Potentials and challenges for future sustainable grassland utilisation in animal production

Leiber F., Jouven M., Martín B., Priolo A., Coppa M., Prache S., Heckendorn F., Baumont R.

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Potentials and challenges for future sustainable grassland utilisation in animal production

F. Leiber[1,*], M. Jouven[2], B. Martin[3], A. Priolo[4], M. Coppa[5], S. Prache[3], F. Heckendorn[1] and R. Baumont[3]

[1]FiBL, Research Institute of Organic Agriculture, 5070 Frick (Switzerland)
[2]Montpellier SupAgro, 2 place Pierre Viala, 34060 Montpellier Cedex 02 (France)
[3]INRA, UMR1213, Centre de Clermont-Ferrand / Theix, 63122 Saint-Genès-Champanelle (France)
[4]University of Catania, Department of Animal Sciences, 95123 Catania (Italy)
[5]University of Torino, Departement of Agriculture, Forestry and Food, 10095 Grugliasco (Italy)
*e-mail: florian.leiber@fibl.org

Abstract. The paper highlights particular benefits and challenges coming along with ruminant production on permanent grasslands and rangelands. A threefold synergy is (i) the utilisation of a nutrient source which is independent of arable land, (ii) the ecological benefits of maintained permanent pastures, and (iii) the production of food with a high nutritional and sensory quality. However, a sustainable use of these pastures requires appropriate management, facing very different challenges depending on the regional conditions. Systemic management schemes based on specific characteristics of the pastures are required for their maintenance and/or development. A further challenge are pasture-bound gastro-intestinal parasites control, which are, however at least partly also an issue of grazing management. The particular nutritional properties of grassland-derived products are scientifically well established, although deeper understanding of specific underlying metabolic mechanisms is still an objective of ongoing manifold research. Implementation of instruments for evaluation of these nutritional values in the market chain is lacking. Scientifically many options for the authentication of grassland-based products are under development, and a major task remains their implementation into practice. Decisive for all successful developments are the economic and political frameworks. A multi-perspective re-consideration of the concepts of efficiency for animal production seems to be required for a fair assessment of the services that production systems based on grasslands and rangelands bring to global food production.

Keywords. Permanent grassland – Forage production – Management – Product quality – Traceability – Animal health.

Potentialités et défis pour une future utilisation durable des prairies en production animale

Résumé. *Cet article met en avant les bénéfices particuliers et les défis auxquels est confrontée la production de ruminants à partir des prairies permanentes et des parcours. Une triple synergie réside dans (i) l'utilisation d'une source de nutriments indépendante des productions des terres arables, (ii) les bénéfices environnementaux du maintien des prairies permanentes, et (iii) la fourniture de produits animaux de haute valeur nutritionnelle et sensorielle. Cependant, une utilisation durable de ces prairies nécessite une conduite appropriée, qui doit faire face à différents défis selon les conditions régionales. Des schémas de conduites systématiques basés sur les caractéristiques spécifiques des prairies sont nécessaires à leur entretien. Un autre défi vient des effets des parasites gastro-intestinaux liés aux prairies, dont la maîtrise dépend en partie de la conduite du pâturage. Les propriétés nutritionnelles particulières des produits animaux issus des prairies sont bien établies scientifiquement, bien qu'une compréhension plus complète des mécanismes métaboliques sous-jacents demeure un objectif de nombreux travaux de recherche. Les moyens techniques pour faire valoir cette valeur nutritionnelle des produits dans les filières économiques sont encore insuffisants. De nombreuses méthodes d'authentification des produits issus des prairies sont en cours de développement, mais une tâche majeure reste de les mettre en œuvre dans la pratique. Le cadre économique et politique est décisif pour tous les développements réussis. Une reconsidération du concept d'efficience de la production animale dans une perspective multiple semble nécessaire pour une évaluation équitable des services que les systèmes de production basés sur les prairies et les parcours apportent à la production alimentaire globale.*

Mots-clés. *Prairie permanente – Production de fourrages – Conduite – Qualité des produits – Traçabilité – Santé animale.*

I – Introduction: European grass- and rangelands and their potential contribution to livestock production, in economic and ecological perspectives

About two thirds of the global agricultural land consists of grasslands and rangelands. In Europe, including the Russian Federation, more than 40% of the total agricultural lands are permanent or temporary meadows and pastures (FAOSTAT, 2013). These areas are the most significant source of feed for domestic herbivores: forages (grazed or conserved) represent approximately 50% of all livestock feedstuffs, globally (Herrero *et al.*, 2013). The permanent pastures are often located in areas, which cannot be used as croplands because of topography, lack of/or oversupply of water, poor soils, or extreme climatic conditions, what defines them as marginal areas. By contrast, temporary meadows are often part of crop rotations and may provide forage with a high density of well digestible nutrients. From both types, a nutrient resource is provided, which can be efficiently converted into human food by ruminant livestock. Due to their digestive physiology, which combines fermentation, chewing and particle sorting in a unique way, ruminants are able to degrade plant fibres efficiently and upgrade nitrogen into amino-acids (Clauss *et al.*, 2010).

A key issue of the evaluation of grassland utilization is the controversial ongoing debate about the contribution of ruminant livestock to counteract or to increase the current environmental problems. Ruminant production on grassland reduces the production pressure on the globally limited arable land (O'Mara, 2012; Taube *et al.*, 2014). However, grassland/rangeland swards largely differ regarding their nutrient density and digestibility (depending on soil and climate conditions, but to a large degree also on management – cf. Boval and Dixon, 2012). This determines their feeding value and the efficiency, including the "eco-efficiency" of ruminant production, if it is calculated as the ratio of resource inputs (nutrients, surfaces, fossil energy and climate-related values) and food nutrient outputs (Herrero *et al.*, 2013; Taube *et al.*, 2014). Because nutrients in swards are not as dense as in grains, this can lead to conclusions, that the intensive grain-based production of pork and poultry products is more efficient and less impacting the climate than any grassland-based ruminant production (Pelletier and Tyedmers, 2010; Herrero *et al.*, 2013). This perspective has to be countered by the fact that a large share of feedstuffs for monogastric animals comprises human edible cereals and oilseeds, thus permanently increasing the pressure towards larger arable land areas, which finally requires ongoing deforestation. It can be further considered that large parts of the global grass- and rangelands can only be maintained with no alternative of utilization other than with ruminants. On this background it is reasonable to calculate the efficiency of livestock production from the inputs of arable land or of human edible protein and calories (Wilkinson, 2011; O'Mara, 2012.). In this respect, ruminant production is highly competitive with that of monogastric livestock, because it relies less on inputs from arable land (O'Mara, 2012), and grassland/rangeland utilisation can be regarded as a core contribution of ruminant livestock to sustainable global resource use. Grassland utilisation with ruminants proved to be the key to reach an efficient conversion rate of human edible feed into animal products (Wilkinson, 2011).

Further, grasslands/rangelands are highly multifunctional and provide important ecological side-effects. These effects are in the first line the habitat function for a high diversity of wild flora and fauna (Mikhailova *et al.*, 2000; Rook and Tallowin, 2003; O'Mara, 2012) and a high potential for carbon sequestration in the soils below grasslands (O'Mara, 2012; Taube *et al.*, 2014). A further important effect of forage-rich diets for livestock is a clear positive impact on the nutritive quality of the resulting products, especially regarding antioxidants, lipid quality and fat soluble vitamins. The quality is clearly related to the botanical biodiversity of the pastures which is associated with a diversity of plant active compounds influencing the animals' metabolism. (Jayanegara *et al.*, 2011; Buccioni *et al.*, 2012; Willems *et al.*, 2014). Summarizing, the use of grasslands for ruminant grazing under proper management affords four main synergistic effects: (i) provision of food which is based on local resources and not in competition to edible arable products, (ii) high-quality products,

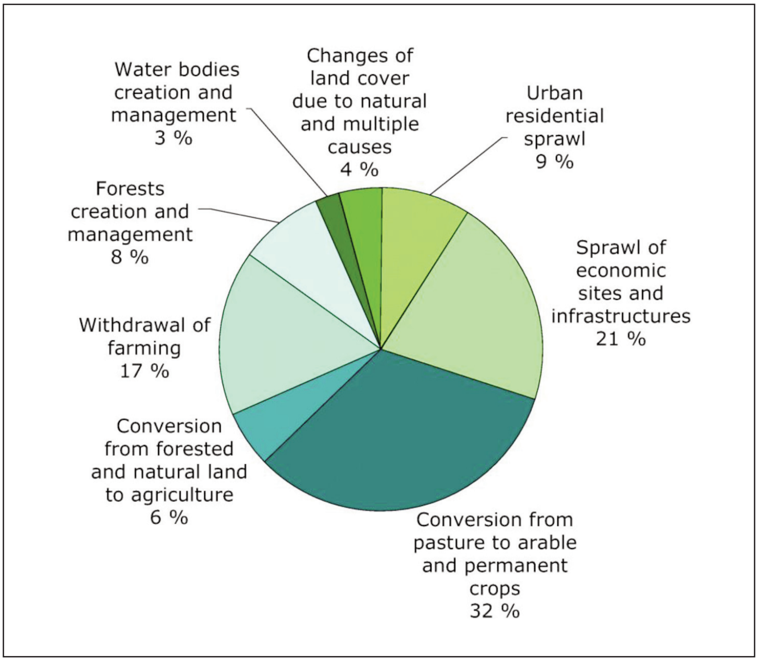

Fig. 1. Causes of loss of grasslands in Europe. From EEA (2010).

(iii) a reservoir of biodiversity, and (iv) a potential carbon sink. These four elements have to be considered together in any assessment of the eco-efficiency of grassland-based livestock systems.

Grassland/rangeland areas are worldwide under high pressure, which appears however in very different forms, depending on the regions. While in many countries overgrazing, i.e. a too high density of livestock per hectare, causes severe degradation, erosion and loss of the natural grasslands (Robinson *et al.*, 2003; Taube *et al.*, 2014), in Europe, particularly in the mountain regions and in southern and eastern European countries, the problem is more often underutilization and abandonment of pastures due to societal and economic changes, followed by encroachment and successive woody vegetations (Hadjigeorgiou *et al.*, 2005; Mikhailova *et al.*, 2000). By contrast, in northern European regions, wherever the conversion into arable land is possible, ploughing up is the main pressure on the permanent pastures (Taube *et al.*, 2014). More than 50% of grassland losses in Europe are due to the reasons mentioned (Fig. 1), which are all rooted in agricultural management decisions. The challenge these cases have in common, is the efficient and long-term sustainable use of the grasslands/rangelands. This means for every region that management options have to be developed, which increase the nutritive value of the grazed forage (Boval and Dixon, 2012; O'Mara, 2012; Herrero *et al.*, 2013), in order to (depending on the region and policy): (i) make the animal production more competitive in economic and ecological scales, (ii) increase the achievable income, and thus increase the stakeholders' motivation to use and maintain the permanent pastures, (iii) adapt animal numbers per hectare to the carrying capacity of the grassland/rangeland and thus implementing management options that avoid degradation, (iv) improve the health of grazing animals, particularly with respect to pasture-born parasites, and (v) introduce active policies (temporary or permanently) that pay to fill the gap between productive and ecological functions. Further, there will necessary be trade-offs between nutritive and ecological values (Baur *et al.*, 2007) as well as between main nutrients and functional plant metabolites that enhance product quality (Leiber *et al.*, 2006; Jayanegara *et al.*, 2011). Management options, which help to reconcile these different aspects, will be highly required for the future maintenance and development of grassland/rangeland-based livestock systems. Additionally, market concepts that provide a higher price for the nutritional quality and ecological function of grassland-derived products are highly needed. These market developments have to be based on a specific product authentication, requiring further research and development efforts.

Summing up, the maintenance and efficient utilisation of European grassland resources requires further efforts on the levels of research, close-to-practice management development and political measures. Important needs and potential in research and practice developments will be specified within this paper.

II – Potential and constraints of permanent pastures (grass- and rangelands) for provision of forage

Species composition of permanent grasslands and rangelands varies in large proportion according to pedo-climatic conditions and management practices. Every sward is a unique mixture of species differing in their functional traits (Violle *et al.*, 2007), and thus responding differently to climatic conditions and utilization. Based on functional traits (e.g. specific leaf area and leaf dry-matter content), plant community ecologists classify species in functional types. These types correspond to plant growth strategies according to fertility level and defoliation rate (Cruz *et al.*, 2002; Louault *et al.*, 2005). Competitive species adapted to fertile soils and frequent (e.g. *Lolium perenne*) or less frequent defoliation (e.g. *Dactylis glomerata*) are characterized by high specific leaf areas and low leaf dry-matter content, favouring fast regrowth after defoliation. In contrast, conservative species adapted to infertile soils (e.g. *Festuca rubra*) show low specific leaf area and high leaf dry-matter content. Theoretically, based on such classifications, each plant species can be associated with a gradient of production and digestibility values (which usually refer to spring growth). At paddock scale, a sward can also be described by its functional composition, which can be translated into technical characteristics, such as precocity, suitability for being grazed late in the season, etc. (Duru *et al.*, 2010; Launay *et al.*, 2011).

A recent study in France (Michaud *et al.*, 2011) characterized a set of 190 permanent pastures representative of most pedo-climatic conditions from Atlantic to Alpine areas (excluding Mediterranean areas). The high variability observed in forage production (between 4.2 and 8.1 t DM/ha obtained with 4 cuts for most of the paddocks) and digestibility (between 0.70 and 0.83 g/g at the beginning of spring) was to some extent related to the functional composition of the grasslands, in terms of botanical families and functional types of grasses (Baumont *et al.*, 2012). The most productive grasslands in spring and during the whole year (r = 0.81 between both) were those richest in competitive grasses. In contrast, a negative relationship was observed between forage yield and the proportion of conservative grasses in the grasslands. Forage quality, both at the beginning and the end of spring, was positively related to the proportion of legumes species in the grasslands, as legume proportion increased crude protein content, but also digestibility in studies for sown multi-species swards (Huyghe *et al*,. 2008). A higher stability of forage quality in spring was related to high proportions of forbs and conservative grasses. Knowledge of the temporal patterns of forage availability and quality can help to define appropriate grassland management to cope with the nutritional demand of the animals (Duru *et al.*, 2010). For example, productive grasslands rich in competitive grasses are adapted for harvesting and need early utilisation to maintain forage quality. Grasslands with high proportion of legumes and thus high protein content will be adapted for grazing by high producing animals. Thus, for each paddock, a range of possible utilizations can be defined, as a result of its grass functional composition. This is particularly true in mountain conditions, where the altitude gradient increases the diversity. Typical mountain pastures rich in conservative grasses have to be exploited in an extensive manner, and can provide grass later in season and due to their botanical diversity other forage services linked to product quality and animal health.

The methods to characterize grasslands cannot, in most cases, be applied to rangelands, for two reasons: first, rangeland vegetation often includes shrubs and trees, and second, rangelands are often grazed after grass growth peak, in such management conditions that the animals are able to select a diet which has little to do with the average composition of the sward. The presence of shrubs and trees creates patches of shade which modify water and light availability for the underlying herbaceous species; thus, the abundance and quality of the underlying grass species are different (Zarovali *et al.*, 2007). While research has been focussed on characterizing the nutritive value of green forage, rangelands are often used in summer or winter, when at least part of the sward is senescent. When animals graze, they compose a diet by selecting plant species and plant parts as a function of the relative quality and palatability of the items available, but also from their previous feeding experience and of the grazing conditions determined by management (Baumont *et al.*, 2000; Provenza *et al.*, 2003). Thus, both the available forage on the pasture and the ingested diet of the grazing animals, are difficult to predict.

The methods effectively used to characterize forage production on rangelands are based on three major assumptions: (1) numeric precision would be vain, since it would be impossible to document the immense diversity of situations encountered, (2) the most pertinent information is the amount and quality of intake, and not the amount and quality of the whole sward, (3) the rangeland cannot be characterized independently from the grazing management applied. Based on such assumptions, a typology was established in the 1990s for French peri-Mediterranean regions (IDELE, 1999). Based on a typology of rangeland vegetation which takes into accounts both the type and abundance of herbaceous and shrub cover, it proposes a range of possible utilizations. An utilization is characterized by the season, stocking density, total or partial consumption of the herbaceous layer, nutritional requirements of the animals, supplementation-if any- and number of daily rations grazed, expressed in “days x sheep”. Thus, the latter information includes an evaluation of the amount and quality (through nutritional requirements of the grazing animals and supplementation) of the forage ingested on the rangeland. Such information has been successfully used for the design of decision support tools (see Martin *et al.*, 2014 ibid). A major challenge in the future will consist in linking the complementary methods of grassland and rangeland evaluation, which might prove that rangelands can be considered as a decent forage resource, even for productive farming systems.

III – Contribution of grasslands to dairy product quality

The sensory and nutritional characteristics of dairy products are governed first by a number of factors linked to the processing of milk. The chemical and microbiological characteristics of the raw milk used also play a major role, in particular in the case of products in which the raw material modifications during processing are restricted. The characteristics of raw milk used are dependent on factors linked to animal characteristics and management that have increasingly been the focus of consumers’ concern. Among these factors, animals’ diets are sensitive because some of them, like pasture, carry a positive image that can be attractive to consumers and most importantly because they may confer special nutritional and sensory properties to the dairy products.

It is now clearly established that the fatty acid and antioxidant content and composition of the feedstuffs fed to ruminants are the main drivers of the plasticity of milk in these nutritionally relevant components. In particular, grazed grass has a high content of fat rich in C18:3n-3 and high amounts of tocopherol and carotene while, on the opposite, maize silage and cereals are rich in C18:2n-6 and contain only little carotene and tocopherol. As a consequence, in comparison to milks derived from diets based on maize silage or cereals, pasture derived milks have a lower content in saturated fatty acids (some having a clear negative impact on human health, i.e. C16:0) and a higher content in unsaturated fatty acids including the major c9C18:1 monounsaturated fatty acid and minor trans and polyunsaturated fatty acids like C18:3n-3 and c9t11CLA considered as positive for human health (Chilliard *et al.*, 2007; Shingfield *et al.*, 2013). Pasture derived milks are also richer in antioxidants like carotenes, retinol, tocopherol and some phenolic compounds capable to protect the unsaturated fat against oxidation (Noziere *et al.*, 2006; Besle *et al.*, 2010). In mixed diets, the enrichment of unsaturated fatty acids and antioxidants in milk is proportional to the percentage of pasture in the diet (Coppa *et al.*, 2013). As the grass content in fat and carotenes decreases while grass matures, the specific positive features of pasture derived milk are higher when pasture is grazed at a vegetative stage. Milk derived from grass preserved in the form of hay or silage has an intermediate pattern because most of the nutritionally relevant compounds in grass are partly lost or oxidized during harvesting: some compounds i.e. C18:3n-3 are close to that of pasture derived milks and most of the other like the major c9C18:1 and C16:0 fatty acids are close to that of maize silage or concentrate derived milks (Chilliard *et al.*, 2007).

From the sensory point of view, many experiments (reviewed by Martin *et al.* 2005) have shown that feeding dairy cattle with pasture grass in comparison to winter diets, in particular those including high amounts of concentrate or maize silage, leads to more yellow butter and cheese because of their higher content in pigments, i.e. β-carotene. Cheeses have also a softer texture due of the lower melting point of the fat, richer in long chain unsaturated fatty acids. The raw milk cheeses issuing from pasture are also generally characterized by their stronger flavor associated to specific volatile compounds arising from the catabolism during ripening of unsaturated fatty acids, carbohydrates and proteins. This effect of pasture on cheese flavor is more difficult to interpret. Nevertheless, as it is partly lost when the milk is previously pasteurized, it cannot be ruled out that the native microbial population of milk and/or the milk components modified by heat treatment like endogenous lipases or proteases may vary according to animals' diets and finally explain the influence of pasture on cheese flavour (Martin *et al.*, 2005). The effects of diets on the sensory properties of cheeses depend also on the cheese type: they seem to be of greater magnitude in the case of large hard cheeses requiring a long ripening time than in the case of small soft cheeses ripened quickly. Lastly, the sensory features of pasture derived raw milk is also stronger maybe due to the production in the rumen of volatile compounds like skatole or dimethyl-disulfide that are transferred to milk when cows graze a vegetative grass particularly rich in easily fermentable nitrogen (Coppa *et al.*, 2011).

Within the grass based diets, the influence of the preservation mode concerns mainly the dairy products' yellow colour and carotene content, which are higher when grass is preserved as silage, by comparison to hay (Nozière *et al.*, 2006). Significant differences in the sensory and nutritional characteristics of milk and derived products are also observed according to the botanical composition of the grasslands. In particular, the highly biodiverse Mediterranean or mountain permanent grasslands containing a wide variety of plant species rich in secondary metabolites reduce the biohydrogenation of fatty acids in the rumen and result in milks and cheeses with a higher content of polyunsaturated fatty acids and plant secondary metabolites like terpenes or phenolic compounds (Leiber *et al.*, 2005; Besle *et al.*, 2010). In addition, it is clearly established that the botanical composition of the grass influences cheese texture, flavour and appearance (Martin *et al.*, 2005). Nevertheless, this influence is particularly difficult to explain as it varies widely according to the local context and cheese types considered.

IV – Contribution of grasslands to meat quality

It is well known that the quality of meat is strongly affected by the animal feeding. In particular, many studies have demonstrated that extensive feeding systems based on green pastures increase the intramuscular unsaturated and n-3 fatty acid proportion (for a review see Wood *et al.*, 2008) and improve the oxidative stability of meat as compared to animals given concentrates in stalls (for a review see Descalzo *et al.*, 2008). However, more recent studies have aimed at increasing the knowledge of how different pastures and different grazing managements can affect these aspects of meat quality.

Several pasture plant species, in both alpine and Mediterranean environment, contain phenolic compounds. These components are able to affect the ruminal ecosystem, thus reducing the biohydrogenation of unsaturated fatty acids (Vasta *et al.*, 2010). Willems *et al.* (2014) have demonstrated that, in alpine environment, different pasture species can lead to differences in the intramuscular and adipose tissue fatty acid composition. In particular, phenolic compounds present in some plants, can prevent ruminal biohydrogenation thus increasing the accumulation of alpha-linolenic and linoleic acid in the tissues of animals grazing these plants. The occurrence of secondary compounds (in particular tannins and saponins) in grasslands is recently being exploited as a natural strategy for gastro-intestinal parasite control (see § 6). Therefore recent studies have aimed at evaluating the possible impact of such strategies on the quality of meat. For instance Brogna *et al.* (2014) found that the inclusion of tannins and saponins –in a concentrate-based diet– as remedy for parasite control – did not affect the main meat quality parameters of lamb, including fatty acid composition and oxidative stability. It would be of interest to evaluate the impact of similar remedy treatments in animals treated with plants secondary compounds naturally contained in grasslands/rangelands. Phenolic compounds are natural antioxidants and are commonly believed to contribute towards an improved antioxidant status of the tissues from pasture-fed animals. However, only few studies have investigated on their bioavailability. López-Andrés *et al.* (2013) have demonstrated that in animals grazing a ryegrass pasture, polyphenols are not detectable in tissues and therefore are not the main contributors to the antioxidant status of pasture-fed animals.

Mediterranean pastures are available during a limited part of the year. Reducing the grazing pressure with a correct grassland management could allow to preserve these pastures. Luciano *et al.* (2012) and Vasta *et al.* (2012) offered to three different groups of growing lambs a sward to graze for eight hours (from 9 am to 5 pm) or four hours either in the morning (from 9 am to 1 pm) or in the afternoon (from 1 pm to 5 pm). They have demonstrated that limiting the daily access to pasture from eight to four hours did not affect carcass weight and composition. Intramuscular fatty acids were affected by the time of grazing with higher levels of polyunsaturated fatty acids and lower levels of saturated fatty acids in the meat of animals given access to pasture in the afternoon as compared to those grazing for eight hours or for four hours in the morning. These results could likely be explained by the diurnal variation of the chemical composition in the plants. It was also found that the restriction of grazing did not compromise the storage stability of meat. In outline, the results of these studies highlighted the need for further research to identify and study the main factors to consider in implementing restricted grazing management which maximum profit without compromising animal health and welfare.

For dairy as well as for ruminant meat products further research is required to achieve a systematic knowledge basis about the factors influencing the specific quality of grassland-derived products. It appears particularly important to study systematically the effects of a wide range of dietary polyphenols, especially if present at high concentrations in other commonly used forages. This would be needed for the targeted production of specific foods, which would safely meet standards and achieve higher prices. Such standards have, however, still to be defined. The basis for their definition and control would be authentication systems as outlined below.

V – Authentication of grassland-derived products

The above presented results on dairy and meat products evidence specific features of grassland-derived dairy products and support the idea that a synergy between sustainable utilisation of the grassland/rangeland resources and positive side-effects on product quality emerges in such production systems. Hence, a clear differentiation adding value to these products appears to be possible at least during summer, when the grasslands are available.

Several factors have contributed to research interest in the area of products authentication, such as: the increasing consumer demand for guarantee about mode of production because of several food crises; the evidence that pasture-feeding can impart beneficial effects on meat and milk from a nutritional perspective; the interest in production practices which are more environmental friendly and more respectful towards animal welfare; the interest for producers to obtain market recognition and premium prices and to avoid piracy of their brands. To meet these demands, research has been developed to identify reliable authentication methods for meat and dairy products to be used in parallel with documentary traceability. Plant biomarkers, coming directly from the diet, have been widely proposed as valuable tools (Prache, 2007; Engel *et al.*, 2007). In particular, terpenes have been used successfully in meat (Priolo *et al.*, 2004) and dairy products (Tornambé *et al.*, 2006; Revello Chion *et al.*, 2010; Coppa *et al.*, 2011) as markers of animal diet, and particularly of pasture-feeding. More recently, polyphenols have proven to be quite valuable to authenticate pasture-derived milk and cheeses, especially if animals graze biodiverse pastures (Besle *et al.*, 2010). However, concentrations of terpenes and polyphenols differ widely according to pasture botanical composition and phenological stage (Cornu *et al.*, 2001; Sangwan *et al.*, 2001; Reynaud *et al.*, 2007). Moreover, the majority of phenolic compounds found in milk remain unidentified and identification of terpenes can vary largely according to the analytical method used (Pillonel *et al.*, 2002). As a result, the analytical methods are limiting at present the routine use of these compounds for the authentication of meat and dairy products.

Carotenoid pigments have also been used successfully to distinguish pasture-derived from concentrate-derived ovine meat (Priolo *et al.*, 2002; Prache *et al.*, 2003a and b), bovine meat (Serrano *et al.*, 2006; Röehrle *et al.*, 2011), and dairy products (Slots *et al.*, 2009; Stergiadis *et al.*, 2012). However, also herbage carotenoid content decreases as herbage phenology develops or when herbage is conserved (Calderon *et al.*, 2006; Nozière *et al.*, 2006). As a consequence, carotenoids become less reliable to authenticate pasture-derived milk and meat when pastures are in an advanced stage of maturity, or in case of stall diets which incorporate green herbage or well-conserved forages (Slots *et al.*, 2009; Prache *et al.*, 2009; Stergiadis *et al.*, 2012). Dose-dependent response studies have shown that lamb fat carotenoid concentration was linearly related to carotenoid intake level (Dian *et al.*, 2007), while the relationship was rather curvilinear for milk carotenoid content (Calderon *et al.*, 2006).

The stable isotopes ratios of oxygen, hydrogen, and sulphur are generally used for geographical origin assessment because they depend on latitude and on proximity of the sea (Manca *et al.*, 2001; Renou *et al.*, 2004; Ehtesham *et al.*, 2013). The stable isotopes ratios of carbon and nitrogen in meat and milk have been especially used to authenticate the diet. Tipically, carbon stable isotopes allow the control of whether or not maize has been used in the animal diet (De Smet *et al.*, 2004; Bahar *et al.*, 2009). A recent study demonstrated that nitrogen stable isotopes ratio allowed to authenticate meat produced from legume-rich diets (Devincenzi *et al.*, 2014), because legumes use nitrogen from the air as a nitrogen source. Fatty acid specific carbon stable isotopes offer the potential to link authentication with aspects of the animals' lipid metabolism leading to effects on the products fatty acid composition (Richter *et al.*, 2012a and 2012b).

The fatty acid (FA) composition of milk and meat also gives precise information about animal feeding diet (Aurousseau *et al.*, 2004; Engel *et al.*, 2007; Coppa *et al.*, 2013). Differences in milk and meat FA profile when using contrasting diets have been observed by several authors both in controlled conditions (i.e. reviews of Chilliard *et al.*, 2007, and Shingfield *et al.*, 2013; Aurousseau *et al.*, 2004) and on farm (Ferlay *et al.*, 2008; Stergiadis *et al.*, 2012; Borreani *et al.*, 2013). However, diet authentication based on FA was less accurate when samples derived from mixed diets were considered (Martin *et al.*, 2014).

Recently, global approaches based on meat, milk and cheese infrared (IR) spectra analysis were proposed as rapid, cheap and chemical-free methods to authenticate animal feeding diet. Near IR spectroscopy (NIRS) and medium IR spectroscopy (MIRS) on milk and cheese was found to be reliable to authenticate the main forage fed to cows (Coppa *et al.*, 2012; Valenti *et al.*, 2013;

Andueza *et al.*, 2013), at least when the dietary proportion of the forage exceeded 50%. However, similarly to FA, the IR methods lost reliability with mixed diets (Coppa *et al.*, 2012). In lamb meat, NIRS of perirenal fat enabled accurate discrimination between pasture-fed lambs and concentrate-fed lambs, the wavelengths regions implicated in the discrimination being probably due to differences in light absorption by carotenoid, haeminic pigments and fatty acids (Dian *et al.*, 2008).

The IR methods have a huge potential in routine application for meat and dairy products authentication, because they are reliable, rapid and chemical-free. In case of doubtful results when using IR data, a more detailed analysis using the specific compounds mentioned above may be performed. Intermediate feeding situations, for example in case of mixed diets or diet switches, may be less easily recognized and may require a combination of tracing methods. In particular, the persistence and the latency of appearance of diet tracers and the corresponding spectral changes in meat and milk are currently under active investigation (de Oliveira *et al.*, 2012a and b). These limits should be taken into account in establishing commitments in meat and dairy products specifications.

VI – Animal Health Issues – focus on gastro-intestinal nematodes

Grazing can have several positive effects on ruminants' health, in general terms (Künzi *et al.*, 1988) or related to udder health (Goldberg *et al.*, 1992). Factors may comprise species-appropriate behaviour including feed choice (Provenza *et al.*, 2003; Villalba *et al.*, 2010), but also the high concentrations of plant active compounds including phenols, essential oils, vitamins and unsaturated fatty acids. However, grazing also comprises several challenges towards animal health.

Apart from possible physiological problems (e.g. acidosis, rumen bloat, milk fever, intoxications), pasture born helminth infections (i.e.. gastro-intestinal nematodes (GIN), liver flukes or lungworms) probably represent the most important production and health problem of grazing ruminants (Perry and Randolph, 1999). The need to control pasture born parasites came along together with the intensification of ruminant production systems with high stocking rates and rotational systems that substantially increased pasture contamination and as a consequence favoured infection and reinfection of the hosts. In 1960 the first class of chemical drugs (i.e. benzimidazoles) were developed and allowed for an effective control of parasites. Although several additional classes of anthelmintics were introduced into the market in the forthcoming years, the excessive use of these compounds led to a rapid occurrence of resistant helminth populations. Today anthelmintic resistance is one of the most pressing problems of pasture based ruminant production (Waller, 2006) and is counteracted by the development of alternative strategies to control the parasites. Amongst those strategies, a pasture management considering the epidemiology of helminths has proven to be particularly successful in cattle (Waller, 2006). Compared to sheep and goats, these animals are able to show a more effective immune response to some helminths, particularly to GIN. Also mixed or alternate grazing with cattle and sheep/goats has shown to be a promising strategy to limit GIN infections in both host species by essentially diluting the infection. The background of the latter strategy is the relative specificity of GIN species to either cattle or sheep/goats.

Another promising strategy to control helminths is the use of plant secondary metabolites (PSM), particularly tannins (see also § 4). There is a substantial body of evidence for anthelmintic effects of tannin-containing legume forages such as sainfoin, sericea lespedeza and some lotus species (Hoste *et al.*, 2012). The observed effects can clearly be attributed to the presence of tannins and include a reduction of the worm fecundity, a reduced ability of incoming larvae to establish within the host and the reduction of the adult worm burden within the host. The latter effect, however, is subject to substantial variability including animal response. Other PSMs to control helminths have rather been used in the form of plant extracts and in some cases have proven being highly effective (Athanasiadou *et al.*, 2007). Generally, however, plant extracts to control helminths seem to be subject to a substantial degree of variability, which originates from a multitude of sources (e.g. site of plant growth, time of harvest, conditions of conservation, a.s.o.). Research for both PSM containing fodder plants and plant extracts is ongoing and remains to be a field with a lot of potential for the control of helminths.

Helminth infections of the gastro-intestinal tract induce extra-costs for the host animal. Colditz (2008) specified these costs amongst others as increased metabolic costs, turnover costs of cells and proteins of the immune system, damage of host tissues and reduced nutrient intake due to anorexia. Coop and Kyriazakis (1999) suggested a partitioning framework in the priority of the allocation of available resources to various body functions. The authors suggest that animals will give highest priority to its maintenance functions (body protein: repair, replacement and reaction to infection in affected tissues). If the animals are immunologically matured, the second highest priority is given to growth and reproductive functions. Therefore Coop and Kyriazakis (1999) conclude that improved nutrition will have beneficial effects on the host-parasite interaction especially in periods of high nutrient demand such as rapid growth. Today it is generally accepted that host resistance to GIN is sensitive to protein scarcity rather than to energy scarcity (Houdijk, 2012) and that GIN infection and its consequences can be alleviated by an improved protein supply. It therefore makes sense not only for general nutritional goals, to increase protein supply of ruminants, but also for parasitological reasons.

Overall, research in the field of alternative control of pasture born helminths needs to be further intensified, in order to handle the negative consequences of these parasites on ruminants' health and productivity. This should be done by using different control strategies in parallel in order to make use of potential synergic effects which may arise from their combination.

VII – Conclusion: Future challenges to sustain and develop the multifunctional role of permanent grasslands in European agriculture

The different perspectives of this paper show that there is a large potential for synergies being achieved by the smart utilisation of the European pastures. The targets which are associated, and can be reached simultaneously, are: (i) producing animal feed source, which is (partly) independent from arable land resources and thus not in competition with food crops, (ii) producing food with a particularly high nutritional value due to increased concentrations of functional fatty acids, antioxidants and vitamins, and (iii) maintaining ecosystems of a high ecological value in terms of biodiversity, carbon sequestration and landscape protection.

Challenges are largely connected to ecological and economical sustainability. One important field of solutions for both is the proper management of pasture aiming at the optimal match of carrying capacity and stocking management (species, densities and rotations, adapted to regional and seasonal characteristics), as indicated in § 2 of this paper. Good integration of research, development and extension, acknowledging the high value of farmers' practical knowledge in this field, could be a basis for concrete developments in pasture management. A future challenge for research could be a deeper understanding of the interactions between animal requirements and spatial grazing and selection behaviour, also with respect to forages rich in plant secondary metabolites. A second important aspect for promotion of the sustainable utilisation of pastures is to bring the positive achievements of pasture-based production efficiently to the market. Particularly the specific nutritional values are –although scientifically proven many times– not considered in the price building, neither between dairies and farmers, nor when the products are sold to the customers. Part of this problem lies in legal frameworks about health claims on products. But part is also due to lacking instruments for authentication of food origin and their properties. This paper showed that the technology will soon be available – implementation is the necessary next step.

However, a very basic problem hindering a development towards better utilisation of the pasture resource is the economic framework in a concrete and in a conceptual sense. Regardless of all possible and necessary improvements in the nutritional value and conversion efficiency of natural grasslands/rangelands there will always be large areas which are lower in nutrient density and feed-to-food conversion efficiency than intensively managed temporary grasslands or even grains from arable lands. This argument is used in concepts of ecological efficiency to disregard grassland-based production systems as ecologically inefficient (e.g. Pelletier and Tyedmers, 2010; Herrero *et al.*, 2013). This will also be an economic reality as long as the feedstuffs derived from arable land are cheap and competitive. However, it has to be countered by the fact that many grasslands and rangelands represent a non-arable land contribution to food production. Especially those areas which carry low quality feed are often without any other alternative for utilisation. Efficiency thus has to be calculated not only as product units per animal or hectare or kg of feed, but rather by considering the inputs of arable land (Wilkinson, 2011; O'Mara, 2012) and all further factors related to intensive arable crop production. Multi-perspective definitions of efficiency appear as one highly necessary precondition for the development of political, legal and economic frameworks within which a sustainable grassland and rangeland economy can develop. The ecological efficiency of these systems is an aspect of societal needs and responsibilities. Therefore, societal refunding of ecoservices provided by grassland-based agriculture still appears to be an important issue for local and European policy, which is currently addressed by the "Greening" policy of the European Commission (EC, 2013). The practicability of this measure has to be proven in future. Research, development and extension activities as outlined in this paper may support the implementation of this subsidy instrument on local scales.

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