The role of grassland based production system in the protein security

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Abstract

Ruminant production systems are under pressure for their inefficient use of land, a recurring idea assuming they consume far more plant proteins than they produce in the form of animal protein and for their methane emission. However feed-food competition does in fact concern those proteins of plant origin that are consumable by human but are actually consumed by animals and this affirmation ignores that ruminants are able to produce products of high nutritive value from grassland and marginal area that cannot be used for crop production. In addition grassland provides many environmental services. In the last decades the intensification of ruminant production system, and particularly those of dairy systems, have increased protein production per ha of land use in Europe but this occurs thanks to an increased use of concentrate which contains edible protein and at the expense of grassland acreage. Therefore the interest of this evolution for the contribution of ruminants to food security may be questioned. Feeding animals mainly from non-edible resources can be seen as a conceptually interesting issue from a global food security point of view. After showing that the decrease in European grassland acreage was closely linked to the intensification of dairy systems and the associated reduction of the number of cows, the paper describes protein production for various ruminant production systems and demonstrates that grassland based ruminant production systems are most often much more efficient than concentrate based systems for procuring proteins. The development of grassland based systems seems very desirable to increase ruminant production systems to protein security. In addition an increased use of grassland for ruminant production could also bring positive responses to societal demand for more natural practices and could contribute to maintaining farmer incomes in a context of price volatility and the provision of various ecosystem services. The challenge might be to increase productivity of grassland based system using sustainable intensification of forage production, well suited animals and grazing management.

Keywords: ,ruminants, protein production, grassland area, food security

Introduction

Livestock production provides one third of the protein consumed by humans across the planet (Herrero *et al.*, 2009) and much more in developed countries. It uses 75% of agricultural land (Foley *et al.*, 2011) of which one third is arable land and two thirds are grassland and rangeland (Steinfeld *et al.*, 2006), consumes 35% of grain products (Alexandratos and Bruinsma, 2012) and emits 14.5% of anthropogenic greenhouse gas (Gerber *et al.*, 2013). Therefore, a recurring idea assumes that livestock, particularly ruminant, is inefficient and consumes far more plant proteins than they produce in the form of animal protein and therefore livestock production is considered as exerting a significant pressure on natural resources. Since the Livestock Long Shadow report (FAO, 2006, Steinfeld *et al.*, 2006), ruminant production systems are also considered to be responsible for the emission of large quantities of greenhouse gases. Consequently, livestock production is under pressure and given this situation, many authors propose to reduce consumption of animal protein (Garnet, 2013; Eisler *et al*, 2014), mainly in developed countries where consumption is high (Bonhommeau *et al*, 2013.) for both reducing environmental degradation and improving the human population health.

From another point of view, grasslands used by ruminants are characterized by multiple functions and values which were the subject of several syntheses (MEA 2005, Peeters, 2008). They are providing forage for grazing and browsing animals, both domestic and wild. Compared with high-density coniferous tree, 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, open space and improve the quality of life of the whole society. For all these reasons, grasslands are not a crop like another. Their social and environmental importance is much higher than other crops, including other forage crops. This importance is increasingly recognized by the society and notably by the European Union (EU).

However, ruminant production systems dramatically evolved in Europe since 30 years and the use of grassland has been significantly reduced in favour to the production of silage maize and other annual crops and the use of high concentrate diet. High milk price has encouraged high-input dairy systems. The number of cows kept indoors for all or part of the herbage growing season has increased considerably in many European countries (Van den Pol-Van Dasselaar *et al.*, 2008). For forty years, dairy cow breeding has been almost exclusively oriented towards genetic potential for milk production. Today, high genetic merit Holstein cows are able to produce more than 10,000 kg milk per lactation in high-input farming systems but cannot produce such amount of milk from grazing alone. Dry matter intake and milk yield of grazing dairy cows are limited compared to conserved forage-based diets (Kolver and Muller, 1998). Similar trends were also observed for beef and sheep meat production although less marked than for dairy production. These evolutions have increased the production per unit area devoted to livestock production in Europe but in the same time European livestock became a net importer of protein as soybean meals and grains (Galloway *et al*, 2008) in spite of exporting livestock products.

Therefore several questions can be raised: Is the claim that ruminant production systems are inefficient applicable everywhere and for all type of production systems? Did the evolution of European ruminant farming systems reduce or on the contrary increase the competition between feed for ruminant and food for human? Are intensive systems more efficient to produce proteins than grassland-based production systems which also provide ecosystem services? Are grassland-based systems less profitable for farmers than intensive production systems? These are questions on which this text attempts to give some responses.

Importance of grassland areas and grassland-based systems in Europe

Surprisingly, very little studies focused specifically on the long-term evolution of the grassland area and grassland-based systems in Europe. Cropper and Del Pozo-Ramos (2006) described the evolution of livestock numbers in the EU but other information is fragmentary and rare. It was thus important to fill this gap in the knowledge of this important topic. The European project Multisward produced a first synthesis (Peeters, 2010; Peyraud *et al.*, 2012; Huyghe *et al.*, 2014) that clarifies and quantifies more precisely the importance and the evolutions of grasslands and grassland-based systems in Europe using Eurostat (2009, 2010a and b) and FAOSTAT databases. In the Eurostat database (public website), data are not available before 1990. The FAOSTAT database provides data since 1961 including for former communist countries.

Surface of grasslands and other forage crops in Europe

In the EU-27 in 2008 the total utilised agricultural area (UAA) covered 172 million hectares or 41% of the total territory. Permanent grassland covered 57 million hectares (Eurostat) (>65 million ha according to FAOSTAT) *i.e.* about 33% of UAA whereas arable land, including temporary grassland, represented

104 million hectares (i.e. 61% of UAA) and permanent crops only 12 million hectares (6% of UAA). Other surfaces including wooded areas cover 43 million ha.

The importance of permanent grasslands varies a lot between countries. Over two thirds of the of the UAA is covered by permanent grassland in Ireland (76%), the United Kingdom (63%), over half in Slovenia (59%), Austria (54%), Luxemburg (52%) and Portugal (51%) (2007). In central and Eastern Europe, the proportion in the UAA is usually lower than the European average, such as in Bulgaria (9%), Hungary (12%) and Poland (21%) (Figure 1). Romania is an exception, this country has an important permanent grassland area and its proportion in the UAA corresponds to the EU-27 average (33%). This variability reflects the differences of ecological conditions, production systems, living standards, history and policies between countries. In terms of number of hectares the United Kingdom (11 million ha), France (9.8 million ha), Germany (4.8 million ha), Italy (4.5 million ha) and Romania (4.5 million ha) are the top 5 and represent about 64% of the total permanent grassland area in EU-27.

The permanent grassland area includes about 16.9 million ha of rangelands ('poor permanent grasslands' made of grazed semi-natural vegetation) in the EU-27 territory (10% UAA in 2007), mainly in hill, mountain and Mediterranean areas. These rangelands have usually a high nature and landscape value. Spain (33.3%), the United Kingdom (24.8%), France (8.1%), Portugal (7.5%) and Italy (5.5%) include about 79% of the total rangeland area of the EU-27.

Temporary grasslands (pure grass, grass/legume mixtures or pure legume) are mixed with forage maize, fodder beat, other annual forage crops and forage legumes in the 'forage crops' statistical category. The importance of temporary grasslands varies a lot across countries. They represent 6% of the UAA in the EU-27 and 15% of the total grassland area in the EU-27. They are more important in the North of Europe (Sweden 35%, Finland 28%, Estonia and Norway 24%, Latvia 21%, Denmark 10% UAA), in Ireland (16%), in Switzerland (11%), in the Netherlands and France (10%) (Figure 1). Temporary grassland is only more important than permanent grassland in Northern Europe (Finland, Sweden and Estonia). They can also be important in some regions like in the Po valley (Italy), in Brittany (France), in the lowlands of the United Kingdom and in the Belgian Ardennes. At the opposite, in the former communist

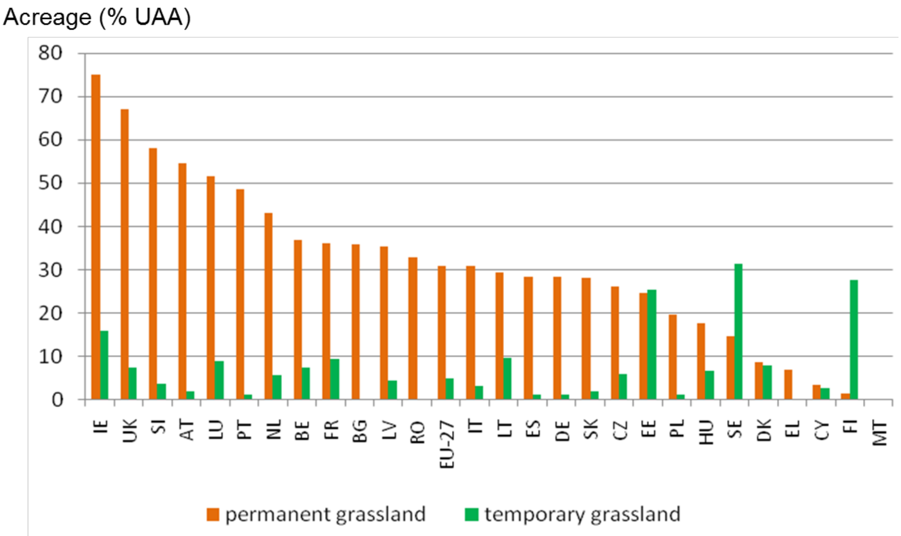

Figure 1. Share of permanent and temporary grassland in EU-27 (adapted from De Vliegher and van Gils, 2010; Eurostat, 2009).

countries, their importance is very low (Czech Republic 0.2%, Hungary 0.2%, Romania 1.4%, Poland 2.0%, Bulgaria 2.2%, Slovakia 2.5%, Slovenia 4.5%).

Maize for silage is an important crop and occupies 5.3 millions of hectares of 3.0% of the UAA. About 58% of the total area is growing in Germany and France. Silage maize is very important in relation to the UAA in Belgium (13.1% of UAA), the Netherlands (12.5% of UAA), Luxembourg (9.9% of UAA), Germany (9.7% of UAA). It represents more than 20% of the grassland area in four countries (Belgium, Netherlands, Denmark and Germany) and in the west part of France and between 10 to 20% in Luxembourg, France, Poland and Slovakia. Maize is used mainly for forage, but Germany uses maize silage on a large scale to generate biogas (De Vliegher and van Gils., 2010).

Evolution of grassland area in Europe and relation with the intensification of the dairy sector

The European grassland area has been significantly reduced during the last 30 years although the estimations of losses of the permanent grassland area vary according to the sources of information (Eurostat, FAO, national statistics). According to Eurostat, in the EU-6, these losses are estimated at about 7.1 million ha between 1967 and 2007 (Eurostat) i.e. about 30% of the value recorded in 1967. This decline is underestimated since the reunification of Germany added about 1 million ha to the total in 1990/91. The losses were very important in Belgium, France, Germany, Italy and the Netherlands (more than 30% decrease) whereas surfaces remained almost stable in Luxemburg (5% increase between 1967 and 2007) and the United Kingdom (4% decrease) (Eurostat database). In Portugal, the surface increased regularly from 0.8 to 1.8 million ha since 1993. In Spain, the surface increased suddenly between 1987 and 1990 and then remained almost stable till 2007. In Bulgaria, the surface was almost multiplied by 3 between 2005 and 2007. These three important increases are probably due, at least partly, to changes in the method of data recording. After 1989, many agricultural areas and especially grassland areas were abandoned in East European countries in transition. It is estimated that at least 30% of grassland areas were abandoned. Marginal grasslands and rangelands tended to be abandoned, especially in mountain and Mediterranean area.

The decline of the permanent grassland area is due to urbanization, afforestation and conversion to arable land. The proportion of permanent grassland in UAA declined from 40 to 29% in EU-6 with similar tendencies in France (40 to 29%), the Netherlands (58 to 43%) and Belgium (48 to 37%). According to Eurostat, the decline of the permanent grassland area seems to be reduced or even stopped after the CAP reform of 2003 which introduced conditionality linked to the maintenance of permanent grassland area to the payment aid. However this trend is not so clear in the FAOSTAT database. Indeed, national statistics reflected aggregated data that can mask contrasting regional evolutions. For example in France, this measure has not prevented a sharp decrease in permanent grassland areas in Lower Normandy and Pays de la Loire (15% or more). The destruction of permanent grassland was also important in the northwest of Germany in favor of maize crop.

The area of poor permanent grassland (rangeland) has marginally decreased from 13.2 to 11.5 million ha between 1990 and 2007 for eight countries (Belgium, Denmark, France, Ireland, Luxemburg, Spain, Netherlands, United-Kingdom). Also the total temporary grassland area can be considered as stable between 2001 and 2007.

The dairy cow population was almost stable between 1975 and 1983 but it felt down by 10 million heads in the EU-9 between 1975 and 2007 (decrease of 40% of the population of 1975 from 25.0 to 15.4 million) after the implementation of the milk quotas in 1984. This evolution was observed for a fixed amount of milk produced thus indicating a very significant increase of milk production per head. At the opposite, the suckling cow population increased by about 3 million head between 1975 and 2007 but the total number of bovine heads decreased by almost 7 million heads. The evolutions are different among countries. The dairy cow population declined sharply (about 50%) in Belgium, Denmark, France and Luxemburg. The substitution with suckling cows was though almost total or even more in Belgium, Greece, Ireland, Luxemburg and Portugal whereas about the half of the dairy cow population was replaced in Germany and France. In Italy and the United Kingdom, the suckler cow population declined, though the dairy cow population also declined, respectively by 35 and 40%.

Finally the reduction of grassland area has been tightly correlated to the reduction of the total number of cows (Figure 2) which in turn is a consequence of the increase of milk yield per cow in a context of milk quota. The intensification of dairy production had led to the development of annual crop and green maize for silage and the utilization of cereals and soybean meal at the expense of permanent grassland. Because part of the concentrate can be used as human food (cereals, soy protein…) whereas grasslands are not edible, one may wonder whether these changes have increased the net contribution of ruminant livestock to the protein security.

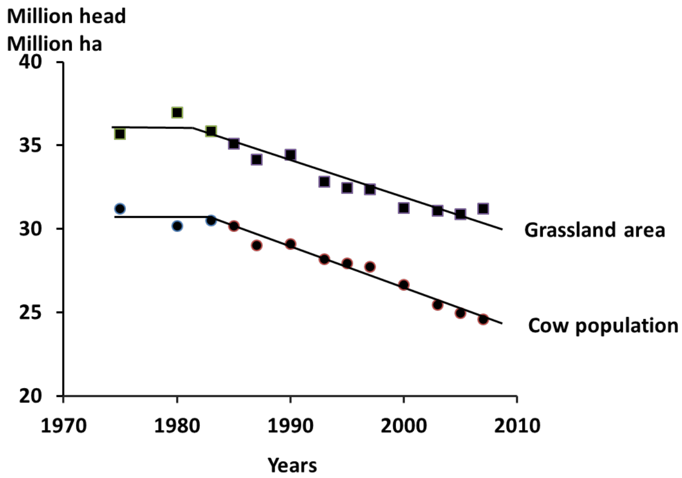

Figure 2. Parallel evolution of permanent grassland area and cow (total dairy and suckler) population in EU-9 (Eurostat, 2010; own calculations).

Contribution of grassland based production system to food security

The overall nitrogen (protein) efficiency of an animal is usually the ratio of nitrogen (proteins) outputs in products and input from ingested nitrogen (protein). In the case of young growing animals, the nitrogen retention rate is also mentioned. This ratio is always far lower than 1.0 and the remainder part of ingested nitrogen is excreted in urine and faeces. The efficiency can also be expressed by the reverse ratio that is the amount of plant protein consumed per kg of animal protein which reflects more directly the competition for the plant resources between the feed for animals and food for humans.

The apparent low protein efficiency of ruminants

Data on livestock nitrogen (protein) efficiency were synthesized by Peyraud *et al.* (2014a). Literature efficiency data show that ruminants are far less efficient than monogastric animals. The efficiency is minimal for dry adult cow or sheep, varies from 10% (dairy heifers) to 20% in growing and finishing animals and is higher in lactating dairy cows (25 to 30%). It takes more than 3 kg of plant protein to produce one kg of milk protein and between 5 and 10 kg of plant protein to produce one kg of bovine proteins. In comparison, a fattening pig fed diets based on cereals and soybean meal, retains about 30-35% of the nitrogen meaning that it takes on average 3 kg of protein of plant protein to produce 1 kg of animal protein. The protein efficiency is of the same order of magnitude for egg production. It is higher for broilers (40% and even 45% for the most productive strains). It takes 2.2 kg of plant protein to make 1 kg of broiler protein on average. These differences are explained primarily by the fact that ruminants are fed with forage-rich diets which are less digestible than diets fed to monogastrics animals.

Advances in genetic merit increased animal productivity and has led to a significant and continuous increase in nitrogen efficiency in all species. The more a dairy cow produces, the highest is the nitrogen efficiency. Efficiency increases by about 5% per tonne of milk on average. Suckler (beef) cows are less efficient than dairy cows, in particular because of their low milk production. Efficiency also increases when the nitrogen (protein) content of the diet is reduced. In dairy cows, efficiency is the highest (about 30%) for maize silage based diets supplemented with soybean meal and can be less than 25% for diets based on green forages with a high protein content (Peyraud *et al.*, 1995). This is why a large number of publications have proposed reducing the proportion of pasture grass in ruminant feeds in favour to a maize silage diet (feed depleted in protein) and a supplementation with soybean concentrates (van Vuuren and Meijs 1987; Valk 1994).

These conclusions suggest that individual cow production has to be increased to be more efficient especially as the same reasoning also applies to the reduction of methane emissions per liter of milk (FAO, 2006; Steinfeld *et al.*, 2006). However this reasoning forgets that the increase in milk and meat production per ruminant and time unit (milk per lactation, average daily live-weight gain) is obtained through an increased consumption of concentrates. These concentrates contain a large proportion of protein that can be consumed by humans. Their use in livestock feeding increases the competition between feed for ruminant and food for humans whereas ruminant have the unique capability of using grassland to produce protein of high nutritional value.

A new insight to the contribution of ruminant grassland based production system to global food security

Competition between feed and food does in fact concern those proteins of plant origin that are consumable by human but are actually consumed by animals. The amount of edible protein of animal origin produced per kg of human edible protein of plant origin is an unbiased view of the contribution of livestock to food security. If the ratio is greater than 1.0, the animal production system positively contributes to food security, if the ratio is below 1.0, the animal production system consumes more plant edible protein than it produces animal protein and if the ratio is 1.0, the system is neutral from the food security point of view. This ratio does not consider the higher nutritional value of protein of animal origin. Taking into account this difference, a ratio of 0.8 would be sufficient to at least maintain a neutral contribution since human beings must ingest less animal protein than plant protein to meet their protein requirements.

The proportions of edible protein in plants are variable between authors (Table 1). Indeed these proportions can be highly variable depending on technological processes and cultural or culinary traditions. In addition, process may change over time. Ertl *et al.* (2015a) expressed the edible fraction of various crops according to three scenarios (Table 1): a low scenario corresponding to a low usage, an average scenario which corresponds to the average data of the literature and a high scenario corresponding to the highest value of literature and potentially attainable values with innovative technologies or changes in eating habits (increased consumption of whole grains, for example). Fresh herbage and grain by-products (wheat bran, gluten feed, distillers grains ...) and beet or citrus pulp do not contain edible protein or very low amounts (i.e. up to 20% for wheat bran). The content of edible protein is high for grains such as wheat, maize and peas (i.e. 70%) and is intermediate for barley (i.e. 60%). Some protein

Table 1. Proportion (%) of edible protein in various feedstuffs.

	Wilkinson (2011)	Ertl *et al.* (2015a)[1]		
		Low	Medium	High
Grass (fresh, conserved)	0	0	0	0
Maize silage	0	19	29	45
Wheat	80	60	80	100
Wheat bran	20	0	10	20
Beet pulps	20	0	0	0
Peas	80	70	80	90
Rapeseed cake	20	30	59	87
Soybean cake	80	50	71	92

[1] A low scenario corresponds to a low usage, an average scenario corresponds to the average data of the literature and a high scenario corresponds to the highest value of literature and potentially attainable values with innovative technologies or changes in eating habits.

from cakes could potentially be extracted for the production of concentrates and the remaining part of protein could be isolated for human diet. The edible protein content of soybean meal ranges from 50 to 90% and lower values were reported for rapeseed cake (0 to 80%). These data show that the lower is the proportion of forage in the diet the lower is the contribution of ruminant to the production of protein.

Feeding animals mainly from non-edible resources can be seen as a conceptually interesting issue from a global food security point of view. Data from Ertl *et al.* (2015b) clearly show that it is possible to produce milk from grassland and crop by-products without using starch. The contribution of various EU livestock production systems to food security was recently evaluated.

In France, the efficiency of different dairy systems were recently analysed using data of the national survey of dairy farms (Institut de l'élevage, 2015) and the three scenarios proposed by Ertl *et al.* (2015a) for the edible fraction of various protein of plant origin (Laisse, unpublished, Table 2). In the lowland, grassland-based dairy systems have a very positive contribution to the supply of edible protein regardless to the selected scenario and more intensive systems using a lot of maize silage and concentrate containing a high proportion of edible protein are far less efficient, contrary to the conclusions that could be drawn from an analysis of the total plant protein consumption (see above). These intensive systems are neutral for the low scenario or consume more edible protein than they produce for the high scenario. Similar results were reported by Ertl *et al.* (2015a) from 30 Austrian mountain dairy farms where the protein efficiency is negatively correlated to the amount of concentrate distributed per kg of milk (r = -0.82). The efficiency of dairy system is lower in mountain than in the lowland because cows are fed with more concentrate per litre of milk to compensate for long winter period and medium quality forages. Finally, results heavily depend on the assumptions made for the proportion of edible protein in plant material thus underlying the necessity to determine more precisely these proportions in various countries and technologies.

According to Wilkinson (2011), who considered English livestock systems, the grassland-based beef production is broadly neutral (efficiency of 0.95 based on the weight of carcass) while intensive beef production systems using large amount of concentrates have a negative contribution to protein security (efficiency of 0.3). Production systems of monogastric animals are intermediate with an efficiency of 0.47 for broilers and pig and 0.38 to 0.43 for eggs.

Table 2. Evaluation of the contribution of various dairy systems to the net production of protein (Data Institut de l'Elevage 2015, treatment S. Laisse, unpublished).

Dairy system	Milk (kg cow^{-1})	Scenario (kg animal protein per kg edible plant protein)[1]		
		Low	Medium	High
Milk from lowland regions				
>30% maize silage in forage area	8,200	1.05	0.69	0.50
10 to 30% maize silage in forage area	7,300	1.36	0.89	0.65
<10% maize silage in forage area	6,000	2.64	1.82	1.39
Milk from humid mountain regions				
>10% maize silage in forage area	7,450	1.14	0.75	0.55
<10% maize silage in forage area	6,200	2.09	1.43	1.10

[1] A low scenario corresponds to a low usage, an average scenario corresponds to the average data of the literature and a high scenario corresponds to the highest value of literature and potentially attainable values with innovative technologies or changes in eating habits.

The grassland based dairy system are the most efficient systems to produce protein. In the study of Wilkinson (2011), dairy systems produce up to 1.4 kg of milk protein per kg of edible protein of plant origin and are the most efficient on average because they always value a lot of forages which are not edible while monogastric animals always need high quality foods. The National Farm Survey data in Ireland (Hennessy and Moran, 2014) shows the average Irish dairy farm reaches an efficiency of 1.5 kg of milk protein per kg of ingested edible plant protein. Under experimental conditions with very efficient grassland-based dairy systems a record efficiency of 4.8 was reported (Coleman *et al.*, 2010). These data clearly demonstrate the potential of grassland-based dairy cows systems to contribute to sustainable protein production.

The poorer is the ration fed to ruminants the more efficient they are and the more they contribute to the supply of protein to local populations. For example, in Egypt and Kenya, the rations for dairy and beef cattle are mainly based on low quality forages and ruminants also have there a decisive contribution to protein security; efficiency actually tending to infinity because these animals eat virtually no edible proteins (Bradford *et al.*, 1999). FAO (2011) also reported efficiencies of around 20 for farms in Kenya and Ethiopia. In Australia, under very extensive farming conditions, Wiedemann *et al.* (2015) showed that sheep and cattle grazing rangelands produced respectively 7.9 and 2.9 kg of boneless meat protein per kg of ingested edible protein of plant origin while finishing systems based on diets with a high proportion of concentrate only produced 0.5 and 0.3 kg animal protein kg^{-1} respectively for sheep and cattle.

Ruminant are often blamed for the emission of methane and it is often proposed to shift from ruminant to more monogastrics production in order to reduce the C footprint of our diet. But this evolution will to a certain extent increase feed-food competition. All the available data show that, contrary to what is often said, ruminants are very efficient animals to produce proteins provided they are fed with forages. On the contrary feeding ruminant with high amount of concentrate do not appears as an efficient strategy for a protein production point of view.

The challenge of efficient land use for increasing the production of edible protein

De Vries and De Boer (2010) calculated the total area required for the production of animal products using life-cycle assessment in a comprehensive study. In conventional systems, the mean values ranged from 5 to 6.5 m^2 to produce one kg of chicken or pork (i.e. 180 to 220 kg of meat protein per ha), 4.5 to 6 m^2 for one kg of egg (i.e. 210 to 280 kg of egg protein per ha), 1.2 to 1.5 m^2 per litre of milk (i.e. 200

to 250 kg milk protein ha^{-1}) and 20-25 m² kg^{-1} live weight of cattle at fattening (i.e. 30 to 80 kg of meat protein ha^{-1}). Again considering land use efficiency ruminants appears less efficient than pig or poultry.

In the case of ruminants, previous calculations took into account the entire land area, including those on which it is not possible to produce annual crops while precisely ruminants can contribute to food security by using permanent grassland area that cannot be used for food production or lead to very low yields of annual crops. In this case, they are not in competition with the production of edible protein of plant origins. At the global level, 3.35 billion ha are used in this way (Sere and Steinfeld, 1996) by more than 360 million cattle and 600 million small ruminants and provide 25% of animal products. In European conditions, permanent grassland and rangelands cover 73 million hectares or 40% of the utilized agricultural area (Eurostat, 2009).

In fertile plains, where grassland can often be converted to arable land, the question of the relative yield of protein by ruminants on grassland or by crops can be raised considering that crop production leads to a much higher production of edible protein per unit of land than milk or meat production because it by-passes the transformation step by animals. Conversely the reduction of grassland area also reduces the provision of ecosystems services. Precise estimates of land area required for livestock production according to the production system were the subject of few studies. The French national survey of dairy farms shows that milk production averages 6,000 kg milk ha^{-1} of forage area in grassland systems representing 180 kg of protein ha^{-1} (Institut de l'Elevage, 2015). This productivity can be considered as rather low as it requires the contribution of the equivalent of 0,015 hectares of cereals to cover the needs of the herd, but in this situation cows produce more than 2 kg of milk protein per kg of edible protein of plant origin and contributes to maintain one ha of grassland and ecosystem services it provides. In Ireland, dairy systems are designed to maximize milk yield per hectare. According to the National Farm Survey (Hennessy and Moran, 2014), the average Irish dairy farm produces 375 kg of milk protein ha^{-1} of grass and milk protein yield reaches a record of 550 kg ha^{-1} under experimental conditions using optimized grassland management and suitable animal genetic for grassland-based systems.

In comparison, one ha of wheat producing 8 t DM with 12% protein or 1 ha of pea producing 3 t DM with 22% protein respectively produce 780 and 540 kg of edible protein (20% of their protein are not edible). But, these differences in productivity must also be balanced considering the nutritional value of protein produced.

The nutritional quality of food proteins is evaluated by the index digestible indispensable amino acid score (DIAAS) which was proposed by FAO (2013). This index is calculated from the composition of Indispensable Amino Acid and digestibility in the small intestine of each IAA. Proteins of animal origin are characterized by a much higher DIAAS index than the protein of plant origin. The AAI composition of meat and dairy products corresponds to human needs as they were estimated by AFSSA (2007) that is not the case for protein of plant origin and intestinal digestibility of animal protein is higher than that of plant protein (Gaudichon *et al.*, 2002). The DIAAS value average 135 for meat and milk. Among plant protein, soy proteins are the most similar to animal protein with a DIAAS index equal to 102. A mixture of wheat and peas achieves a DIAAS value of 105 whereas pea and wheat have far lower value due to an imbalanced profile of IAA (80 and 60 respectively). This means that it is necessary to eat 20 to 25% more protein of plant origin than protein of animal origin to cover daily human requirements. This nutritional factor must be taken into account when comparing the productivity of land used for producing animal protein versus edible plant protein.

These data demonstrate the potential of grassland-based dairy cows systems to contribute to sustainable protein production. This requires developing more efficient dairy systems based on grazing. This necessitates many levers and technical innovations as increasing stocking rate, extending the grazing season, using multispecies sward and adapted fertilisation, improving herbage quality, using appropriate animals etc. that were described in many publications (e.g. Peyraud *et al.*, 2004; 2010).

Does intensification of dairy systems allow increasing the net protein production?

The increase in milk and meat production per animal and time unit is obtained through an increased consumption of concentrates containing large proportions of edible protein which ultimately leads to reducing the contribution of ruminant to the net supply of protein. The intensification of dairy farming should be analysed regarding its interest for the supply of edible protein although this strategy allows increasing animal protein production per hectare of the farm it relies on virtual hectares of imported feed. For example in France, intensive dairy systems based on maize silage produce more milk protein per hectare than more extensive systems (270 vs 180 kg protein ha^{-1}; Institut de l'élevage, 2015), allow to produce crops on available land not used for grassland production but, in the same time these systems require more imported soybeans and grain for feeding the herd.

For analysing the impact on the real protein efficiency, we simulated a dairy farm (75 ha UAA, 400,000 l of milk or 12,000 kg of milk protein) in an intensive system with maize silage versus a grassland-based system with low inputs of concentrate. For the same level of milk production, the intensive system can use part of the land area for producing annual crops. The intensive system produces more milk proteins per ha of forage (261 vs 166 kg), a little less meat protein because the herd has fewer cows but produces more protein crops. However the intensive system requires buying more soy protein and a little more grain to feed the herd compared to the grassland-based system. In the end, the net production of edible protein hardly differs between the two systems, but the maize based system is much less efficient than the grassland-based system (respectively 0.92 and 1.97 kg of animal protein kg^{-1} of edible plant protein consumed by the herd). The net protein production of these two systems is in fact strongly influenced by the proportion of edible protein in soybean cake. If this latter increases from 50 (as it is stated in Table 3) to 70% (due to technological progresses for example) the net production of edible protein will become very low in intensive systems (206 kg) and will be maintained at a higher level (i.e. 7,700 kg) in the grassland based system.

Do ruminant grassland-based production systems allow high incomes for farmers?

The comparisons made at the world level show that dairying systems maximising grassland utilisation appear to be highly competitive compared to intensive systems based on indoors feeding and concentrates. A study of international competitiveness (Dillon *et al.*, 2008) has shown that the total cost of production is negatively related to the proportion of grass in the cow's diet. This cost is therefore 50 to 60% higher in Denmark and the Netherlands than in Ireland, whereas France and UK are intermediate. However this is a global approach comparing countries where climatic conditions are very different. Ireland benefits from a climate ideally suited for grassland-based production systems but which does not allow producing cereals in a competitive way. To (re)develop ruminant production systems based on grassland in region where farmers can choose between grassland and annual crops, it is worth checking that these systems provide a sufficient income for farmers. Few studies have been published comparing economic performances across farm according to the production system in a fixed regional context. They show that alternative paths to scale enlargement and spurred intensification are feasible.

In France, Peyraud *et al.* (2014) compared average data of grassland-based and more intensive dairy farms from the 'Sustainable Agricultural Network' (SAN) (about forty farms) and from the French Farm Accounting Agency (RICA) between 2008 and 2012. The farms of the French SAN network are on average smaller than those of the RICA network (56 vs 78 ha), use more grass (87 vs 67% of their

Table 3. Simulation of production of edible protein for two contrasting dairy systems (Delaby and Peyraud, unpublished).

Farm characteristics	Maize-based system	Grassland-based system
Land: Grassland – Maize silage – Crops (ha)	12.9 – 35.5 – 26.6	72.1 – 0.0 – 2.9
Yield: Grassland – Maize silage – Crops (t DM[1] ha^{-1})	7.0 -12.0 – 7.0	8.0 – 0.0 – 6.0
Dairy cows (Total livestock units including heifers)	50 (83,3)	63 (98,9)
Stocking rate (Lu ha^{-1} forage area)	1.72	1.37
Milk (kg cow^{-1} $year^{-1}$)	8,700	6,900
Milk (kg ha^{-1} forage area)	8,264	5,547
Total production of edible protein (farm gate)		
Milk	12,000	12,000
Meat (culled cow and calves)	930	1,163
Crops[2]	17,900	2,088
Concentrate required to feed the herd		
Purchases soybean meal (t $year^{-1}$)	77.0	9.1
Purchased or home grown cereals (t $year^{-1}$)	49.5	46.8
Edible Proteins of plant origin[3] required to feed the herd		
as soybean meal (kg $year^{-1}$)	18,400	2,184
as cereals (kg $year^{-1}$)	4,752	4,492
Net production of edible proteins[4] (kg)	7,678	8,575
Efficiency of protein production of animal origin[5]	0.92	1.97

[1] Dry matter.

[2] Assuming that 20% of cereal protein are non-edible.

[3] Assuming that 50% of soybean protein and 20% of cereal proteins are not edible.

[4] Difference between total production of protein at farm gate and consumption of edible protein of plant origin by the herd.

[5] Kg of protein of animal origin per kg edible protein consumed by the herd.

Main Forage Area) and thus less silage maize (11 vs 32%) and produce less cereals (8 vs 20 ha). In spite of a lower quota (266,500 vs 349,900 l yr^{-1}) and a smaller total value of products per agricultural working unit (AWU) (88,454 vs 104,840 € AWU^{-1}), the farms of the SAN network produce an income before tax that is higher (21,907 vs 17,261 € AWU^{-1}) than on the average farms of the RICA, because of savings on the production costs (248 vs 568 € ha^{-1}). These savings relate mainly to the purchases of concentrated feed (154 vs 320 € ha^{-1}) and inorganic fertilizers (21 vs 92 € ha^{-1}). The economic result before tax and without subsidies, which reveals the real technical performance of the system, is much higher in the farms of the SAN network (7,180 vs 1,490 € AWU^{-1}) (Peyraud *et al.*, 2014).

Another study (Samson *et al.*, 2012) has compared the technical and economic performances of dairy farms from three French lowland regions (Brittany, Lower Normandy and Loire Region) according to their intensification level, in a sample of specialized dairy farms from the RICA network over 3 years (2004-2006). Their farm typology distinguishes three classes of intensification/ self-sufficiency rate on the basis of thresholds of input costs: extensive/more self-sufficient (<390 € ha^{-1}), intermediate (between 390 and 590 € ha^{-1}) and intensive/less self-sufficient (>590 € ha^{-1}). The French studies put figures on different farming paths and compare them in terms of performance and viability The three classes of intensification/self-sufficiency based on the input costs per ha of the RICA network are closely associated to a variation of grassland in the main fodder area (grasslands + other green forage cropped on arable area). More self-sufficient farms include more grasslands than less self-sufficient ones. The degree of intensification does not seem to be a key explanatory factor for the differences in technical-economic performances. The differences in net margins per worker between the three levels of intensification are low, Brittany being the only region where the net margin increases with the levels of intensification (respectively 9,800, 10,800 and 12,100 € AWU^{-1} from extensive to intensive levels) whereas, in the other regions, the most extensive class has on average better performances than the most intensive class (respectively 13,600, 10,300 and 6,800 € UWA^{-1} on average). In this study, the most self-sufficient, which are also the more grassland-based systems, appear to be more resilient to price crises because the share of variable costs in the cost of milk production is always significantly lower than in the more intensive systems (0.10 vs 0.13 vs 0.16 € l^{-1} respectively for the extensive, intermediate and more intensive systems) whereas the market price of milk practically does not vary from one system to another. The strong reduction in milk price in 2009 had relatively less impact on the systems of the SAN network than on the specialized farms of the RICA network. The average level of income before the price crisis was reached again in 2010 after an improvement in the milk price level. In the latter study, as well as in the previous one, the variability of the results within farm class is very important which shows that progress in margins exist in all these systems.

In the Netherlands, Oostindie *et al.* (2013) studied a sample of 1000 dairy farms collecting precise farm accountancy data for the 2007-2010 period. A group of so-called 'economical farmers' could be distinguished (using farming style analysis). Keeping costs associated with the acquisition of external inputs as low as possible was key in their strategy. The same applies to financial costs: debts were kept at low levels. They showed that in the economical farms the costs for animal feed per dairy cow equalled 393 € cow^{-1} $year^{-1}$ (in 2010). This is far below the level of large-scale intensive farms (560 € cow^{-1} $year^{-1}$) and of small-scale intensive farms (619 € cow^{-1} $year^{-1}$). Similar or even larger differences were found for fertilizer use. In years with relatively good milk prices (2007, 2010), the net farm incomes realized within the different styles were similar, even while the size of the large-scale, intensive farms (1,400,000 kg of milk) was far beyond the one of 'economical farmers' (560,000 kg of milk). However, in years with low milk prices (2008, 2009), the income of the latter was far higher than of large-scale, intensive farmers. A part of the large-scale, intensive farms even faced a negative cash flow.

Conclusions

The competition between feed for animal production and food for human is becoming a crucial issue considering the expected increase of human population. In this context, livestock and particularly ruminant production are often blamed for their inefficient use of resources including land and for their methane emission. The contribution of ruminant production systems to protein security cannot simply be evaluated by the ratio between animal protein production and the total amount of proteins of plant origin consumed because ruminants have the ability to produce high nutritional products from grassland which cannot be used directly in human food. Grassland-based dairy system can produce up to 2 kg of animal protein or even more per kg of edible plant protein consumed by cows and thus have a very positive contribution to protein security. The intensification of ruminant production system with the development of maize silage and the utilisation of high amount of concentrate at the expense of grassland has indisputably contributed to increase protein yield per hectare used in Europe but has also increased the imports of protein thus reducing European autonomy. Their contribution to protein security does not exceed those of grassland-based systems and indeed are often lower and they increase the feed-food competition. The true efficiency of these systems might be even weaker in the future when the development of new technologies will allow using more protein of plant origin (i.e. cakes) in human food.

From a feed security point of view, the challenge will be to increase protein production per hectare for grassland-based system. Protein yield per hectare of grassland are quite variable and thus there is quite considerable scope to improve the performances of dairy systems based on grassland. We must consider a better management of forage production and conservation, better management of grazing (Peyraud *et al.*, 2010, 2014) and utilization of more appropriate ruminant phenotype to maximize forage use efficiency and limit the appearance of livestock inefficiencies such as fall in fertility or rearing mortality.

An increased use of grassland for ruminant production could also bring positive responses to societal demand for more natural practices and could contribute to the provision of various ecosystem services. In addition, several studies also demonstrated that the economic performances of grassland-based systems are similar and sometimes higher than those observed in more intensive systems. However, grassland utilization remains dependent on the willingness of farmers that are often reluctant and on the attitude of the other actors of marketing chains.

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