Japanese Society of Grassland Science ISSN1744-6961

REVIEW ARTICLE

# Importance, evolution, environmental impact and future challenges of grasslands and grassland-based systems in Europe

Alain Peeters

RHEA (natural Resources, Human Environment and Agronomy), Gentinnes, Belgium

**Keywords**
Agro-fuel; biomass; feeding quality; green bio-refinery; multi-functionality.

**Correspondence**
Alain Peeters, Rue des Anciens Combattants 13, B-1450 Gentinnes, Belgium.
Email: alain.peeters@rhea-environment.org

This paper is an updated version of an invited talk presented at the 22nd General Meeting of the European Grassland Federation (EGF) in Uppsala (Sweden) on 9–12 June 2008.

Received 6 April 2009;
accepted 4 June 2009.

doi: 10.1111/j.1744-697X.2009.00154.x

## Abstract

The importance and the diversity of grasslands and grassland-based systems are illustrated. Their multiple functions and values are highlighted. The main trends of the evolution of the systems in the last half-century are summarized including the effect of the Common Agricultural Policy of the European Union. Grasslands are compared with annual forage crops for forage production potential and impact on the environment. New challenges are analyzed especially in relation to agro-fuel production. The potential of grasslands for fuel production is discussed as well as the possible effect of first-generation agro-fuels on the grassland area. The fractionation of grassland biomass into several products like fibers, lactic acid and amino acids is described in relation to possible industrial uses. Policy recommendations are proposed.

## Introduction

Grassland is by far the first land use in the agricultural area (AA) in Europe. Grasslands and rangelands cover 56 million ha (33% AA) (in the EU27, in 2005). This area includes approximately 17.5 million ha of rangelands (10% AA), mainly in mountain and Mediterranean areas (EUROSTAT 2008). This average importance of grasslands hides big differences between Member States of the EU. In West Europe, the proportion of grasslands in the AA is usually higher, as in the UK (62%) and Ireland (73%), while in Eastern Europe the proportion is usually lower, such as Poland (21%) and Romania (33%). That reflects the differences of ecological conditions, production systems, living standards, history and policies between countries.

Diversity is a keyword for grasslands and grassland-based systems in Europe. It is induced by the variability of the ecological conditions (soil, climate), species composition, use, management system and performances.

Grassland plant communities are classified in the EU into seven main habitats according to EUNIS (2006): dry grasslands, mesic grasslands, seasonally wet and wet grasslands, alpine and subalpine grasslands, woodland fringes and clearings and tall forb stands, inland salt steppes and sparsely wooded grasslands. Grassland swards can be species-rich or species-poor, dominated by grasses, by legumes, or by a balanced mixture of grasses and legumes. In some swards, usually species-rich, these two plant families can even have a minor importance compared with other species types.

Grasslands may be permanent or temporary (regularly sown). They can be only grazed, only cut or provide mixed use for grazing and cutting. The use of inputs $ha^{-1}$ (fertilization, amendments, herbicide use, re-sowing or over-sowing, irrigation) in grassland can be highly variable, much more than for arable land. The large variation in input use, management, vegetation types and ecological conditions induces large differences in dry matter production, forage quality, stocking rate and animal production. Low-production swards can only produce annually approximately 2–3 t DM ha$^{-1}$; they can be grazed by sheep for instance. High-production swards can yield as much as 10–12 t DM ha$^{-1}$ for grazed swards and 15–20 t DM ha$^{-1}$ for cut swards under good production conditions; they are usually used for dairy cows. A poor-quality, low-digestibility hay has high fiber (crude fiber [CF] ~35–40% DM) and low protein contents [crude protein (CP) about 6.25% DM] while a highly digestible young grass is fiber-poor (CF about 15–20% DM) and protein-rich (CP about 18–22% DM). Some mountain swards for instance can only feed two to three ewes (0.17–0.25 livestock units [LU]) ha$^{-1}$ during the summer months while a productive lowland sward can be stocked with five to six dairy cows (or LU) in spring and three to four cows (or LU) in summer. In North-West European countries, where grassland yields are the highest without irrigation in Europe (Peeters and Kopec 1996), the annual milk yield is estimated at 9000–13 000 kg ha$^{-1}$ of forage crops (Kristensen *et al.* 2005). Marginal grasslands can just cover the maintenance needs of low-requirement animals. This range of values has no other purpose than illustrating the wide variability of grassland production potential in Europe.

Grassland-based systems are also highly diverse according to the main animal production. Dairy systems are the most intensive ones while meat-sheep systems are usually the most extensive ones. In some systems, animals are kept indoors all year long while sheep and heifers for instance can stay outdoors at all seasons. Pflimlin *et al.* (2005) identified seven forage and livestock regions in the EU15: (i) northern regions (Scandinavia); (ii) wet mountain regions (Alps, Vosges, Jura, Massif Central, Pyrenees, Cantabrian mountains); (iii) Mediterranean regions in fertile plains and valleys as well as in dry mountain rangelands; (iv) grassland regions (permanent grassland dominant in the AA) (e.g. Ireland, Wales, Scotland, South and North-West England, Belgian Ardennes, North-East France); (v) grassland and maize regions (e.g. North-West Germany, east of the Netherlands, ‘‘Bocage’’ of Normandy); (vi) forage crops regions (temporary grasslands plus maize) (e.g. Brittany, Belgian Flanders, South East of the Netherlands, West of Galicia); (vii) arable land and livestock regions (e.g. margins of the Parisian Basin, north of the Pô Plain, part of Bavaria, central part of England). The majority of livestock holdings (60%) are located in less favored areas (LFA) (mountain, Mediterranean and grassland regions). Livestock systems are using at least 42% of the EU15 agricultural land but probably much more (Vidal 2001).

Grasslands are characterized by multiple functions and values. They are providing forage for grazing and browsing animals, both domestic and wild. Compared with high-density coniferous tree plantations, they have a positive influence on the recharge of water tables. Compared with annual crops, they have a protection effect for water quality and a good potential of carbon sequestration in the soil. They protect the soil from wind and water erosion, and enhance soil fertility. They are the support of an important biodiversity; some extensive grassland types have a very high nature value. They are supporting rural economies and are a source of livelihood for local communities. Grassland landscapes are aesthetically pleasing, provide recreational opportunities and open space, and improve the quality of life of the whole society.

An analysis of the outlook of grasslands and grassland-based systems must take this diversity and this multi-functionality into account. Changes in socioeconomic factors do not have the same effect on each of these systems. This paper focuses on the factors that can affect grassland area, grassland-based systems and their production potential in the future. It does not tackle specifically the environmental aspects. It analyses the possible future uses of grasslands in the context of energy and primary raw material production. Agro-fuel, bulk chemicals, human food, animal feed and fiber production could be developed from grassland forages in the future in addition to the traditional use of ruminant feed.

## Main trends in the last half-century

Two major trends characterized grassland-based systems in the last 50 years; that is, roughly since the beginning of the Common Agricultural Policy (CAP) of the EU in the early 1960s, intensification and land abandonment. In the lowlands, nitrogen fertilization in grassland started to be used to a large extent since the 1960s. Stocking rate, frequency of cutting for conservation, fertilizer use, drainage, irrigation, re-sowing and over-sowing with improved cultivars, weed control with herbicides became increasingly important. The number of plant species (and biodiversity in general) fell dramatically in grassland swards while forage yields increased and feeding quality improved. At the same time, farm and farmer numbers were reduced and farm size increased. That modified the traditional landscape by an enlargement of plot size and, as a direct consequence, a decrease in field margins and edges. Between 1975 and 1990 (EU15), the grassland area was significantly reduced in favor to the production of fodder maize and cash crops. After 1989 and the fall of communist regimes, many agricultural areas and especially grassland areas were abandoned in countries in transition. It is estimated that at least 30% of grassland areas were abandoned in countries like Bulgaria and Romania. Actually, in some regions, including in mountain areas, the quasi-totality of grasslands were abandoned. That can be illustrated by the dramatic decrease of ruminant numbers. In Bulgaria, for instance, total LU (cattle, sheep, goats) in 2005 were 34% of its value in 1985

(NSI Sofia 2005). The same calculation for Slovakia between 1990 and 2004 (cattle, sheep) gives a similar value of 35% (NSI Bratislava 2004). Even in the EU15 countries, marginal grasslands tended to be abandoned, especially in mountain and Mediterranean areas. Intensification and abandonment are two sides of the same coin. When yields are increasing, less acreage is necessary for achieving the total production and the production costs are increasingly important in marginal regions compared with favorable, intensively used regions.

The specialization of productions resulted in the progressive disappearance of mixed farming. Some regions specialized in arable crops while other regions specialized in animal husbandry. The importance of temporary grasslands, and especially *Medicago sativa*, declined everywhere, even in grassland regions. In the 1950s and 1960s, this trend was reinforced by the decline of agricultural manpower that made traditional haymaking very difficult. The use and the proportion of legume species (especially *Trifolium repens*) in swards were also reduced by a widespread use of nitrogen fertilizers. Animal breeds were specialized for milk or meat production, while dual-purpose breed populations were reduced. Dairy systems were concentrated in the lowlands (74% EU dairy cows) especially in Atlantic climates (regular rainfall and mild temperatures are ideal for grass growth), and also at medium altitude in mountain areas (11% EU dairy cows) (Pflimlin *et al.* 2005). Beef meat systems occupied more marginal soils and climates. As a consequence of specialization, animal performances increased. In dairy systems, from an average of 4500 L $cow^{-1}$ and $year^{-1}$ in the 1970s, the annual production increased to 7500 L $cow^{-1}$ while some herds or some cows are reaching now an annual production of 10 000–12 000 L $cow^{-1}$. This regular increase of dairy performances of approximately 1% $year^{-1}$ was possible thanks to an international effort of breeding of a restricted number of dairy breeds among which the Holstein breed is undoubtedly largely dominant. That led to a decrease of the populations of many less performing breeds. Yield increases also induced changes in animal feeding. More concentrates were used at the expense of green forages. The implementation of milk quotas in 1984 slowed down this trend because the control of the volume of production required a decrease of production costs. This was achieved by a better utilization of green forage that are less expensive than concentrates and by an even higher production per cow. Indeed, this made it possible to decrease the share of maintenance feeding needs and to increase the share of production needs. More milk had to be produced per cow on the basis of grass and maize. However, the CAP reforms of 1992 and 2000, induced a significant decrease of cereal price (~50%) and that encouraged again dairy farmers to use this product in animal feeding. Moreover, farmers tended to use more maize silage at the expense of grass grazing and grass silage when dairy cow production is above a certain threshold (roughly >6000 L $cow^{-1}$). They did not trust grass quality and grass intake potential of their high-yielding cows especially because of rainy weather and unfavorable temperatures. They tend thus to partially keep cows indoors or to systematically complement grass grazing with maize silage. That led to a decrease of grassland proportion in the AA. This trend was very strong in the forage crop and the grassland and maize regions. In the grassland region, the strategy of farmers was a bit different; they used less maize but increased concentrate use. They also tried to better reduce production costs by a better use of grazing and grass silage. In the wet mountain region, farmers have smaller herds, use more green forages including grass, and they can increase their income by selling high-quality cheeses promoted by a Protected Designation of Origin (PDO) system at a high price. In beef production systems, a small number of good conformation breeds emerged too. Local traditional breeds tended to be progressively crossed with three dominant breeds: Charolais, Limousin and Belgian Blue. Grazing remained the basis of suckling cow systems and animals were fed in winter mainly with hay and haylage. Concentrates and maize silage were restricted mainly to bull fattening. Ox fattening disappeared almost in favor of young bulls. In Mediterranean regions where most sheep and goats are located, the number of grazing animals decreased leading to a large abandonment of dry rangelands. All these system changes had impacts on landscape and wildlife by reducing diversity and complexity. In the forage crop region and in some intensive parts of the grassland and maize region, farmers had to face criticisms for their negative effect on the quality of ground- and surface-waters. Measures had to be taken to decrease nitrate and phosphate pollution.

The CAP expenditures are made of two main areas or "pillars". The first pillar provides income support through direct payments to farmers. It also includes, to a lesser extent, market support measures. The second pillar is devoted to rural development policies. These policies are aimed at providing assistance to difficult farming areas, encouraging environmental services, and promoting food quality, higher standards and animal welfare (EUROPA 2004; CEC 2007). Some of the measures of the second pillar were designed for correcting perverse effects of the first pillar. Rural development expenditures were increased after the reform of 2000. In 2006, they represented €7.7 billion annually and 15% of the total CAP expenditures (€4.4 billion and 10% in 2002) (EUROPA 2004). LFA payments contribute significantly to livestock farmers' income because more than one-half of them are operating in these areas and the amounts of payment are not negligible though much lower than those from the first pillar (Pflimlin *et al.* 2005; Roeder *et al.* 2007). While the annual payments from the first pillar sum up to roughly €300 $ha^{-1}$ on average

**Table 1** Importance of annual payments for less favored areas (LFA) in the EU15 (Roeder *et al.* 2007)

| Annual payment (€ ha$^{-1}$) | % of agricultural area within LFA | | |
|---|---|---|---|
| | <20 | 20–60 | >60 |
| <25 | BE, DK, NL | IT | ES, PT |
| 25–50 | | FR, SE, UK, DE | |
| >50 | | IE | AT, GR, FI, LU |

Sources: EEA (2004, 2005) EUROSTAT (2005). BE, Belgium; DK, Denmark; NL, Netherlands; IT, Italy; ES, Spain; PT, Portugal; FR, France; SE, Sweden; UK, United Kingdom; DE, Germany; IE, Ireland; AT, Austria; GR, Greece; FI, Finland; LU, Luxembourg.

in the EU15, the LFA payments range from less than €25 to more than €50 ha$^{-1}$ according to Member States (Table 1). These payments are often linked with specified stocking rates. Agri-environmental measures (AEM) were designed to encourage farmers to protect and enhance the environment on their farm. Farmers receive a payment in return for a service. Their commitment of improving the environment is only rewarded if it goes beyond the application of usual Good Agricultural and Environmental Practices (GAEP). Some measures tried to promote grassland areas and limit the increase in maize and cash crop areas but they were not able to reverse the general trend. They probably decreased the reduction rate of biodiversity in grassland and the simplification of landscapes. Agri-environmental payments remained relatively modest. In 2002, the EU15 spent €2 billion for AEM implementation, namely, approximately 4.6% of the total amount of CAP funds. In 2000–2003, €16.3 were spent, on average, per ha AA of the EU for AEM. It reached €89 ha$^{-1}$ AA in Austria. An average of €89 were received by EU farmers ha$^{-1}$ under AEM contract. In 2002, the share of agricultural land enrolled in AEM in the EU15 reached approximately 25% of the AA but it varies from less than 5% in the Netherlands and Greece to more than 80% in Austria, Sweden, Finland and Luxemburg (EEA 2006). AEM included the support of the conversion to organic farming (OF) and in some Member States to the maintenance of OF. OF is characterized by a mixed farming (crop and animal husbandry) and is based on a large use of grassland and forage legumes. It has developed rapidly since the implementation of the AEM in 1992, with more than 5.8 million ha, 3.4% of the AA and almost 140 000 organic farms in 2004 (EEA 2007). Except in some regions and Member States, it remains marginal and did not change the main evolutionary trends of the EU agriculture. The new Rural Development policy 2007–2013 focuses on three areas: improving competitiveness for farming and forestry; environment and countryside; and improving quality of life and diversification of the rural economy. A fourth axis called the "leader axis" based on experience with the Leader Community Initiatives introduces possibilities of direct support to locally-based bottom-up approaches to rural development (EUROPA 2007).

The CAP reform of 2003 introduced four new principles into the previous systems: decoupling, cross-compliance, modulation and partial re-nationalization. With regard to grasslands, these modifications had some important consequences. Decoupling induced that premiums were not linked with crop or animal types but to the eligible area. That suppressed the "maize premium" that encouraged farmers to use this forage crop at the expense of grasslands. The use of grasslands was also not anymore indirectly supported through animal premiums but directly through area payments (the system was though applied with a certain amount of flexibility among Member States according to the renationalization principle). This measure reduced the distortions that were unfavorable to grasslands. Cross-compliance required that farmers must comply with a set of GAEP, including the obligation to maintain the proportion of permanent grassland in the AA, in order to maintain their land in Good Agricultural and Environmental Conditions (GAEC). Farmers have also to respect the Habitat, Bird and Nitrate Directives. The Nitrate Directive is mandatory for farmers and had a significant influence on farm structures and practices of intensive livestock systems by regulating the stocking rate and the management of nitrogen. The modulation principle intended to transfer a part of the first pillar budget to the second pillar. Partial renationalization concerns notably the way Members States can define the GAEC and the eligible area. It also has an impact on the implementation of the modulation principle.

The successive CAP reforms in EU led to modernization of the sector, farm size increase, a dramatic farmer-population decrease, specialization of productions, intensification of grassland and animal husbandry, increase in the volume of production, increase of grassland and animal yields, reduction in legume use, reduction in grassland area and its proportion in the AA, and reduction in the diversity of landscape, grassland species and communities, domestic animal breeds and local products. The implementation of milk quotas reduced the number of dairy cows which induced stocking rate decrease in some cases or the development of suckling cows systems in complement to dairy systems in other cases.

In addition to agricultural policies, a social factor had an influence on grassland systems: the constant reduction in beef and sheep meat consumption of European citizens in favor of pig and poultry meat. If less ruminant meat is consumed and the grassland area does not change, an extensification of grassland management is possible, but it is more likely that a higher demand for monogastric meat will induce replacement of a part of the grassland area by crops.

**Table 2** Comparison of typical yields of the main forage crops in North-West Europe (Deprez *et al.* 2007)

| | Forage maize | Fodder beet | Cutting temporary grassland | Grazed permanent grassland |
|---|---|---|---|---|
| Fresh matter (t FM $ha^{-1}$) | 50 | 120 | 50 | 57 |
| %DM | 30 | 13–19 | 20–30 | 15–20 |
| Dry matter (t DM $ha^{-1}$) | 13–18 | 14–21 | 12–16 | 8–12 |

## Grassland versus other crops for forage potential

In order to understand and to forecast the future potential role of grasslands in the European farming systems, it is necessary to compare grasslands with its direct alternatives for forage production. Table 2 summarizes typical yields of the main forage crops, forage maize and fodder beet, compared to intensive cutting temporary grasslands and grazed permanent grasslands in the conditions of North-West Europe. Dry matter yields of fodder beet are usually higher than those of maize. Yields of temporary grassland under cutting are very high too, but on average a bit lower than maize. Grazed permanent grasslands have lower yields notably because of frequent defoliations and trampling. Table 3 compares typical feeding values and intake characteristics of these forage crops. The energy content is the highest for fodder beet followed by maize and grass. Grass has higher protein and mineral contents than maize and fodder beet. The voluntary intake of fodder beet is excellent but it must be limited for controlling acidosis of the rumen. Intake of maize silage is very good, usually better than that of grass silage, but similar to that of grazed grass.

Conserved and grazed grasses are complete feeds, rich in energy, protein and minerals. Grazed grass is even too rich in protein and in K. It must be complemented by energy-rich and protein-poor feeds. Maize silage is energy-rich, highly digestible and has very good intake characteristics but it is deficient in protein. This table demonstrates the complementarities between grazed grass and maize silage on the one hand, and grass and maize silages on the other. Table 4 evaluates the ease of the main forage crops for cropping, conservation and animal feeding. Maize silage is easy to crop, to harvest and to conserve. Grass silage is easy to crop, but more difficult to harvest because it requires several cuts $year^{-1}$. It is also poorer in soluble carbohydrates than maize and is thus a bit less easy to conserve. The distribution is similar. All technical aspects are difficult to control for fodder beet.

**Table 3** Comparison of typical feeding value and intake characteristics of the main forage crops in North-West Europe (Deprez *et al.* 2007)

| | Forage maize | Fodder beet | Cutting temporary grassland | Grazed permanent grassland |
|---|---|---|---|---|
| Energy ($kg^{-1}$ DM) | | | | |
| UFL | 0.90 | 1.15 | 0.90 | 0.80–0.98 |
| UFV | 0.80 | 1.16 | 0.84 | 0.83–0.94 |
| Protein (g $kg^{-1}$ DM) | | | | |
| CP | 70–85 | 50–100 | 120–170 | 120–240 |
| DP | 45–55 | 65 | 70–100 | 80–120 |
| PDIA | 20 | 10 | 25 | 27 |
| PDIN | 50 | 60 | 85 | 75–115 |
| PDIE | 65 | 85 | 75 | 80–110 |
| Minerals (g $kg^{-1}$ DM) | | | | |
| P | 1.6–2.8 | 1.5–2.0 | 2.8–4.0 | 3.0–4.8 |
| K | 12–16 | 22 | 22–30 | 25–40 |
| Na | 0.05–1.0 | 1.0 | 3.0–4.0 | 1.0–2.0 |
| Ca | 2.5–4.4 | 2.0–2.5 | 3.0–6.0 | 5.5–9.4 |
| Mg | 1.5–1.8 | 1.5 | 1.5–3.0 | 1.3–2.5 |
| Digestibility (%) | 68–73 | 90–94 | 68–72 | 70–80 |
| Intake (g DM $kg^{-1}$ LW) | 23–30 | Excellent but must be limited (acetonemia) | 16–20 | 20–33 |

UFL, fodder unit milk, net energy content of 1 kg of barley for milk (1700 kcal NEl); UFV, fodder unit meat, net energy content of 1 kg of barley for meat (1820 kcal NEg); CP, crude protein; DP, digestible protein; PDIA, feed protein ruminally undergraded and truly digested in the small intestine; PDIN, protein truly digested and absorbed in the small intestine when a degradable N deficient diet is fed; PDIE, protein truly digested and absorbed in the small intestine when a ruminal fermentable energy deficient diet is fed.

 

**Table 4** Evaluation of the easiness of the main forage crops for cropping, conservation and animal feeding (Deprez *et al.* 2007)

| | Forage maize | Fodder beet | Cutting temporary grassland |
|---|---|---|---|
| Cropping | ++ | − | ++ |
| Harvest | ++ | − | + |
| Conservation | ++ | − | + |
| Distribution | ++ | − | ++ |

**Table 5** Parameters of forage crop profitability (for Belgium in 2005) (Deprez *et al.* 2007)

| | Forage maize | Fodder beet | Cutting temporary grassland | Grazed permanent grassland | Species-rich hay meadow |
|---|---|---|---|---|---|
| Farm rent (€ ha$^{-1}$) | 150 | 150 | 150 | 135 | 135 |
| Installation costs (€ ha$^{-1}$) | | | | | |
| Seed bed preparation | 125 | 125 | 120 | – | – |
| Sowing | 50 | 50 | 100 | – | – |
| Seeds | 165 | 125 | 75 | – | – |
| Maintenance | - | - | - | 150 | 75 |
| Total | 340 | 300 | 295 | 150 | 75 |
| Inputs (€ ha$^{-1}$) | | | | | |
| Fertilizers | 270 | 230 | 275 | 90 | – |
| Herbicides | 100 | 210 | 30 | – | – |
| Insecticides | | 20 | | | |
| Total | 370 | 460 | 305 | 90 | 0 |
| Harvest costs (€ ha$^{-1}$) | | | | | |
| Cutting-ensiling | 265 | 340 | 650 | – | – |
| Plastics + silo | 150 | 75 | 130 | – | – |
| Total | 415 | 415 | 780 | 0 | 135 |
| Annual yields | | | | | |
| t DM ha$^{-1}$ | 17 | 18 | 14 | 10 | 4 |
| UFL t$^{-1}$ DM | 940 | 1100 | 830 | 900 | 750 |
| kg CP t$^{-1}$ DM | 70 | 75 | 130 | 140 | 100 |
| Cost price without premium (€) | | | | | |
| ha$^{-1}$ | 1275 | 1325 | 1309 | 375 | 345 |
| 100 kg$^{-1}$ DM | 7.50 | 7.36 | 9.35 | 3.75 | 8.63 |
| UFL$^{-1}$ | 0.08 | 0.07 | 0.11 | 0.04 | 0.12 |
| kg$^{-1}$ CP | 1.07 | 0.98 | 0.72 | 0.27 | 0.86 |

DM, dry matter; FM, fresh matter; UFL, fodder unit milk, net energy content of 1 kg of barley for milk (1700 kcal NEl); CP, crude protein.

Table 5 compares the profitability of the same forage crops and additionally of hay from species-rich meadows. It appears that annual crops and cutting grasslands have similar costs ha$^{-1}$ (slightly higher for grass silage) and much higher than grazed grasslands and hay meadows. Temporary grasslands and hay meadows have the highest costs kg$^{-1}$ DM and per energy content and grazed grasslands the lowest ones. All kinds of grasslands and especially grazed grasslands have the lowest costs kg$^{-1}$ of crude protein.

## Grassland versus other forage crops for impact on the environment

Tables 6 and 7 summarize the effect of different forage crops on some important parameters of the environment: pollutions by nitrate, phosphate and pesticides, as well as biodiversity conservation. Table 6 shows that all types of intensive grasslands have lower risk of pollutions than maize and fodder beet. Nitrate leaching can though occur after the destruction of temporary grasslands if basic rules are not respected. The most intensive grazed grasslands can also contribute to nitrate leaching especially if fertilized after the end of August and heavily stocked. Phosphate and nitrate pollutions of surface water can occur in grasslands with the access of animals to rivers and with manure applications on slopes and in rainy periods or in winter. Annual fodder crops present higher risks of pollution (except fodder beet for nitrate leaching) including for pesticides that are not

**Table 6** Pollution risk at plot level for the main forage crops (Deprez *et al.* 2007)

| | Forage maize | Fodder beet | Cut temporary grassland | Grazed permanent grassland |
|---|---|---|---|---|
| Nitrate | — | + | + to – | + to – |
| Phosphate | — | – | + | + to – |
| Herbicide | — | – | + | + |
| Insecticide | - | – | + | + |

—, very high risk; –, medium to high risk; -, medium to low risk; +, low or no risk.

**Table 7** Synthesis of the impact of several forage crops on biodiversity (Deprez *et al.* 2007)

| | Forage maize | Fodder beet | Cut temporary grassland | Grazed permanent grassland | Species-rich hay meadow |
|---|---|---|---|---|---|
| Agricultural biodiversity | 0 | 0 | ++ | + | 0 to + |
| Functional biodiversity | | | | | |
| Flora | 0 | 0 | + | ++ | +++ |
| Soil activity | 0 to + | 0 to + | ++ | +++ | +++ |
| Insects | – to 0 | – to 0 | 0 to + | ++ | +++ |
| Patrimonial biodiversity | | | | | |
| Flora | – | – | – to 0 | ++ | +++ |
| Insects | – to – | – to – | 0 to + | + to ++ | +++ |
| Birds | – to 0 | – to 0 | 0 to + | + to ++ | +++ |
| Mammals | – to 0 | – to 0 | + | ++ | ++ |

–, very negative impact; –, negative impact; 0, neutral effect; +, positive impact; ++, very positive impact; +++, extremely positive impact.

used, or little used, in grasslands. Table 7 illustrates that all types of biodiversity can better develop in grasslands compared with annual fodder crops that can be compared to ‘‘deserts’’ for biodiversity. Species-rich grasslands have of course the highest nature value but they are much less productive and have lower digestibility and intake values.

## SWOT analysis of grasslands compared to maize for forage production

A SWOT analysis is based on the study of strengths, weaknesses, opportunities and threats.

Strengths of grasslands compared to maize are good DM yields of intensive swards, excellent grazing quality, high protein and mineral contents, permanent soil cover, low production costs, no or little pesticide use, possibility of variable use of fertilizers, usually acceptable levels of nitrate and phosphate pollutions, soil and water protection, positive or very positive effects on biodiversity. Grasslands (grass-legume mixtures) are one of the pillars of OF. Dairy and possibly meat products from grassland-based systems can be more tasty and sometimes even more healthy than products from maize-based systems, for instance, for PDO products. Extensive grazing systems can indeed be associated with high-quality products protected by labels. Grassland systems can produce high quality landscapes that can be associated with (agri-)tourism activities.

Weaknesses of grasslands are related to the fact that they must be harvested in several cuts, grass conservation relies on weather conditions, feeding quality and intake (grazing and silage) can be reduced in case of unfavorable weather conditions, costs for silage making are relatively higher, nitrogen content can be too high in some feeding systems especially during grazing, nitrate pollution risk after sward destruction (especially after plowing) of temporary grasslands can be important, intensive cutting systems can be very detrimental to wildlife, and intensive grazing systems can produce nitrate and phosphate pollutions as well as drastic wildlife reduction.

The disappearance in 2003 of the ‘‘maize premium’’ of the former CAP system is an opportunity for grasslands. The protection of the grassland area is integrated in the present CAP cross-compliance system (GAEP). There is a social demand and a political willingness to protect the environment, landscape and biodiversity. There could be an increasing demand for meat and dairy products on the world market in the future. An increase of fossil energy and input prices can increase the attractiveness of grass–legume mixtures. The present increase of cereal price can induce higher and better use of green forages including grasslands for animal feeding.

A reduction of agricultural supports could be a threat in the future as well as a stagnation or a reduction of the importance of the rural development policy (second pillar) compared with the first pillar of the CAP. A significant proportion of the grassland area could be destroyed for agro-fuel production, especially with first-generation agro-fuels and for bio-gas production. An increase of grain and other crop prices could encourage farmers to plough grasslands for crop production. A decrease of the consumer’s purchasing power could reduce beef and sheep meat as well as high-quality dairy product consumption.

The above data and information show the important potential of grasslands compared with other forage crops. This potential is still underestimated, including by agronomists and farmers. It is thus essential to advertise it and to promote the use of grasslands much more than it is done today.

## New challenges

After a period of over-production and control of the productions in Europe by quotas, set-aside and decoupling, new demands for cereals and other agricultural products are appearing on the world market because of the fast increase of the world human population and the emergence of new economic powers including China. The increasing price of fossil energy and environmental concerns about climate changes are also inducing crop-based agro-fuel production and demand. Both factors are leading to the increase of prices of agricultural products. Higher global demand for food has not yet had an impact on dairy and ruminant meat products in the EU but agro-fuel production has already induced a pressure on the European grassland area.

There are two major types of agro-fuels. Monocultures cropped on fertile soils can produce ethanol from starch or sugar of corn, wheat, barley, sugarcane and sugar beet, or bio-diesel from oil extraction from oilseed rape, oilpalm and soybeans mainly. Ligno-cellulosic agro-fuels can be produced from wastes such as straw, corn stove, or from annual and perennial crops like maize silage, $C_4$ grasses (*Miscanthus* spp. in Europe), *Populus* spp., *Salix* spp. as well as from temporary (high-yielding grasses and *M. sativa*) and permanent grasslands. The first agro-fuels belong to the so-called ‘‘first generation’’ while the ligno-cellulosic ones are recognized as ‘‘second generation’’. First-generation agro-fuels compete with food production on good arable land, increase pollution from fertilizers and pesticides and threaten biodiversity by inducing higher intensification on the whole agricultural surface and by converting high nature value land into intensive agro-fuel productions. Some second-generation agro-fuels like maize silage and, to a lesser extent, grass silage, mixed with slurry for methane production have the same effect. Other second-generation agro-fuels and grasslands can be produced on marginal agricultural lands, are less competitive with food production, do not require (high amounts of) fertilizers and pesticides, and should have a better impact on biodiversity. Other agricultural wastes that have low ligno-cellulose contents like slurry, mixed with maize and/or grass silage, can be used for methane production.

When considering their full life cycle, there are increasing evidences that first-generation agro-fuels (bio-ethanol and bio-diesel) in Europe are carbon sources. They release more greenhouse gases (GHG) during cropping, transportation and processing than the amount of $CO_2$ equivalent they fix. Effective agro-fuels should be carbon negative.

With respect to energy production, grassland biomass can be transformed into energy by several processes. Biological processes can be used for producing biogas (methane) by anaerobic digestion. Biomass can produce energy by direct combustion, notably in mixture with coal. It can also be transformed by gasification and other subsequent chemical reactions. Gasification relies on chemical processes at elevated temperatures (>700°C) and includes pyrolysis. In a first reaction step, the ligno-cellulosic material is partially converted to CO and $H_2$ (syngas). In a second step, the syngas can be transformed into methanol, ethanol, mixed alcohols, hydrogen, Fischer–Tropsch (FT) diesel, or combusted for heat or electricity. The FT process is a catalyzed reaction in which carbon monoxide and hydrogen are converted into liquid hydrocarbons of various forms. Combination of biomass gasification (BG) and FT synthesis is considered a very promising route to produce a synthetic fuel that can be used in diesel engines. All these transportation fuels are also referred to as "biomass-to-liquid" (BTL) fuels.

Not all grasslands types have the same aptitude for bio-methane production. Methane yields are the result of two parameters: (i) the specific methane production rate ($m^3$ $kg^{-1}$ organic dry matter [ODM]); and (ii) the biomass yield (kg ODM $ha^{-1}$) (Taube *et al.* 2007). It seems that grass species and cultivars differ little with respect to methane production rates. The development stage seems to have more influence; methane production rates seem to decrease with maturity and cutting number ranking. That has still to be investigated: the relation between digestibility and methane productivity seems not to be very close. Increasing crude fiber contents can increase methane production. Crude protein content has a negative effect which is a weakness of lucerne in this context (Eder 2006; Gröblinghoff *et al.* 2006). Typical methane annual yields of intensive grasslands would be of approximately 5000 $m^3$ $ha^{-1}$, methane yields being much affected by biomass production. Maize and whole crop small grain cereals have comparable methane production rates to grasses but usually higher biomass yields. Typical methane yields of maize for instance range 4000–10 000 $m^3$ $ha^{-1}$. As a result, biogas farmers tend to use more maize than grasses and to convert permanent grassland to maize whenever possible. In this context, the use of grass silage for bio-methane production will be mainly restricted to swards that cannot be ploughed and in marginal environments in general.

Combustion of biomass from grassland is less favorable compared to other crops or residues like straw because of higher nitrogen, sulfur, chlorine and potassium contents (Taube *et al.* 2007). Spring harvest of standing hay could reduce these contents but yield is then very much reduced (Hadders and Olsson 1997). $C_4$ grasses are better than $C_3$ grass species because of lower ash contents. $C_4$ grass cropping (*Miscanthus*) could be effective in this context.

Grassland biomass can be used as many other organic products for producing BTL fuels. However, by comparing biomass resources (straw, hay from surplus grasslands, wood residues from forestry and corn silage) in Baden-Württemberg (Germany), Leible *et al.* (2005) concluded that the use of hay from surplus grasslands and corn silage is definitely less economical than the use of wood and straw. Fresh or conserved grass could though be used with an economical support because of the multiple functions that grasslands and grassland landscapes can provide to the society. A significant research effort is still needed to better define the possible use of grassland biomass by gasification and FT synthesis.

In the USA, Tilman *et al.* (2006) have shown that agro-fuels derived from species-rich grasslands (SRG) (including several $C_4$ grasses) growing on degraded soils can produce more energy, greater GHG reduction and less pollution $hectare^{-1}$ than corn grain ethanol or soybean bio-diesel. They calculated that SRG biomass burned with coal in electric generation facilities would produce a net gain of approximately 18.1 GJ $ha^{-1}$, when converted in cellulosic ethanol and electricity of approximately 17.8 GJ $ha^{-1}$, and through gasification and FT synthesis of approximately 28.4 GJ $ha^{-1}$. According to them, net energy gains from corn and soybeans from fertile arable land are approximately 18.8 and 14.4 GJ $ha^{-1}$, respectively. They explain these differences mainly by low-energy inputs in SRG biomass production and by the use of all above-ground biomass rather than just seed. These results have been considered as highly controversial and were strongly criticized (Russelle *et al.* 2007). These comments themselves were discussed and the initial results were defended by their authors (Tilman *et al.* 2007). The conclusions have to be extrapolated with care to European conditions notably because yields are different and $C_4$ grasses are absent from European swards. Calculations from existing results and new experiments should be carried out in Europe. Tilman *et al.*'s experiment shows at least that energy balance calculations are not sufficient for comparing performances of different grasslands and crops, a life cycle analysis taking into account carbon dynamic in soil (sequestration or release) and other GHG emissions is necessary in the context of GHG mitigation.

Still in North America, cropping perennial $C_4$ grasses like switchgrass (*Panicum virgatum*) can produce 5–11 t DM ha$^{-1}$, a net energy yield of 60 GJ ha$^{-1}$ and 540% more renewable energy than non-renewable energy consumed (Schmer *et al.* 2008). Life cycle analysis showed that switchgrass crops are GHG-positive, -neutral or -negative depending on the use of inputs and subsequent yields. They have theoretically lower GHG emissions than annual crops notably because part of the biomass can be used for bio-refinery. Performances of *Miscanthus* crops should be checked in Europe.

In this new context of agricultural production, grasslands have advantages and shortcomings. They are summarized in a SWOT analysis of grasslands compared to other crops for agro-fuel production.

The strengths of grasslands are good DM yield and long persistency. Their lignin contents are low compared with some other second-generation agro-fuels. They do not require pesticide use or only low amounts. The use of nitrogen fertilizer, high fossil energy demanding for its industrial synthesis, can be reduced by the presence of legumes in the sward. Their production costs are low (long persistency, nitrogen fixation). Nitrate and phosphate pollutions are reduced. They protect soil and water. Their effect on biodiversity could be positive or very positive especially with late cuts and lucerne. Some native and persistent legume and grass species (*M. sativa*, *Phalaris arundinacea*, *Arrhenatherum elatius*, *Dactylis glomerata*, *Festuca arundinacea*) and some exotic persistent grass species (*Miscanthus* spp.) are very well adapted to low-input biomass production in Europe. In contrast with trees (*Populus* spp. and *Salix* spp.), there is no interest in using genetically modified organisms in grassland. In contrast with first-generation agro-fuels, marginal land could be used except for *Medicago*.

Weaknesses of grasslands are low sugar, starch and oil contents compared with first-generation agro-fuels. In particular, methane production kg$^{-1}$ biomass grass silage is low compared with maize silage. Abandoned or extensive grasslands are often located on sites where harvest of biomass is too expensive. An increasing demand for grassland biomass could induce intensification (e.g. slurry spreading) of the whole grassland area including of species-rich swards. Grassland used for agro-fuel could have a positive effect on wildlife only with late-cut systems, for instance one or two cuts year$^{-1}$ while better energy yields seem to be achieved with several cuts. Apart from methane production, the technology for producing energy from ligno-cellulosic material like grasses and legumes are not yet mature. Its cost is thus higher than for producing energy from first-generation agro-fuel. As a source of ligno-cellulosic material, grassland biomass has a low dry matter content compared with wood, wood residue or $C_4$ grasses. Wilting increases production costs.

The disappearance of the ''cereal and oilseed rape premium'' of the former CAP system is an opportunity for grasslands. The protection of the grassland area is integrated in the present CAP cross-compliance system (GAEP). There is a social demand and political willingness to protect the environment, landscape and biodiversity. The increase of fossil energy and input prices can increase attractiveness of perennial grasses and legumes compared with first-generation agro-fuels. An increase of cereal price can induce higher profitability of perennial species for agro-fuel production.

Threats can consist of a reduction of agricultural supports and a stagnation or a reduction of the importance of the rural development policy (second pillar) compared with the first pillar of the CAP. A significant proportion of the grassland area could be destroyed for production of first-generation agro-fuels. Agri-environmental premia could be reduced for finding financial resources of supporting agro-fuel production.

Cherney and Baker (2006) have developed a system of quotation of agro-fuels and applied it to grassland (Table 8). This table could be completed for first-generation agro-fuels. It would certainly appear that they perform worse for GHG emissions, nutrient management benefits, soil conservation, specific societal benefits, pollution, pesticide usage and biodiversity.

The same approach can compare the aptitudes of different grassland types for biomass production and GHG mitigation (Table 9). Apart from perennial $C_4$ grass cropping, the best performing swards would be legumes and

**Table 8** Score sheet of environmental and production characteristics of grass agro-fuel (Cherney and Baker 2006)

| Criteria | Maximum score (including relative importance of each factor) | Grass biomass scores |
|---|---|---|
| Greenhouse gas emissions | 15 | 14 |
| Economic feasibility | 10 | 9 |
| Local energy security | 9 | 9 |
| Energy conversion efficiency | 9 | 9 |
| Nutrient management benefits | 8 | 8 |
| Soil conservation | 8 | 8 |
| Specific societal benefits | 7 | 4 |
| Pollution potential | 6 | 4 |
| Rural development | 6 | 5 |
| Grower acceptance | 6 | 6 |
| Land suitability | 6 | 6 |
| Maintaining open spaces | 4 | 4 |
| Pesticide usage | 2 | 2 |
| Wildlife nesting/winter cover | 2 | 1 |
| Encourage species diversity | 2 | 1 |
| Total | 100 | 90 |

**Table 9** Aptitudes of different grassland types for biomass production and greenhouse gases (GHG) mitigation

| Grassland types | Aptitude for agro-fuel and GHG mitigation |
|---|---|
| Temporary | |
| Pure grass + N | — |
| Pure grass 0N | + to +++ |
| Grass + legume | +++ |
| Persistent legume (lucerne) | +++ |
| Permanent | |
| Species-poor, intensive + N | – |
| Species-poor, previously intensive, extensified 0N | +++ |
| Species-rich, extensive 0N | ++ |

—, very bad; –, bad; +, acceptable; ++, good; +++, very good.

legume-based mixtures as well as extensive grasslands including species-rich swards.

Grassland biomass can be an energy source, but it may be additionally fractionated for the production of chemicals, biogenic materials and plant fibers. The "Green Biorefinery Austria" is an example of the implementation of this idea (Wachter *et al.* 2003). The raw material from grassland (grass, legume or mixtures) is fully used to produce a multitude of "product groups". The Green Biorefinery concept from Austria is different from other international projects in so far as it allows a continuous operation of the plant; it involves not only processing of direct-cut grass but mainly of grass silage that can be stored for year-round operation. The first stage of the process consists in a mechanical fractionation of the primary raw materials into a liquid (press juice) and a solid fraction (press cake). The liquid fraction contains valuable water-soluble substances (such as lactic acids and amino acids), while the major part of the press cake consists of grass fibers. These fibers can be used for animal feeding, heating or fermentation in biogas plants. They should mainly be used as basic material for insulation materials (fiber boards, mats, fleeces, dry-blow injection insulation materials), building panels (chip boards, fiber boards, fireproof boards), materials for gardening and landscaping (mulch boards, plant bolsters, peat substitute), fiber reinforced composites (bio-composites, pre-formed parts for the automotive industry), packaging materials, additives for various building materials (bricks, plasters, mortars, wall fillers), gypsum fiber boards, paper and pulp, energy source (fuel pellets, biogas) and animal feed (pellets). The crude fiber yield from the press cake reaches 30% dry matter, which corresponds to approximately 95% of the total crude fiber content. Protein extraction seems not to be profitable yet but amino acids could be extracted from silage juice. They can be used for cosmetics, fermentation or food. Lactic acid produced by the ensiling process could be provided as a raw material for the chemical industry and could be used in the production of biodegradable plastics, environmentally friendly solvents and chemicals for the foodstuff industries. There is a wide market for this product. The technology has still to be developed but it is promising. It could use the grass produced in excess because of the decline of livestock and dairy farming, for instance the first spring cuts. It could have the effect of protecting cultural landscapes by stabilizing the grassland area.

## Discussion

The above data show that although the potential of forage production of grasslands is well documented, an important research effort has still to be devoted to the understanding of their potential for biomass and energy production.

Roeder *et al.* (2007) analyzed the impact of the CAP reform of 2003 on the use of grassland in Europe on the basis of ex ante analysis of this reform and of some more recent data. They concluded that decoupling would lead to a reduction in animal numbers (dairy and suckling cows, sheep). Accompanying measures like cross-compliance, the GAEC requirement and the implementation of the NATURA 2000 network would though stabilize the grassland area including in new Member States. They also recorded in recent years high price increases of cow milk and beef meat across several European countries. This trend could reduce the decline in the number of animals. Many other factors make the predictions difficult. Climate change mitigation policies could support the conversion of arable land to grassland for carbon sequestration; that could be implemented mainly in marginal cropping areas (South and North Europe). The production of agro-fuels can have the reverse effect by increasing the competition of maize silage towards grass silage for methane production and of many crops (sugar beet, oilseed rape, cereals) towards grassland for ethanol and bio-diesel production. That could lead to a reduction of the grassland area and a further intensification of all grassland types including species-rich grasslands. The EU biomass action plan could though be reconsidered and the ambitions for agro-fuel production lowered following the pressure of some Members States like Germany, the Organisation for Economic Cooperation and Development (OECD), the Food and Agriculture Organisation of the United Nations (FAO), many stakeholders and even the World Bank and the International Monetary Fund (IMF). Alternatively or in addition, a Code of GAEP could be imposed to first-generation agro-fuel production during a transitory phase that would lead to the development of second-generation agro-fuels. This code could impose the use of a minimum proportion of grassland biomass or the interdiction to produce crops for fuel on previous grassland areas. The

**Table 10** Influence of several technical, economic, social and political factors on grassland system components

| | Grassland yield | Grassland surface | Animal yield | Animal number | Feed price | Meat and/or milk price |
|---|---|---|---|---|---|---|
| Intensification | + | − | + | 0 | | |
| Production specialization | + | According to regions: + or − Average: − | + | − | | |
| Milk quotas | + | 0 or − | + | − | | + |
| Decoupling | + | ? + or − according to other factors | | − | | |
| Cross-compliance | 0 | 0 (without: −) | | 0 | | |
| Modulation | | + (potentially) | | | | |
| Nitrate Directive | 0 | 0 or + | +? | − | | |
| Other environmental policies | 0 | 0 or + | | 0 or − | | |
| Reduction in beef and sheep meat consumption in Europe | 0 | | | - | | |
| Increasing food demand from emergent markets | | − or +? | | | ++ | + |
| Agro-fuels | | −? | | | ++ | + |

+, increase; −, decrease; 0, stable effect.

increasing demand for cereals and other crops from developing countries could increase the pressure on the grassland area and encourage agricultural intensification in Europe. Price increases could also affect milk and meat which would temper the decrease of grassland area but would be an additional encouragement for intensification. A reduction in the EU agricultural budget due to the enlargement and changes in the world trade policies could have contrasting effects in the grassland and livestock regions leading to extensification and abandonment in some regions and intensification in others. Table 10 summarizes the influence of several technical, economic, social and political factors on grassland systems components. It appears that the clearest trends are related to the increase of intensification of grassland and animal productions as well as food and feed prices. The changes in grassland area and animal numbers are more hazardous to predict.

The future of grasslands and grassland-based systems cannot be separated from the multiple functions that they offer to society (see Introduction). In this sense, grassland is not a crop like any another and livestock systems are different from arable systems. Forage and livestock systems should be supported by the society for the services they provide including biodiversity conservation and landscape protection. They also offer recreational opportunities and they are contributing to the quality of live by producing healthy and tasty products. That is an essential part of the European culture and heritage. A higher part of the CAP budget should be devoted to the second pillar of the CAP and should target grassland systems. Additionally, agricultural and environmental policies should be modulated according to the typology of livestock systems (Pflimlin *et al.* 2005) in order to be better adapted to their specific needs. The EU is too large to apply the same policies from the north of Scandinavia to Malta and from Connemara to the Black Sea. It is easy to understand that dairy farmers from Scandinavia are facing different problems than shepherds from Sicily. Specific policy measures should be crossed with specific systems, even if a system type can include regions that are remote from each other in the EU: Spanish mountain farmers from the Pyrenees can have similar problems to Romanian farmers from the Carpathians. Grassland systems should be supported everywhere in the EU but the mountain, Mediterranean and grassland regions require the highest attention. The PDO policy of the EU should be reinforced, particularly in the countries in transition. These countries should be helped to implement this policy in regions where traditional systems were fought for approximately 50 years by centralized and very authoritative regimes. The agro-fuel policy of the EU should be reconsidered on the basis of the important amount of information that became recently available. Some political choices were obviously wrong and should be corrected. This concerns not only European citizens but also a big part of the world population that is undernourished or that could have increasing problems to find food because of the production of these agro-fuels. A new biomass policy must be defined because the "cure would be worse than the disease" (Doornbosch and Steenblik 2007).

There is no doubt that the future increase of fossil fuel price and the consequent increase of the nitrogen fertilizer price will force European farming systems to drastic reform in the next decades. In the future, systems will have to be less energy demanding. Fortunately, there are important possibilities to spare energy per ha or per ton of milk for instance

(Haas *et al.* 2001). Future researches have to focus systematically on energy costs and GHG emissions per production system and per product for developing such energy efficient systems. A new integration of grassland and arable land at the farm and/or the region levels will probably be necessary, for instance, for reducing transportation costs. Nitrogen fixation by legumes will be one of the pillars of these future systems for saving the huge amounts of fossil energy that the artificial nitrogen fertilizers require. A special effort will have to be done by livestock systems because they are less energy efficient than arable systems $kg^{-1}$ of food produced. Future systems will also have to release less GHG in the atmosphere, not only $CO_2$ but also $CH_4$ and $N_2O$. Grasslands and grassland-based systems are thus facing a new revolution.

## Acknowledgments

The author would like to thank Dr C. Huyghe (INRA-Lusignan, France) for his critical review and proof reading of the manuscript and the European Grassland Federation (EGF) for authorization to publish this article.

## References

CEC (Commission of the European Communities) (2007) 36th financial report from the Commission to the European Parliament and the Council on the European agricultural guidance and guaranteed fund, Guarantee section (2006 financial year). *COM* 562: 1–14.

Cherney JH, Baker EV (2006) *Benefits of Grass Biomass*. Cornell University, Department of Crop and Soil Sciences, Ithaca, New York. Bioenergy Information Sheet 2: 1–2.

Deprez B, Parmentier R, Lambert R, Peeters A (2007) *Les prairies temporaires: une culture durable pour les exploitations mixtes de Moyenne Belgique*. Ministère de la Région Wallonne, DGA (Belgium), Les dossiers de la recherche agricole, 2: 1–86.

Doornbosch R, Steenblik R (2007) *Biofuels: Is the Cure Worse than the Disease? Round Table on Sustainable Development*. OECD, Paris, France. General Secretariat, SG/SD/RT(2007)3: 1–57.

Eder J (2006) Maisanbau für die Biogasanlage. GFP-Workshop 'Futterpflanzen – perspektiven für die energetische Nutzung' Freising 9-10 March 2006. Bayerische Landesanstalt für Landwirtschaft, Institut für Pflanzenbau und Pflanzenzüchtung, Freising (Germany), available from URL: www.lfl.bayern.de/ipz/gruenland/18480/index.php [cited June 2006].

EEA (European Environmental Agency) (2004) *High Nature Value Farmland: Characteristics, Trends and Policy – Challenges*. EEA-report 1/2004. Copenhagen: 1–32.

EEA (European Environmental Agency) (2005) *Agriculture and Environment in EU-15 – The IRENA Indicator Report*. EEA-report 6/2005. Copenhage, Denmark, 1–128.

EEA (European Environment Agency) (2006) *Integration of Environment into EU Agriculture Policy — The IRENA Indicator-Based Assessment Report*. EEA Report No 2/2006: 1–60.

EEA (European Environment Agency) (2007) *Europe's Environment*. The fourth assessment. EEA, Copenhage, Denmark: 1–452.

EUNIS (2006) *EUNIS Habitat types*. European Environment Agency, Copenhagen (Denmark), available from URL: http://eunis.eea.europa.eu/habitats-code-browser.jsp?habCode=E#factsheet [cited 2006].

EUROPA (2004) *The Common Agricultural policy – A Policy Evolving with the Times*. European Commission, DG Agriculture, 1–14. European Commission, Brussels (Belgium), available from URL: http://ec.europa.eu/agriculture/publi/capleaflet/cap_en.htm [cited 2004].

EUROPA (2007) *Rural Development Policy 2007–2013*. European Commission, Brussels (Belgium), available from URL: http://ec.europa.eu/agriculture/rurdev/index_en.htm [cited 18 April 2008].

EUROSTAT (2005) *Structure of Agricultural Holdings by Region, Main Indicators*. European Commission, Brussels (Belgium), available from URL: http://epp.eurostat.cec.eu.int [Cited 2005].

EUROSTAT (2008) *Agriculture and Fisheries*. European Commission, Brussels (Belgium), available from URL: http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database [cited 2008].

Gröblinghoff F-F, Wulf S, Clemens J, Berendonk C, Lütke Entrup N (2006) Gräser in Biogasanlagen – erste Ergebnisse aus Nordrhein-Westfalen. In: 47. Fachtagung des DLG-Ausschusses' Gräser, Klee und Zwischenfrüchte, 35–42.

Haas G, Wetterich F, Köpke U (2001) Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. *Agric Ecosyst Environ* 83: 43–53.

Hadders G, Olsson R (1997) Harvest of grass for combustion in late summer and in spring. *Biomass Bioenergy* 12: 171–175.

Kristensen T, Soegaard K, Kristensen IS (2005) Management of grasslands in intensive dairy livestock farming. *Livest Prod Sci* 96: 61–73.

Leible L, Kälber S, Kappler G (2005) [Development of scenarios for the supply of biomass from agriculture and forestry in two model regions of Baden-Württemberg for the production of synthetic liquid fuels - Regional biomass scenarios]. Study on behalf of DaimlerChrysler AG, Karlsruhe: Forschungszentrum Karlsruhe, 1–42. (in German.)

NSI (National Statistical Institute) Bratislava (2004) *Statistical Yearbook*. 1–825.

NSI (National Statistical Institute) Sofia (2005) *Statistical Yearbook*.

Peeters A, Kopec S (1996) Production and productivity of cutting grasslands in temperate climates of Europe. In:


 

*Grasslands and Land Use Systems*. Parente G, Frame J and Orsi S (eds.). *Grassl Sci in Europe* 1: 59–73.

Pflimlin A, Buczinski B, Perrot C (2005) Proceedings of the 16th European Grassland Federation, Grado (Italy). *Grassl Sci in Europe* 1: 59–73.

Roeder N, Hennessy T, Stilmant D (2007) Impact of the CAP-reform of 2003 on the use of pastoral land in Europe. *Grassl Sci in Europe* 12: 445–462.

Russelle MP, Morey RV, Baker JM, Porter PM, Jung H-JG (2007) Comment on 'Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass'. *Science* 316: 1567b.

Schmer MR, Vogel KP, Mitchell RB, Perrin RK (2008) Net energy of cellulosic ethanol from switchgrass. *Proc Natl Acad Sci USA* 105: 464–469.

Taube F, Hermann A, Pötsch EM (2007) What are the consequences of producing energy crops in the European Union for grassland renovation and new forage production systems? *Grassl Sci in Europe* 12: 463–471.

Tilman D, Hill J, Lehman C (2006) Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science* 314: 1598–1600.

Tilman D, Hill J, Lehman C (2007) Response to comment on 'carbon-negative biofuels from low-input high-diversity grassland biomass'. *Science*, 316: 1567c.

Vidal C (2001) Extensive areas account for at least 42% of agricultural land. *EUROSTAT, Statistics Focus* 25: 1–8.

Wachter B, Mandl M, Boechzelt H, Schnitzer H, Kromus S, Narodoslawsky M (2003) Green biorefinery Austria – an integrated and sustainable technology system for utilization of green biomass. *Joanneum Res* 25: 1–5.