agronomy* **2**(1), 11–17.

Plantureux, S. 1996. Biodiversité, type de sol et intensité de l'exploitation des prairies permanentes du plateau lorrain. *Acta Botanica Gallica* **143**(4/5), 403–410.

Rook, A.J.& Tallowin, J.R. (2003). Grazing and pasture management for biodiversity benefit. *Animal Research*, ?, 181–189.

Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., WallisDeVries, M.F., Parente, G. & Mills, J. 2004. Matching type of livestock to desired biodiversity outcomes in pastures – a review. *Biological conservation* **119**, 137–150.

Smart, S.M., Bunce, R.G.H., Firbank, L.G.& Coward, P. 2002. Do field boundaries acts as refugia for grassland plant species diversity in intensively managed landscapes in Britain? *Agriculture, Ecosystems and Environment* **91**, 73–87.

Walker, K.J., Stevens, P.A., Stevens, D.P., Mountford, J.O., Manchester, S.J & Pywell R.F. 2004. The restoration and recreation of species rich-lowland grassland on land formerly managed for intensive agriculture in the UK. *Biological conservation* **119,** 1–18.

Zechmeister, H.G., Schmitzberger, I., Steurer, B., Peterseil, J. & Wrbka T. 2003. The influence of land-use praticices and economics on plant species richness in meadows. *Biological conservation* **114**, 165–177.