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Grasslands, a source of richness and support for innovation for more sustainable and acceptable ruminant livestock farming

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■ Technical knowledge and tools currently exist to make better use of grasslands. In addition to their use by ruminants, grasslands provide many advantages, whether for the environment, product quality, animal and human health, or climatic and economic hazards. However, the ecosystem services that grasslands provide still need to be better quantified, their responses to climatic hazards better assessed and their recognition improved.

Introduction

Agriculture, particularly livestock farming, is currently experiencing a major crisis. Livestock farming is criticised for its environmental impacts, such as contribution to global warming through deforestation and greenhouse gas emissions (Steinfeld *et al.*, 2006), loss of biodiversity and eutrophication of water. Western societies are calling livestock farming into question for ethical reasons (*e.g.* animal welfare, the idea of livestock farming itself) (Lacroix and Gifford, 2019) and for its impacts on human health, related to excessive consumption of animal products. In most European countries, this is reflected by a decrease in individual meat consumption, particularly red meat (Sanchez-Sabate and Sabate, 2019; Wang and Basso, 2019) and by an increase in schools of thought that advocate reducing or stopping the consumption of animal products (*e.g.* flexitarianism, vegetarianism, veganism).

This crisis of acceptability is compounded by increasingly frequent climatic and economic hazards that influence production systems and their viability. In a context of globalisation, in which regulatory frameworks, socio-economic conditions and the societal environment vary greatly among countries, French and European agriculture is in a full identity crisis: What future does livestock farming have? What will future forms of livestock farming be? How can livestock farming remain competitive? How can livestock farming be made acceptable to society and livestock farmers and be sustainable? Livestock farming will have to reconfigure itself to meet these challenges.

This questioning of livestock farming by a small but growing and influential part of the public and consumers concerns all animal sectors. Returning grasslands to a central place in livestock farming could help solve these issues, particularly for the production of ruminants herbivores (*e.g.* cattle, sheep and goats). Indeed, the general public have a positive image of grasslands because they are associated with "natural" production and perceived as favourable for animal welfare, the quality of animal products and ecosystem services. These grassland qualities depend on the type of grassland, and this article discusses both temporary and permanent grasslands. Among permanent grasslands, semi-natural grasslands are more diversified and less intensified, according to an expert group of the European Grassland Federation (Peeters *et al.*, 2014).

Despite the wishes of public authorities, the area under permanent grassland has declined sharply since the 1970s in both France and the rest of Europe, after having increased sharply during the 20th century. Although they still cover approximately one-third of agricultural area in France (Agreste, 2018), their continued existence in many areas is uncertain due to competition with fodder and cash crops or because they are threatened by changes in land use (*e.g.* urbanisation, fallowing, reforestation). Some livestock farmers have no interest in grasslands, mainly due to the lack of technical, scientific and economic reference data and the existence of social obstacles (Michaud *et al.,* 2008). For example, for some livestock farmers and their agricultural advisers, permanent grasslands are an outdated and unsuitable technical model, and the fodder deficits associated with the droughts and heat waves of recent years further aggravate this assessment. There are certainly objective arguments against grasslands, such as having fodder yields that are generally lower than those of other fodder crops such as maize, unstable feed value, management complexity and the toxicity of certain grassland species. These arguments are often the only ones put forward, with no consideration or promotion of the benefits associated with permanent and/or diversified long-term grasslands and their use. This reality persists despite many studies conducted over several decades to provide more reference data on the agronomic and environmental value of grasslands, with the aim of optimising and promoting inclusion of grasslands in production systems (*e.g.* in France: Petit *et al.,* 2004; Cruz *et al.,* 2010; Launay *et al.,* 2011; Hulin *et al.,* 2012; Michaud *et al.,* 2013; Couvreur *et al.*, 2018; Petit *et al.*, 2019; Hulin *et al.,* 2019).

In this context, this article assess innovative knowledge and tools for grassland management, in light of the changing challenges of ruminant livestock farming in temperate zones. The grasslands considered in this article are permanent and temporary grasslands (Box 1). This summary identifies advantages that increase the interest of including grasslands in ruminant production systems (i.e. cattle, sheep and goats), as well as key points to be examined in greater depth to understand future challenges. This article is set in a French context, but its discussion has a wider scope, particularly for similar agro-climatic zones. We address the role of grasslands in milk and meat production, and in environmental conservation. We then discuss effects of grasslands on animal and human health and the role they can play in production systems in a context of climate change and economic hazards, while considering the main obstacles to their development.

1. Grasslands for milk and meat production

■ 1.1. A strong challenge: meeting global demand

The human population is expected to grow from 7.7 billion people at present to 9.1 billion in 2050 (Paillard *et al.,* 2010). This increase will occur mainly in Africa and Asia. While some of humanity, particularly in industrialised countries, must make efforts to rebalance the plant:animal ratio of its diet, ensuring the global supply of animal products remains a major challenge. To meet the growing demand for food, combined with the increase in the purchasing power of densely populated countries, FAO recommendations call for a 70% increase in global meat production (all types of meat) and a 60% increase in milk and egg production (Steinfeld *et al.,* 2006; Paillard et *al.,* 2010), in a context of shrinking land area (*e.g.* desertification, rising sea level, urbanisation).

If animal production is to increase, it will be necessary to reconsider how these sectors are organised within territories and the issues at stake in order to make room for crops (*e.g.* cereals) and vegetables (*e.g.* pulses, other vegetables) for human consumption in the areas that are most favourable for them. How to reorganise the destinations of crops must also be considered. Indeed, a large percentage of crop production from arable land (34% of the world's surface area) is currently used to feed livestock, with a low valorisation of yield, as it takes 2.5-10 kg of plant protein to produce 1 kg of animal protein (Laisse *et al.,* 2018; Mottet *et al.,* 2018). However, it is important to put this last argument, which is often mentioned, into perspective. In fact, farm animals, particularly ruminants in areas with little or no crop production, consume mainly plant products that cannot be consumed directly by humans (*e.g.* crop residues, co-products from agri-food industries, fodder). Thus, for example, a grassland dairy system can produce up to twice as much human-consumable protein in milk and meat as it does in cereals and protein crops (Laisse *et al.,* 2018). To limit food/feed competition, future livestock farming systems must therefore be designed to complement crop production for human consumption and give priority to food co-products and fodder produced in areas that are less or not suitable for crops. Moreover, this debate must be associated with the choices made for non-food use of agricultural land (*e.g.* energy production, urbanisation) and the need to reduce waste (Paillard *et al.,* 2010; Couturier *et al.,* 2016).

■ 1.2 New knowledge and innovations to improve use of grasslands by ruminant livestock farming

Grassed areas, particularly permanent grasslands, are usually located where crop production is not possible for reasons of accessibility (*e.g.* mountains) or where yields are too low (*e.g.* soils of low fertility, harsh climate). They contribute to the development of animal production, which makes plant products

Box 1. ***Definitions and functioning of permanent and temporary grasslands and the assessment of their environmental and agricultural value (nutritive value and production).***

Permanent, temporary and artificial grasslands

Grasslands are agricultural areas whose vegetation is used to produce fodder for harvest and/or for grazing livestock. The term "grasslands" includes permanent, temporary, and artificial grasslands (Allen *et al.*, 2011; Peeters *et al.*, 2014). In mainland France, the distribution of grasslands varies by administrative department, and grassland area has decreased in the main grassland regions since 1950 (figure 1).

Permanent grasslands

Permanent grasslands contain perennial or native species in an ecosystem managed over the long term (Allen *et al.*, 2011; Couvreur *et al.*, 2018). They are more complex to manage than other types of grasslands. Among permanent grasslands, **semi-natural grasslands** (the **most diversified**) that have been established for more than 10 years are distinguished from more **recent grasslands**, 5-10 years old or **more intensively** managed (Peeters *et al.*, 2014). These grasslands contain grasses (Poaceae), legumes (Fabaceae) and other dicotyledons (i.e. "various species" in agronomy), proportions of grasses, legumes and other dicotyledons vary from one grassland to another. The floristic diversity of a permanent grassland in Europe ranges from 15-100 species (Plantureux *et al.*, 1993; Tornambé *et al.*, 2010) with averages of up to 30-60 species (Jeangros and Schmid, 1991).

Temporary grasslands

Temporary grasslands contain annual, multiannual or perennial seeded species less than 6 years old (Allen *et al.*, 2011), mainly grasses and legumes. Other dicotyledons are used in mixtures sown for specific purposes (*e.g.* drought resistance). The floristic diversity of temporary grasslands can reach 12 species in a mixture.

Artificial grasslands

Artificial grasslands are areas less than 5 years old sown almost exclusively with fodder legumes. These grasslands are not detailed in this article.

Diversified grasslands

Diversified grasslands generally contain several species. They may be **temporary** (with more than 3 species) or **permanent** (with more than 35 species). They can be used for harvest and/or for grazing in production systems and are thus considered in the fodder system, the grazing system or, if they also contain woody species, the pastoral system.

Grassland dynamics depend on environmental conditions and management practices

The floristic composition of temporary or permanent grasslands depends on their environmental conditions and management practices. Several studies have shown effects of the environment (*e.g.* elevation, soil composition) and management practices (*e.g.* number of cuts, stocking rate) on the botanical or functional composition of vegetation (Hopkins, 1986; Plantureux *et al.*, 1993; Diaz et *al.*, 1998; Klimek et *al.*, 2007; Batary *et al.*, 2010; Michaud et al., 2011; Pierik et *al.*, 2017; Roukos et *al.*, 2017).

Assessing the environmental value of grasslands

Based on their botanical or taxonomic composition

Grassland species or the floristic composition of a grassland can be assessed based on their botanical or taxonomic composition (*i.e.* by considering vegetation as a set of species), with each species being an entity of its own (Maire, 2009). In this approach, the abundance and dominance of the species present is observed.

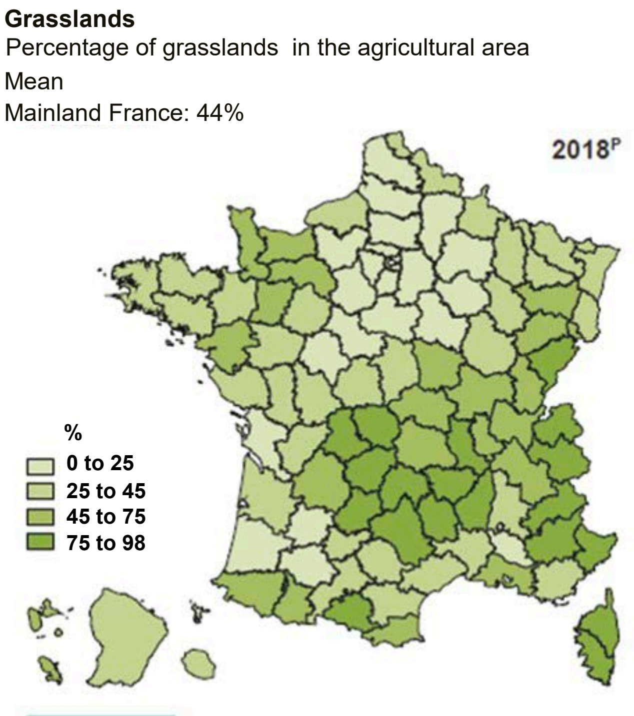
Based on their functional composition

Grasslands can also be assessed based on the functional composition of their species, in which species are grouped according to their functions (*e.g.* plants that use the wind for pollination) (Grime, 1977).

Assessing the agricultural value of grasslands (production, nutritional value)

Increased knowledge about relations among the environment, management practices and vegetation has increased understanding of the main factors involved in predicting production or nutritive value. In particular, this research has been extended to **permanent grasslands**, whose high diversity (*e.g.* multiple phenologies) makes it difficult to estimate their agricultural value. To date, prediction models with differing degrees of complexity of the nutritive value and production of permanent grasslands have been developed based on the **functional composition**, especially the functional types developed by Cruz *et al.* (2010), temperature and other vegetation components (Duru *et al.*, 2008; Michaud et al., 2014; Pierik et *al.*, 2017). In **temporary grasslands,** this allows sown species to adapt better to the environment (Simon *et al.*, 1997; Litrico et *al.*, 2016).

Figure 1. ***Percentage of grassland in the agricultural area of administrative departments of mainland France and changes in grassland area since 1950 in the main grassland regions of mainland France (Agreste, 2018).***



	1950	1980	2000	2010	2018P
	thousands of hectares				
Mainland France of which	**17 915**	**16 434**	**13 213**	**12 900**	**12 617**
Auvergne-Rhône-Alpes	2 666	2 623	2 247	2 214	2 213
Nouvelle-Aquitaine	2 419	2 429	1 955	1 925	1 913
Occitanie	2 367	2 065	1 874	1 888	1 905
Bourgogne-Franche-Comté	1 777	1 668	1 415	1 405	1 381
Pays de la Loire	1 485	1 499	1 134	1 088	1 018
Grand Est	1 715	1 399	1 035	968	913
Normandie	1 637	1 480	1 075	968	898
Bretagne	825	981	704	684	673
Centre-Val de Loire	900	671	494	501	502
Hauts-de-France	860	597	395	373	362

1. Artificial grasslands, temporary grasslands and permanent grasslands.
Source: Agreste - annual agricultural statistics

from these areas "edible" for humans. The high diversity of temporary and permanent grasslands has made it difficult to acquire reference data for their production characteristics and the factors that determine them. Since the early 2000s, many studies have characterized the performance of certain types of grassland and developed more generic approaches, drawing in particular on concepts of functional ecology (Diaz *et al.*, 1998; Duru et *al.*, 2007; Cruz et *al.*, 2010) (Box 1).

The factors that determine grassland species composition, growth and quality are now much better known (Plantureux *et al.*, 1993; Klimek *et al.*, 2007; Klimas and Balezentiene, 2008; Pakeman *et al.*, 2009). The characteristics, functioning and forage value of most species that contribute to grassland yield are now known (Grime *et al.*, 1979; Cruz *et al.*, 2010). This refined knowledge of biological and agronomic mechanisms makes it possible to recommend adjustments to management practices for a given objective (*e.g.* maintaining grassland biodiversity, increasing productivity) (De Foucault, 1992; Petit *et al.*, 2004; Cruz *et al.*, 2010; Hulin *et al.*, 2012). Knowledge about the sensitivity of grassland species to fertilisers or soil characteristics is also better known (Ebeling *et al.*, 2008; Batary *et al.*, 2010). The knowledge acquired in recent years, particularly about permanent grasslands (Michaud *et al.*, 2011 and 2014; Hulin *et al.*, 2019), has thus been applied to specific French grassland areas (Jeannin *et al.*, 1991; Petit *et al.*, 2004; Collectif, 2006; Galliot *et al.*, 2019) or at the scale of France (Launay *et al.*, 2011). Knowing grasslands' potential, seasonal distribution of production and feed value can contribute to the balance of the production system that uses them.

Thus, reference data exist for the production and feed value of vegetation cycles of temporary and permanent grasslands (figure 2; Table 1). Research in France (Launay *et al.*, 2011) has characterised the diversity of grassland types by distinguishing permanent grasslands (intensive and semi-natural) at high elevation (5 types) and in semi-continental zones (6 types), oceanic zones (5 types) and coastal zones (3 types). For these 19 types, production and food-value reference data were estimated for the first vegetation cycle and regrowth (Launay *et al.*, 2011). While permanent grasslands have mean annual production of 6.2 t DM/ha (Baumont *et al.*, 2012), these reference data confirm that their production varies. Annually, permanent grasslands produce from 1 to more than 8 t DM/ha (Jeangros and Schmid, 1991; Baumont et *al.*, 2012). In terms of feed value, the energy and nitrogen contents of most types of permanent grassland at high elevations and in semi-continental and oceanic zones are similar to those of pure species such as ryegrass, cocksfoot and fescue present in INRAE's tables of the feed value of fodder (Baumont *et al.*, 2018).

Figure 2. ***Ecosystem services provided by and advantages and disadvantages of grasslands for animals and herds, farmers, consumers and citizens.***

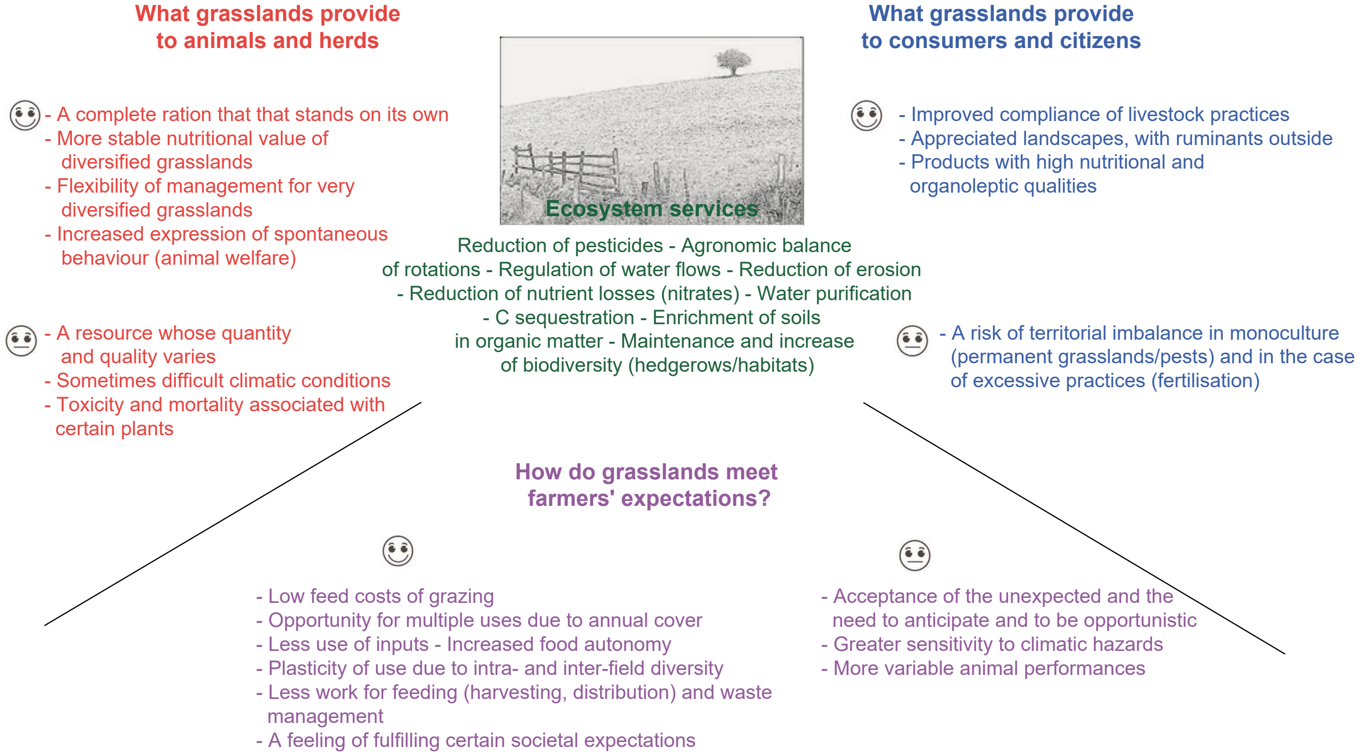


Table 1. ***Production and nutritive-value benchmarks (in UFL, PDI and UEL) for temporary grasslands (Perennial ryegrass-white clover mixture) and three types of permanent grasslands common in France (Sources: Launay et al., 2011; Jeulin and Delaby, personal data).***

Benchmark	Temporary grasslands	Permanent grassland types		
		High elevation PA2	Plains and hills PSC4	Oceanic PO2
Early spring (grazing stage)				
Production (t DM/ha)	1.8	1.9	1.6	1.9
Feed value				
UFL (/kg DM)	1.00	0.97	0.99	1.04
PDI (/kg DM)	105	102	102	105
UEL (/kg DM)	0.97	0.97	0.97	0.95
Late spring (silage harvest stage)				
Production (t DM/ha)	4.0	5.0	4.6	5.2
Feed value				
UFL (/kg DM)	0.88	0.76	0.81	0.82
PDI (/kg DM)	85	78	82	79
UEL (/kg DM)	1.04	1.08	1.06	1.06
Summer regrowth (6 weeks)				
Production (t DM/ha)	1.5	0.8-1.0	1.0-1.2	0.6-0.8
Feed value				
UFL (/kg DM)	0.90	0.92	0.83	0.88
PDI (/kg DM)	105	105	93	98
UEL (/kg DM)	0.98	0.98	1.03	1.00

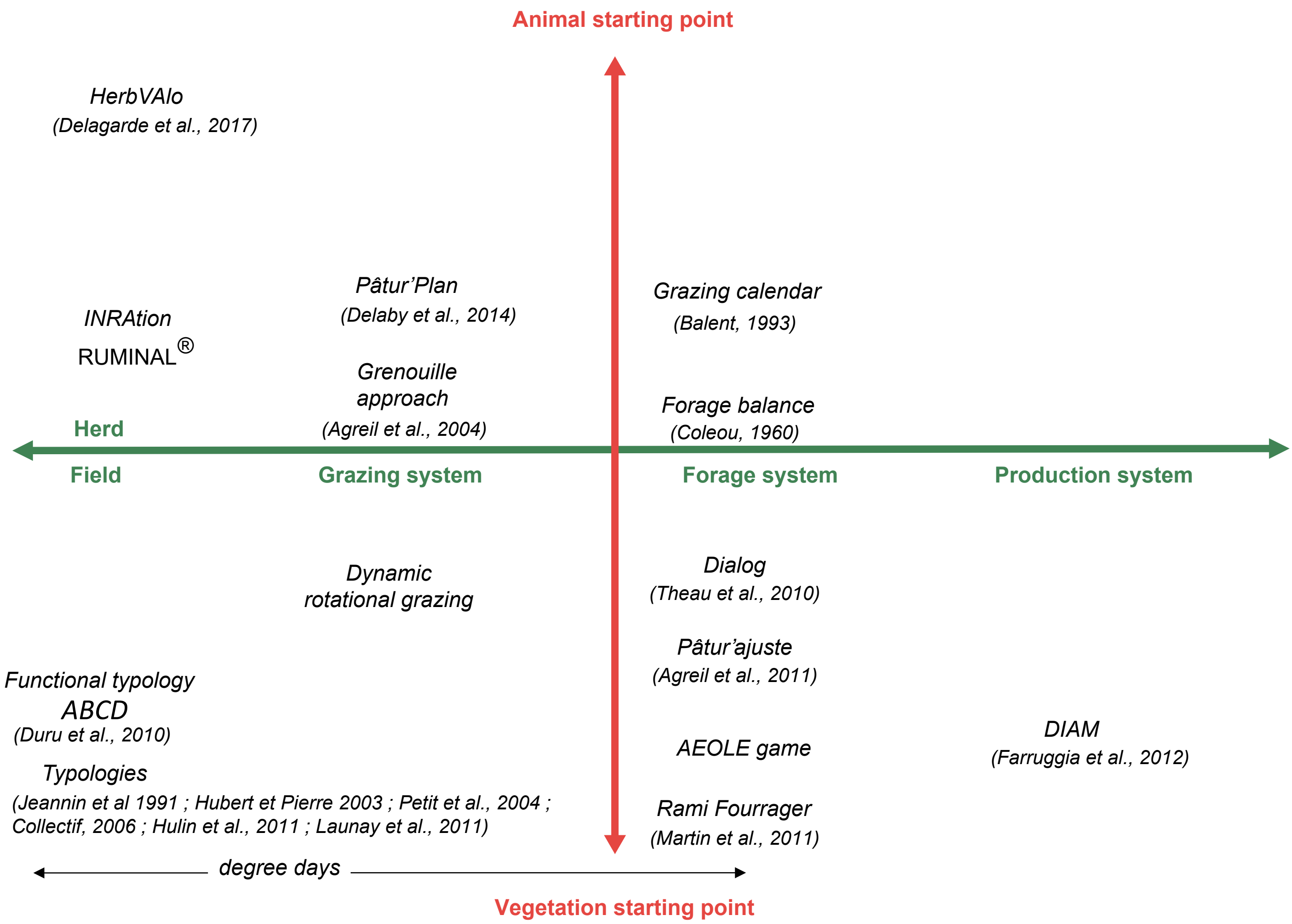
PA2: Low-fertilised mixed grasslands at high elevations with sweet vernal grass and red fescue; PSC4: Low-legume grasslands in plains and hills with common bentgrass and perennial ryegrass;
PO2: Low-fertilised, grazed oceanic grasslands with perennial ryegrass and white clover.
UFL: unité fourragère lait (Net energy for lactation); PDI: protein digestible in the intestine; UEL: unité d'encombrement lait (Fill value for dairy cows and dairy goats).

This general and local scientific knowledge can be disseminated as such or in the form of an educational book (Couvreur et *al.*, 2018) or as a tool to assist grassland management. Many of these tools exist at a national scale, and their starting points are vegetation or animals. Several analysis tools are available (figure 3):

i) at the scale of the herd, flock or field(s). The most traditional tools that provide general reference points for grasslands are grassland typologies. These tools reference the values of grasslands from an agricultural and/or environmental viewpoint based on their floristic diversity. These tools are based on the diversity of grass types (*e.g.* ABCD functional typology of grassland grasses) (Duru *et al.*, 2010) or on the overall floristic diversity at a national (Launay *et al.*, 2011) or local scale (Jeannin *et al.*, 1991; Hubert and Pierre, 2003; Petit *et al.*, 2004; Collectif, 2006; Galliot *et al.*, 2020). This research has made it possible to develop, in particular, reference data for the feed value of grasslands at a national scale, which can then be applied at a local scale to refine recommendations. For farmers, better knowledge of the value of each type of grassland and its dynamics helps them allocate grasslands (pasture or harvested grass) better to different categories of animals, which may have different needs. A grassland is not good or bad but instead more or less adapted to a category of animal at a given time of the season; relations between grassland types and forage functions in this sense have been identified (Launay *et al.*, 2011). Other tools, focussed on the herd or ration, make it possible to provide animals with fodder or a daily grassland ration that meets their needs (*e.g.* INRA 2018 feeding system, INRAtion® v.5 and RUMINAL® software developed with France Conseil Élevage (INRA, 2018)). In-depth knowledge about grassland types has made it possible to improve these tools.

(ii) at the scale of the grazing system. These tools are highly developed in France and concern the management of grazing systems with high stocking rates (*e.g.* Pâtur'Plan; Delaby *et al.*, 2014), those that adopt rotational grazing or more extensive systems based on cover with woody plants (*e.g.* Grenouille method in Mediterranean environments; Agreil *et al.*, 2004). *A posteriori* analysis tools that objectify the use of these grasslands, such as HerbValo (Delagarde et *al.*, 2017), are also available.

Figure 3. ***Positioning of the main analysis tools and games for direct grassland management in France according to the scale of application (*e.g. *field) and the starting point (animal or vegetation).***



(iii) at the scale of the fodder system. The fodder system includes fields for grazing or for winter storage. These tools can be simple to adopt, such as calculating the forage balance (Coleou, 1960), or more complex, such as considering the management of grazing and stocks in a grassland area (*e.g.* Dialog; Theau *et al.,* 2018) or in a pastoral environment (*e.g.* Pâtur'Ajuste; Agreil *et al.,* 2011). They provide an overall view of grazing and/or fodder stocks. Games are also available to simulate management of a forage system in an enjoyable way (*e.g.* Rami Fourrager; Martin *et al.,* 2011) and complementarity between grasslands (*e.g.* AEOLE game; AEOLE program, INRAE, pers. comm).

(iv) at the scale of the production system. These tools take a wider view of the system: they include analysis of the fodder balance sheet and other farm performances related to the presence of grasslands, such as environmental performance (*e.g.* DIAM assessment; Farruggia *et al.,* 2012; see section 2.2).

Farmers adopt these tools relatively easily, although training from agricultural advisers or tool developers is sometimes necessary. To facilitate the dissemination of innovations and exchanges, local and national groups of advisers and stakeholders in the field have been established (*e.g.* RMT Prairies Demain: Mixed Technological Network on the use of grasslands (2014-2019), whose expanded activities continue in the RMT Avenirs Prairies (2021-2025)).

■ 1.3. Research and innovation needs

Although knowledge about grasslands has progressed significantly in recent years, particularly at the scale of the plant community, understanding of intra- and inter-annual dynamics of the agricultural value of temporary and permanent grasslands still needs to increase to better understand the room that agricultural management has to manoeuvre. Better understanding of effects of management practices on grassland dynamics, especially of their plant species, is also a research avenue, whether for their production or environmental value. The increase in damage by wildlife (*e.g.* wild boar, rodents) also requires better understanding of the dynamics of grassland restoration in order to optimise its management.

Existing knowledge about the management of permanent and temporary grasslands responds to different expectations at the scales of the field, the grazed area and the fodder system. Few tools have been developed at a territorial scale. A few games address territorial aspects (Ryschawy *et al.,* 2019; Dernat *et al.,* 2020) but do not focus on grassland management. Such tools could help consider collective management of grasslands at a territorial scale or meet more global expectations, particularly environmental expectations (*e.g.* water flow, hedgerows, landscape).

Precision-farming techniques, such as motion or geolocation sensors, can also help manage grasslands (Shalloo *et al.,* 2018). These tools, currently under development, could in particular automatically record the grazing calendar, an element essential for analysing performances and improving understanding of the functioning of grass-based systems and grasslands. The use of drones and satellite images is also being researched to develop new tools for grassland assessment and management (Pottier *et al.,* 2017).

2. Grasslands to preserve and improve the environment

■ 2.1. A strong challenge: contributing to the agroecological transition

Future modes of production will have to remain productive but more respectful of the planet, as agricultural activities impact the environment strongly (Stassart *et al.,* 2012). Indeed, the global livestock sector uses 30% of the land, 32% of the total agricultural water use and rainfall and contributes 18% of greenhouse gas emissions (Herrero *et al.,* 2015). Livestock farming in its intensive form (i.e. a large use of inputs due to an imbalance between the potential of the environment and the stocking rate) also contributes to several other major environmental problems, such as eutrophication, soil degradation, deforestation and loss of biodiversity (Steinfeld *et al.,* 2006). These elements fuel questions about the place of livestock farming in the global landscape of tomorrow and contribute to renewing societal expectations of agriculture (*e.g.* environment, health risks).

Faced with this situation, the alternatives are either to reduce negative impacts by improving existing systems or to design new systems based on agroecology, to which autonomous low-input production systems (*e.g.* Alard *et al.,* 2002) and organic agriculture (Tichit and Dumont, 2016) are related. In addition to reducing environmental impacts, agroecology replaces chemical and energy inputs with natural processes, in particular by increasing the diversity of systems and improving the closing of cycles (*e.g.* minerals, energy, water). Permanent grasslands and, to a lesser extent, temporary grasslands, fit well into this agroecological option. While these alternative systems may have 5-30% lower productivity per hectare or per animal, depending on the situation (De Ponti *et al.,* 2012; Ponisio *et al.,* 2014), they have advantages, such as greater resilience to climate change (Chen and Chappell, 2009) or respect for the environment (Tuomisto *et al.,* 2012). These production systems, which rely greatly on grass and a connection to the soil, are thus interesting avenues for addressing agricultural and environmental issues in a vision of increasing overall agricultural production while considering territorial conditions under which grassland systems would be less productive but would compensate for this with greater environmental value (Huguenin-Elie *et al.,* 2018).

■ 2.2. The capacity of grasslands to produce ecosystem services

The concept of "ecosystem services", although little used by the general public, provides a framework for reflection that can highlight benefits of including grasslands in livestock farming systems; these benefits were previously described in part as "multifunctionality" (Béranger and Bonnemaire, 2008; Amiaud and Carrère, 2012). This concept, which appeared in the 1970s, was first defined in the early 2000s as a set of benefits (or advantages) that humans derive from ecosystems (Millennium Ecosystem Assessment, 2005; Fisher and Turner, 2008). The French EFESE study on the assessment of ecosystem services called this definition into question by defining them no longer as benefits in themselves but instead as ecological processes or elements of ecosystem structure from which humans derive benefits (Therond *et al.,* 2017).

Grassland ecosystems provide many benefits from which humans benefit (figure 2). Permanent and temporary grasslands have many and varied environmental benefits: limiting erosion; regulating water flows (*e.g.* preventing floods, storing water); filtering mineral and organic pollutants; preserving floristic, faunal and microbial biodiversity (especially under extensive management); reducing net greenhouse gas emissions in livestock farming by sequestering nearly as much carbon as forests; and providing landscape benefits, especially permanent grasslands (Mauchamp *et al.,* 2013).

Any benefits to humans from agricultural ecosystems are related to two types of factors: the ecosystem services themselves and the use of "human capital" (*e.g.* inputs, energy, labour) to provide these benefits. To produce 1 t of fodder, a grassland generally uses less human capital (*e.g.* fertilisers, pesticides, machinery, working time) than a fodder crop (Couvreur *et al.,* 2018). In this sense, the benefits that humans derive from grasslands are interesting because they are based largely on ecosystem services.

Thus, the concept of ecosystem services can highlight the many positive effects of grasslands. Several studies have attempted to list ecosystem services provided at the landscape scale (Lavorel *et al.,* 2011; Lasseur *et al.,* 2018) or by permanent grasslands (Baumont *et al.,* 2012; Michaud *et al.*, 2013; Galliot *et al.,* 2019) in differing degrees of detail (Therond *et al.,* 2017; Lemaire *et al.,* 2019). Some of them even estimate levels of services in a qualitative or quantitative manner (Therond *et al.,* 2017). Qualitative assessments are admittedly not precise as they are often calculated indirectly, such as for pollination or carbon sequestration, but they do provide benchmarks for society. Quantitative assessments are rarer because they are more complex to perform but are relevant for discussing the fair value of these services.

This knowledge is beginning to be transferred into grassland management tools to better express the potential to provide ecosystem services. Recent grassland typologies have included several ecosystem services based on the floristic composition of grasslands (Launay *et al.,* 2011; Theau *et al.,* 2017; Galliot *et al.,* 2020). A tool at the scale of the production system (DIAM; Farruggia *et al.,* 2012) includes agricultural aspects and the ecosystem services provided by grasslands. This type of tool can show environmental benefits of grassland systems to a public of advisers, farmers and citizens (figure 4).

■ 2.3. Research and innovation needs

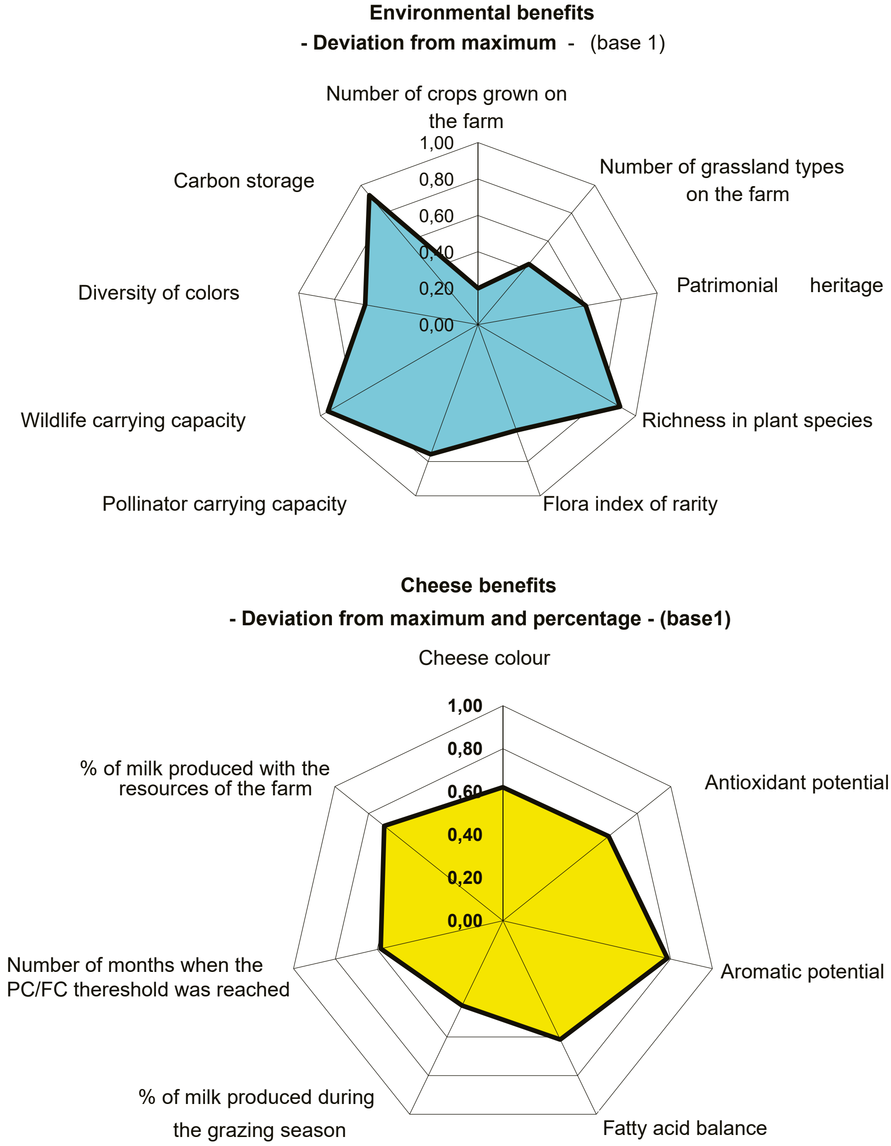
Analysis of the ecosystem services provided makes it possible to assess the environmental role of grassland systems at multiple scales (*e.g.* territory, system). However, because these services are not communicated to society sufficiently well, they are not estimated or remunerated at their fair value. Several avenues need to be considered. First, services must be quantified economically. Although this research is underway, it needs to be developed further, especially as not everyone accepts the idea of monetising nature. Knowledge remains to be acquired about paying for carbon storage by grasslands, as well as on the precise amount of storage and the number of years that grassland soils can continue to store carbon (*e.g.* the French "Low-Carbon Label", under development). It also seems important to quantify the cost, in money and time, of the "technical" implementation of each service or specification as management practices on a farm. This will enable policy makers to pay livestock farmers, thereby giving them an incentive to conserve grasslands and keep them in a state that provides ecosystem services. Finally, the selling price of animal products needs to reflect payment for these services. Consequences of the loss of existing ecosystem services should also be quantified to better communicate the challenges of maintaining them. Ultimately, payment for services requires both progress in agronomic and economic knowledge, but also implies political and social innovations.

3. Grasslands to improve consumer health, animal health and welfare and product quality

■ 3.1. Strong challenges: ensuring human and animal health and welfare

Current production methods and health inspection of products provide healthy food that is free from immediate and serious food risks (*e.g.* zoonoses, poisoning, contamination). Moreover, animal products provide an essential

Figure 4. ***Example radar graphs generated by the DIAM tool (multifunctional assessment of forage area) for environmental benefits of permanent grasslands and benefits of cheese.***



DIAM quantifies advantages of permanent or diversified grasslands for the environment or for the quality of cheese for farms that produce it. The assessment is based characterising a farm's permanent grasslands and makes it possible to discuss the potential to manage them in light of environmental issues. PC: protein content; FC: fat content.

source of certain nutrients in both developed countries, for certain sections of the population (*e.g.* protein for the elderly), and developing countries, and also contribute to human well-being through the organoleptic and technological quality of the products, mainly in countries with high purchasing power, especially those with a strong culinary tradition. However, several events in recent decades (*e.g.* mad cow disease crisis, concerns about pesticide use) have led to public mistrust of more insidious, long-term health risks associated with the food consumed, particularly in countries with high purchasing power. Some citizens want to know more about what they eat and where and how their food is produced (Lacroix and Gifford, 2019; Sanchez-Sabate and Sabate, 2019; Wang and Basso, 2019). While the health of consumers must be guaranteed, the health and welfare of farm animals must also be considered. Indeed, these elements are the subject of recurring and influential questions from society, which is increasingly sensitive to animal production methods and their effects on animals (Saatkamp *et al.*, 2019). The concept of "global health" (Koplan *et al.*, 2009) or "single health" (Duru *et al.*, 2016) connects human, animal and environmental health. This global and systemic approach aims to understand humans, animals, the environment and their interrelationships with a view to the health and well-being of these objects (Rockström et *al.*, 2009). Grasslands can be an interesting response to global health issues, whether through their less environmentally damaging management practices, the ecosystem services they provide (Lasseur et al., 2018) or their effects on animal health (Likkesfeldt and Svendsen, 2007; Zeiler *et al.,* 2010; Durand et *al.,* 2013).

Finally, animal welfare and health are debated in Western societies. This even leads to wider reflections on what relationship humans should have with animals, which calls into question modes of agricultural production and the consumption of meat and animal products in general. Grassland systems make sense in such debates, but it is important to objectively assess positive effects of grasslands on these elements of the debate and to recognise them as such (Mee and Boyle, 2020).

3.2. Grass has a positive influence on human and animal health, the organoleptic quality of animal products and animal welfare

Although dairy products have been criticised for their high saturated fat content, which is a risk factor for cardiovascular disease, this criticism should be placed into perspective, in particular by highlighting effects of the composition of plant species in animal rations on the fatty-acid composition of animal products (Martin *et al.,* 2019) (figure 2). Grasslands are rich in omega-3 fatty acids, which are then found in dairy products (Chilliard *et al.,* 2007) and have protective effects on cardiovascular disease risks. The floristic composition, growth conditions (*e.g.* climate, soil) and harvesting stage of grasslands and how their grass is stored strongly influence the type and quantity of secondary metabolites (Fraisse *et al.,* 2007), some of which are of interest for human health (*e.g.* phenolic compounds, terpenes, carotenoids, alkaloids, quinones) (Mulligan and Doherty, 2008; Poutaraud *et al.*, 2017). The content of carotenoids, which are precursors of vitamin A, or polyphenols in grass helps limit oxidative phenomena, which cause infectious and inflammatory diseases (Miller *et al.,* 1993; Likkesfeldt and Svendsen, 2007; Farruggia *et al.,* 2008; Durand *et al.,* 2013). Much research is underway to clarify relations between the quality of grass consumed by ruminants, the quality of animal products (*e.g.* milk, meat, cheese) and human health (Martin *et al.,* 2019).

Although focus lies on balanced nutrition and health of consumers, the health of ruminants is also a concern. Effects of antioxidants on problems related to oxidative stress are well known in several animal species (Miller *et al.,* 1993; Celi, 2010; Niki, 2010), and some effects have been highlighted, such as the ability of vitamin E and selenium supplementation to reduce the risk of mastitis (Zeiler *et al.,* 2010). Effects of other secondary metabolites on animal health have been highlighted, such as antiparasitic effects of condensed tannins (Minh *et al.,* 2003; Hoste *et al.,* 2005). More broadly, certain effects, whether medicinal or toxic, of grassland plant species on animals are fairly well known (Valnet, 1972; Bruneton, 2016), particularly in the veterinary field. Consequently, some farmers have established "medicinal grasslands" to test the health effects of a reportedly beneficial plant or mixture of plants. Species that influence health are offered to the animals during a given period, either alone or as a mixture in grasslands, or even in groves planted on the edges of grasslands. Finally, grazing on grasslands allows animals to express their natural behaviour more frequently by letting them choose their food and move freely.

Grasslands also influence the organoleptic quality of animal products. Relations between the grazing system or type of grassland and the creaminess, colour, flavour or taste of cheese have been established (Jeangros *et al.,* 1997; Farruggia *et al.,* 2008; Coppa *et al.*, 2012) but need to be better controlled and enhanced. Several mountain PDO (protected designation of origin) cheeses also emphasise this point in their marketing information to increase the recognition and promotion of their products. The Comté PDO has thus developed a rosette of the flavours of its cheeses, in line with the diversity of the grasslands. More anecdotally, hay from diverse grasslands can be used in cooking, as flavourings or in the form of herbal teas ().

3.3. Research and innovation needs

Quantifying health effects of diversified grasslands is an important research avenue, as it would constitute additional arguments for using them in production systems. Agronomists, animal scientists, veterinarians, toxicologists, pharmacologists and doctors should be involved in research programmes, in line with the concept of "global or one health". Although the potential "health" role of grasslands (Bareille *et al.,* 2019; Sulpice *et al.,* 2019), particularly diversified grasslands, has been researched, avenues of research remain to be explored. As animal and human health are eminently multifactorial, isolating the specific influence of grasslands is a major experimental challenge. Moreover, knowing that a plant species found in grasslands may benefit health is not sufficient: the grassland must actually contain it, the animal must eat it, and effective doses, molecular forms that trigger an effect on health and potential synergies and antagonisms must be determined. Techniques for measuring molecules of interest to health have made great progress in recent years by lowering detection thresholds, reducing analysis costs and enabling "high-speed" analysis, which opens up interesting prospects. Although the secondary metabolite composition of the main forage species/varieties is known (Nozière *et al.,* 2006; Reynaud *et al.,* 2010; Graulet *et al.,* 2012; Pickworth *et al.,* 2012), that of plants less common in permanent or highly diversified grasslands remains to be determined. Moreover, in an agroforestry approach, the influence of woody plants in grasslands remains largely unknown, despite initial studies on their feed value (Emile *et al.,* 2017). Effects of plants with secondary metabolites on animal or human health also remain to be clarified. More broadly, indicators for measuring these secondary metabolites in animals that have ingested the plants are rarely evaluated on commercial farms due to methodological difficulties or high implementation costs (Huang *et al.,* 2005; Dudonné *et al.,* 2009): it seems important to develop this type of indicator, particularly in a framework of agroecological transition.

The "medicinal" role of plants also remains to be clarified, particularly that of the more diversified plants of permanent mountain grasslands. Although medicinal characteristics of certain plants in humans and animals are well known (Valnet, 1972; Poutaraud *et al.,* 2017), more needs to be known about relations between the ingestion of "medicinal" plants and animal health to specify the doses required and the frequency of intake (Valnet, 1972; Poutaraud *et al.,* 2017).

Concerning the toxicity of certain plants, more detailed analysis is needed of effects of toxic doses of molecules with biological activity, toxic synergies (i.e. the "cocktail effect"), and thus acceptable proportions of these species in grasslands, as well as animals' ability to avoid ingesting them, in order to prevent harmful effects on animal performance that can sometimes lead to death. Because of the problems they cause, toxic plant species are better known individually and are well documented in veterinary literature. However, the maximum proportions of these species in the biomass of grasslands are not well known.

In addition, it is also important to consider effects of consuming fodder, which helps filter pollutants, on animals, their health and that of humans. These effects may thus depend on grassland's location in a region. Research on contaminants is underway but focuses more on crops (Rychen *et al.,* 2008; Chatelet *et al.,* 2015).

4. Grasslands to resist climatic and economic hazards and reduce production costs

■ 4.1. A context of climate change and economic uncertainty

Since 1980, the climate change observed in Europe has increased mean annual temperature (1.7°C higher in 2019 than in the pre-industrial era), the frequency of heat waves and drought periods (EEA, 2019) and the CO_2 content of the air (Soussana *et al.,* 2002; IPCC, 2018). A continuation of these trends seems inevitable at the global scale, with a temperature increase of 1.5°C predicted by 2030 (IPCC, 2018). Europe would therefore be strongly impacted in coming years by global warming and its consequences, which would lead to large variations in crop yields, including those of fodder crops. This impact is unfavourable overall, with a decrease in yields (IPCC, 2018), although some regions may experience some beneficial effects due to a longer annual growing season (Chang *et al.,* 2017). Effects of climate change on grasslands are already being measured, whether on their botanical composition, their yield (Mosimann *et al.,* 2013), particularly without irrigation (Knapp *et al.,* 2001), with decreases of up to 30% depending on the year (Picon-Cochard *et al.,* 2013), or on the functional response of species (Volaire *et al.,* 2009; Volaire *et al.,* 2016). These effects can perturb the fodder balance of farms and the annual distribution of grassland production, often requiring farms to buy fodder, reduce the number of livestock and/or resort to irrigation. Resisting or adapting to climate change will require an evolution or even a revolution in the design of livestock farming systems.

Overall, climate change has a negative impact on the economic health of farms and is often compounded by economic uncertainties that are increasingly common in livestock farming: with the increase in international trade in raw materials and animal products, the global livestock market is sensitive to unpredictable fluctuations in the prices of raw materials and foodstuffs. This uncertainty influences prices of products (*e.g.* milk, meat) and inputs (*e.g.* cereals, fertilisers, petroleum), as shown by the fall in products prices on world markets and the milk crisis in 2009, as well as the increase in the prices of raw materials in 2008 (Institut de l'Élevage, 2019).

Farms must therefore become more resilient to better withstand and adapt to climatic hazards and these price fluctuations; one avenue for reflection is to decrease production costs of farms greatly. As feed costs represent a large percentage of production costs (ca. 25% in dairy cattle farming), working with low-input raw materials such as those from grasslands provides room to manoeuvre (Caillaud *et al.,* 2013; Rubin *et al.,* 2017; Devienne *et al.,* 2018).

■ 4.2. The potential of grassland systems to adapt to climate change and economic hazards

Climate change has led all stakeholders in the livestock sector (i.e. farmers, advisers, scientists, policy makers) to seek solutions to adapt to the climate's changing trend and increased variability. Some of these solutions have already been implemented, while others are avenues to be evaluated (Pottier *et al.,* 2007). We believe that grasslands can play a decisive role in adaptation to climate change at several scales (figure 2):

(i) At the scale of the grassland, which unlike fodder crops such as maize, can be exploited throughout the year; thus, climatic stress in summer can be com-

pensated by early growth in spring and later growth in autumn or even winter (Pottier *et al.,* 2007), allowing it to take advantage of intra-year climatic opportunities. Indeed, climate change has caused milder autumns and winters in recent years and thus increased grass growth, despite less favourable summers. Moreover, grasslands seem to show plasticity and dynamics in the face of climatic hazards (Tuba and Kaligaric, 2008). The diversity of their plant species makes them less sensitive to climatic hazards than single-species grasslands and thus reduces the critical threshold of climatic stress. Indeed, relying on a mixture of species with different light, water and temperature requirements makes it easier to cope with periods of high climatic hazard (Durand *et al.,* 2016; Hofer *et al.,* 2016). For example, one species may not be able to withstand a drought period, but the other species present can ensure a minimum yield from the field. While interspecific diversity is important, intraspecific genetic diversity can also enhance adaptation potential (Durand, 2016; Meilhac *et al.,* 2019). Finally, establishing species that are more resistant to extreme conditions such as intense droughts is a solution. Several studies are underway to test the forage value of species such as alfalfa, plantain and chicory (Gauly *et al.,* 2013; Delagarde *et al.,* 2014; Lee *et al.,* 2015), in pure or mixed form, at the field scale.

(ii) At the scale of the group of fields, solutions exist to decrease effects of global warming. These solutions can apply to vegetation cover besides grasslands (*e.g.* planting hedgerows and trees). In addition to the benefits that hedgerows provide (*e.g.* lower wind or humidity; Liagre, 2007), trees provide shelter for animals and lower high temperatures (Béral *et al.,* 2018). This fodder resource can also be used in ruminant rations: research is underway to quantify effects of trees on herbivore nutrition (Vandermeulen *et al.,* 2018), the palatability and nutritional value of woody plants to animals (Habib *et al.,* 2016; Bhatta et *al.,* 2017) and effects on fodder crops grown under tree canopies (Lima et *al.,* 2019).

iii) At the scale of the fodder system, room to manoeuvre is based on managing fields with diverse environmental conditions and agronomic potentials. Indeed, having fields that are more humid or, conversely, less hydromorphic makes it easier to traverse a period of uncertainty. Having fields of differing productivity during the year is also a factor of flexibility. Although grasslands that produce less biomass and begin growing later in the year are less useful for feeding herds, their flexibility is of interest in a context of uncertainty because their potential use can be delayed by a few weeks (Michaud *et al.,* 2011). If a period of intense drought or rainfall occurs when a low-productivity grassland should have been mown, its agricultural value will remain more stable and decrease less over time than that of a more productive grassland. Finally, the grass supply can also be managed by carrying it over in the field (i.e. keeping a plot in which grass is not consumed, which serves as a reserve) or by using more flexible grazing methods.

Besides the room to manoeuvre for grassland area, the herd can also be managed differently. A one-time reduction in the stock or rearing fewer heifers or replacement ewe lambs would reduce the stock at the farm scale and thus increase flexibility in grassland management in the event of a hazard. In terms of herd organisation, moving from one calving season to two or more would also reduce risk on the farm (Pottier *et al.,* 2007). However, these adjustments in herd management require predicting the balance between optimising grass management and climatic risks.

While grasslands show potential in the face of climate change, their economic advantages are undeniable. Many studies have shown that grassland systems have lower production costs than conventional systems, which gives grassland systems greater resilience (Rubin *et al.,* 2017; Dieulot and Meyer, 2018). Grassland systems have greater economic resilience because forage production costs are lower than those of maize silage and because grazing costs less. In addition, these systems often depend less on inputs and thus on fluctuations in input prices (Delaby and Fiorelli, 2014; O'Donovan and Delaby, 2016). In this sense, a few local initiatives are emerging to try to recognise milk made from grass or hay; however, this type of initiative remains uncommon on the market.

■ 4.3. Research and innovation needs

Although grasslands with high floristic diversity have advantages in the face of climate change, many areas of research remain to be clarified. The sustainability and stability of their floristic composition needs to be understood better to guarantee long-term expression of the fitness of this composition. Several studies are underway to quantify effects of repeated climatic hazards on grassland production (Zwicke *et al.,* 2013), responses of grassland species (Zwicke *et al.,* 2015) and their potential adaptation (Volaire *et al.,* 2018) to these hazards. This research should be pursued, particularly to adapt management practices as a function of these hazards.

For temporary grasslands composed of sown species, research remains to be performed on mixtures of species that have differing degrees of drought resistance, mixtures of many grassland species and mixtures of grassland species and cereals to improve resistance to climatic hazards. More generally, grassland systems will have to adapt to climatic hazards: many research avenues remain to be explored on possible adaptations of the functioning of production systems, fodder systems or both. Analysis of the place of grasslands in fodder systems (*e.g.* productive, dry and wet grasslands) and how grasslands fit into farm management depending on climatic conditions remains to be fine-tuned.

5. The need to overcome farmers' reluctance to use grasslands and to facilitate their work

■ 5.1. Grasslands seen as uncertainty and thus stress

While the economic argument advanced to promote grassland systems should appeal to farmers and facilitate the development of grasslands and grazing (Caillaud *et al.*, 2013), this is not always the case, particularly for dairy systems (figure 2). Indeed, while "grazing" know-how is transmitted from generation to generation in certain regions, grasslands have been replaced in other regions by more productive fodder crops that are more stable over time, which makes it easier to produce a stable amount of milk over time. In the areas where grazing is less common, besides the related technical obstacles (*e.g.* scattered fields, fields that are too small to produce the grass that the herd requires (Gomas *et al.,* 2008)), grasslands are considered difficult to manage due to the high variability in milk production, which is related to the variability in grass growth and value: dairy farmers have difficulty accepting "saw-tooth" milk production because milk is their main source of income (Michaud *et al.,* 2008). They often prefer the better-known, reputedly simpler rations based on maize silage and complementary feed, which provide stable production over time and do not require transitioning. Grazing management considered to require observation and prediction to adapt to climatic conditions and grass growth (Michaud *et al.*, 2008; Frappat *et al.,* 2014).

This concern about including grasslands in dairy production systems is also highlighted by Couvreur *et al* (2019), who identified four categories of farmers who use grassland: "fulfilled grazers", "moderates", "flexible optimisers" and "undecided conservatives". In these categories, grassland can represent an unquestioned heritage, be part of the system in a moderate way or even be a mechanism for sustainability. For farmers who use grasslands as the central element of the fodder system (i.e. "successful farmers" according to Couvreur et *al.* (2019)), other studies mention a degree of technicality in grassland management (Darré *et al.,* 2004; Mathieu, 2004). Indeed, livestock farmers' predictions over time, estimates of effects of spring grazing on summer grazing and view of their grasslands shows the importance, technicality and transmission of this knowledge. Finally, although grazing can be a source of daily stress or an additional workload for certain farmers, for others (*e.g.* "fulfilled grazers"; Couvreur et *al.,* 2019), the search for well-being at work can be a favourable development path toward a production system based on grazing (Lusson *et al.,* 2014). For these farmers, their working and living conditions, as well as their new view of their herds, are arguments in favour of this transition.

■ 5.2. Research and innovation needs

Although much research has been performed to improve understanding of grasslands and develop accessible management tools, technical and sociological obstacles remain, with differences among types of farmers. Technical support for these system transitions is necessary (Lusson *et al.,* 2014) and is developed in action-research projects (Devienne *et al.,* 2018; Coquil *et al.,* 2019). Development is also important for transmitting this knowledge and its image. More generally, providing farmers with the best possible support depending on whether or not they decide to enhance the value of grasslands in their systems is a major challenge. To do this, it seems essential to understand farmers' visions (i.e. how they perceive their surroundings and worldview). Cayre *et al* (2018) highlighted farmers' worldviews according to the production methods they chose. This initial study provides avenues to reflect on the type of technical support to provide given the sociological vision (*e.g.* favouring a type of grassland on the farm that is consistent with preserving biodiversity) to implement in response to farmers' perception of their environment and, more broadly, in work on agroecology.

Moreover, the image and technical nature of grasslands have yet to be updated to give them a place in current systems, which increasingly use digital and technology. There is a need to raise awareness about the multiple benefits of grasslands, including grasslands with high floristic diversity, which is less common. An interesting example is the flowering grassland competition launched in France in 2007, which brings together ca. 60 organising territories each year that represent 400-500 livestock farmers (De Sainte Marie *et al.,* 2018). It recognises the farmers' technical ability to manage their grasslands by awarding a symbolic prize to those who use diversified permanent grasslands to increase economic and societal performance.

Obstacles to grazing are often mentioned for dairy systems, even though cow-calf systems use the most grassland. For dairy systems, the future trajectories of grassland and grass-based systems can be questioned. Should systems be geared primarily towards dairy production, with fodder such as maize and productive grasslands being the main ration and diversified grasslands being more of a supplement? Or should it be acceptable to adapt the system's production to the area's potential rather than vice-versa; in this framework, grasslands, especially diversified grasslands, can find their place at the heart of the feeding system.

Conclusion

In a world in which producing in quantity is no longer sufficient, and producing better with less is becoming necessary, grasslands have advantages that are increasingly better known due to the progress of scientific and technical knowledge and the availability of technological tools that are not sufficiently recognised. They have a rightful place in tomorrow's herbivore farming systems: the beneficial effects they have on the environment, as well as human and animal health and welfare, fully meet society's expectations. They also help improve society's image of livestock farming. However, several challenges need to be addressed: help farmers consider grasslands more favourably, use them better and change the paradigm by abandoning the principle of "always more", but also to make the advantages of grasslands known and transform them into added value, following the example of PDO production. Doing so implies training farmers, supporting them and enabling them to have an acceptable quality of life with grassland of production. While grasslands fully meet society's expectations for farming, health and the environment, their place in the reform of the European Union's Common Agricultural Policy must be defended so that these systems are recognised and remunerated for their multiple benefits.

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References

Agreil C., Meuret M., Vincent M., 2004. GRENOUILLE : une méthode pour gérer les ressources alimentaires pour des ovins sur milieux embroussaillés. Fourrages, 180, 467-481.

Agreil C., Barthel S., Barret J., Danneels P., Greff N., Guérin G., Guignier C., Mailland Rosset S., Magda D., Meignen R., Mestelan P., De Sainte Marie C., 2011. La gestion pastorale des milieux naturels : mise en œuvre des MAE-t et gestion adaptative avec la démarche PATUR'AJUSTE. Fourrages, 208, 293-304.

Agreste 2015. Statistique agricole annuelle. Résultats semi-définitifs de l'année agricole 2014. https://www.epsilon.insee.fr/jspui/bitstream/1/34174/1/agr_PC_2015_10.pdf

Agreste, 2018. Mémento de la statistique agricole. Édition 2018 de la forêt et des industries agroalimentaires. Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt, 1-40.

Alard V., Béranger C., Journet M., 2002. Étude de systèmes Herbagers économes en Bretagne, INRA Éditions, 340p.

Allen V.G., Batello C., Berretta E.J., Hodgson J., Kothmann M., Li X., McIvor J., Milne J., Morris C., Peeters A., Sanderson M., 2011. An international terminology for grazing lands and grazing animals. Grass Forage Sci., 66, 2-28.

Amiaud B., Carrère P., 2012. La multifonctionalité de la prairie pour la fourniture de services écosystémiques. Fourrages, 211, 229-238.

Bareille N., Haurat M., Delaby L., Michel L., Guatteo R., 2019. Quels sont les avantages et risques du pâturage vis-à-vis de la santé des bovins ? Fourrages, 238, 125-131.

Batary P., Baldi A., Saropataki M., Kohler F., Verhulst J., Knop E., Herzog F., Kleijn D., 2010. Effect of conservation management on bees and insect-pollinated grassland plant communities in three European countries. Agricult. Ecosys. Environ., 136, 35-39.

Baumont R., Michaud A., Delaby L., 2012. Services fourragers des prairies permanentes : production d'herbe et valeur alimentaire pour les ruminants. Fourrages, 211, 219-228.

Baumont R., Tran G., Chapoutot P., Maxin G., Sauvant D., Heuzé V., Lemosquet-Simon S., Lamadon A., 2018. Tables Inra de la valeur des aliments utilisés en France et dans les régions tempérées. In: Nozière P., Sauvant D., Delaby L., Inra, 2018. Alimentation des ruminants. Apports nutritionnels – Besoins et réponses des animaux – Rationnement – Tables des valeurs des aliments, 521-616. Versailles, France, Éditions Quae. 728p.

Béral C., Andueza D., Ginane C., Bernard M., Liagre F., Girardin N., Emile J.C., Novak S., Grandgirard D., Deiss V., Bizeray D., Moreau J.C., Pottier E., Thiery M., Rocher A., 2018. Agroforesterie en système d'élevage ovin : étude de son potentiel dans le cadre de l'adaptation au changement climatique. Synthèse. INRA, ADEME, 20p.

Béranger C., Bonnemaire J., 2008. Prairies, herbivores, territoires : quels enjeux ? Quae Éditions, Versailles, France, 188p. https://www.quae.com/produit/946/9782759214518/prairies-herbivores-territoires-quels-enjeux

Bhatta R., Saravanan M., Baruah H., Malik P.K., Sampath K.T., 2017. Nutrient composition, rate of fermentation and in vitro rumen methane output from tropical feedstuffs. J. Agric. Sci., 155, 171-183. https://doi.org/10.1017/S0021859616000642

Bruneton J., 2016. Pharmacognosie, phytochimie, plantes médicinales (5e Éd.). Éditions Lavoisier, Tec & Doc, 1504p. https://www.lavoisier.fr/livre/genie-pharmaceutique/pharmacognie-phytochimie-plantes-medicinales-5e-ed/bruneton/descriptif-9782743021658

Caillaud D., Couéffé D., Georgel R., Moussu J.P., Zsitko J.M., 2013. Les systèmes laitiers herbagers de l'Est de la France : une réussite paradoxale. Fourrages, 213, 3-9.

Cayre P., Michaud A., Theau J.P., Rigolot C., 2018. The coexistence of multiple worldviews in livestock farming drives agroecological transition. A case study in French PDO cheese mountain areas. Sustainability 10, 4, 1097. https://doi.org/10.3390/su10041097.

Celi P., 2010. The role of oxidative stress in small ruminants' health and production. Revista Brasileira de Zootecnia, 39, 348-363.

Chang J., Ciais P., Viovy N., Soussana JF., Klumpp K., Sultan B., 2017. Future productivity and phenology changes in European grasslands for different warming levels: implications for grassland management and carbon balance. Carbon Balance Management, 12, 1-11. https://doi.org/10.1186/s13021-017-0079-8.

Chatelet A., Fournier A., Jurjanz S., Lerch S., Toussaint H., Delannoy M., Feidt C., Rychen G., 2015. L'épandage de matières fertilisantes d'origine résiduaire sur les prairies comporte-t-il des risques en termes de transfert de polluants organiques et inorganiques vers la chaîne alimentaire ? INRA Prod. Anim., 28, 383-298.

Chen Y.D., Chappell N.A., 2009. Climate regulation of Southeast Asian hydrology. Critical states: environmental challenges to development in monsoon Southeast Asia. Gerakbudaya, Kuala Lumpur, 205-220.

Chilliard Y., Glasser F., Ferlay A., Bernard L., Rouel J., Doreau M., 2007. Diet, rumen biohydrogenation and nutritional quality of cow and goatmilk fat. Eur. J. Lipid Sci. Technol., 109, 828-855.

Coleou J., 1960. Les références concernant le rationnement des animaux. Le bilan fourrager. Écon. Rurale, 43, 1, 33-54.

Collectif, 2006. Le Massif Vosgien : Typologie des prairies naturelles. Document INPL-INRA/Chambres d'agriculture 67, 68, 88/ PNR des Ballons des Vosges/ Institut de l'Élevage. Éditions Chambre d'Agriculture des Vosges. Brochure, 27p.

Coppa M., Ferlay A., Monsallier F., Verdier-Metz I., Pradel P., Didienne R., Montel M.C., Pomies D., Martin

B., Farruggia, A., 2012. Le système de pâturage influence-t-il les caractéristiques nutritionnelles et sensorielles des fromages ? Fourrages, 209, 33-41.

Coquil X., Junior D.S., Lusson J.M., Miranda M., 2019. Les réseaux Rad et Rede Capa : la technique au service du projet politique d'un autre modèle agricole ? Natures Sci. Soc., 27, 53-62.

Couvreur S., Delaby L., Doligez E., Mahmoudi P., Marnay L., Michaud A., Navelet C., Paulin S., Plantureux S., Puthod R., 2018. Les prairies au service de l'élevage. Comprendre, gérer et valoriser les prairies. Édition : Educagri, Dijon, France, 328p.

Couvreur S., Petit T., Le Guen R., Ben Arfa N., Jacquerie V., Sigwalt A., Haimoud-Lekhald A., Chaib K., Defois J., Martel G., 2019. Déterminants techniques et sociologiques du maintien des prairies dans les élevages bovins laitiers de plaine. INRA Prod. Anim., 32, 399-416. https://doi.org/10.20870/productions-animales.2019.32.3.2940

Couturier C., Charru M., Doublet S., Pointereau P., 2016. Afterres 2050-Un Scénario Soutenable Pour l'agriculture et l'utilisation. Des Terres En France à l'horizon 2050. https://afterres2050.solagro.org/wp-content/uploads/2015/11/Afterres2050-Web.pdf

Cruz P., Theau J.P., Lecloux E., Jouany C., Duru M., 2010. Typologie fonctionnelle de graminées fourragères pérennes : une classification multitraits. Fourrages, 201, 11-17.

Darré J.P., Mathieu A., Lasseur J., 2004. Le Sens des pratiques : conceptions d'agriculteurs et modèles d'agronomes. Éditions Quae, Versailles, France, 320p.

De Foucault B., 1992. Les apports de la phytosociologie au pastoralisme. Fourrages, 130, 211-221.

Delaby L., Fiorelli J.L., 2014. Élevages laitiers à bas intrants : entre traditions et innovations. In : Numéro spécial, Quelles innovations pour quels systèmes d'élevage ? Ingrand S., Dedieu B. (Eds). INRA Prod. Anim., 27, 123-134.

Delaby L., Duboc G., Cloet E., Martinot Y., 2014. Pâtur'Plan : Un outil dynamique pour favoriser la gestion anticipée des parcelles en système de pâturage tournant. Renc. Rech. Rum., 21, 387-390.

Delagarde R., Roca-Fernández A.I., Peyraud J.L., 2014. Prairies multispécifiques avec ou sans chicorée : densité du couvert mesurée à l'herbomètre et composition chimique. Fourrages, 218, 177-180.

Delagarde R., Caillat H., Fortin J., 2017. HerbValo, une méthode pour estimer dans chaque parcelle la quantité d'herbe valorisée par les ruminants au pâturage. Fourrages, 229, 55-61.

Dernat S., Rigolot C., Cayre P., Vollet D., Dumont B., 2020. Knowledge sharing in practice: a methodology for the identification of a common prospective in a PDO cheese production area. J. Agric. Educ. Ext., submitted November 22, 2019.

De Ponti T., Rijk B., Van Ittersum MK., 2012. The crop yield gap between organic and conventional agriculture. Agricult. Syst., 108, 1-9.

De Sainte Marie C., Ba S.N., Barbier M., Gaunand A., Avelange I., 2018. Des Prairies Fleuries. Réconcilier production et conservation de la biodiversité sur les surfaces herbagères. Rapport de recherche, INRA SAD. hal-01923595

Devienne S., Vertès F., Garambois N., Akkal-Corfini N., Durand P., Parnaudeau V., 2018. Supporting transition to low inputs production systems: economic and environmental assessment. Proc. 20th Nitrogen Workshop, Rennes, France, 466-467.

Diaz S., Marcelo C., Casanoves F., 1998. Plant functional traits and environmental filters at a regional scale. J. Veget. Sci., 9, 113-122.

Dieulot R., Meyer A., 2018. L'observatoire technico-économique des systèmes bovins laitiers. Évolutions sur 10 ans. Réseau CIVAM, 16p.

Dudonné D., Vitrac X., Coutiere P., Woillez M., Merillon J.M., 2009. Comparative study of antioxidant properties and total phenolic content of 30 plant extracts of industrial interest using DPPH, ABTS, FRAP, SOD, and ORAC assays. J. Agric. Food Chem., 57, 1768-1774.

Durand J.L., 2016. Adaptation des prairies semées au changement climatique : amélioration génétique et intensification écologique. Rapport Métaprogramme ACCAF CLIMAGIE, INRA. 41p. https://hal.archives-ouvertes.fr/hal-01594783/

Durand D., Damon M., Gobert M., 2013. Oxidative stress in farm animals: general aspects. Cah. Nutr. Diet., 48, 218-224.

Durand J.L., Andrieu B., Barillot R., Barr, P., Combes D., Enjalbert J., Escobar-Gutierrez A., Faverjon J., Lescarpentier C., Litrico I., Louarn G., Migault V., Sanchez L., 2016. Designing and improving mixed grasslands: advances made in modelling forage variety performance. Fourrages, 225, 21-28.

Duru M., Cruz P., Theau J.P., Jouany C., Ansquer P., Al Haj Khaled R., Therond O., 2007. Typologies des prairies riches en espèces en vue d'évaluer leur valeur d'usage : bases agro-écologiques et exemple d'application. Fourrages, 192, 453-475.

Duru M., Cruz P., Al Haj Khaled R., Ducouturieux C., Theau J.P., 2008. Relevance of plant functional types based on leaf dry matter content for assessing digestibility of native grass species and species-rich grassland communities in spring. Agron. J., 100, 1622-1630.

Duru M., Cruz P., Theau J.P., 2010. A simplified method for characterising agronomic services provided by species-rich grasslands. Crop Pasture Sci., 61, 420-433.

Duru M., Hazard L., Magrini M.B., 2016. La santé comme cadre d'analyse pour penser conjointement les questions agricoles, environnementales et alimentaires. 4p. Toulouse, France.

Ebeling A., Klein A.M., Schumacher J., Weisser W.W., Tscharntke T., 2008. How does plant richness affect pollinator richness and temporal stability of flower visits? OIKOS 117, 1808-1815.

Emile J.C., Barre P., Delagarde R., Niderkorn V., Novak S., 2017. Les arbres, une ressource fourragère au pâturage pour des bovins laitiers ? Fourrages, 230, 155-160.

European Environment Agency (EEA), 2019. Indicator assessment: Global and European temperatures; https://www.eea.europa.eu/data-and-maps/indicators/global-and-european-temperature-9/assessment. Accessed August 2019

Farruggia A., Martin B., Baumont R., Prache S., Doreau M., Hoste H., Durand D., 2008. Quels intérêts de la diversité floristique des prairies permanentes pour les ruminants et les produits animaux ? INRA Prod. Anim., 21, 2, 181-200.

Farruggia A., Lacour C., Zapata J., Piquet M., Baumont B., 2012. DIAM, un diagnostic innovant déclinant les équilibres, production, environnement et qualité des fromages au sein des systèmes fourragers des zones AOP du Massif Central. Renc. Rech. Ruminants, 19, 13-16.

Fisher B., Turner R.K., 2008. Ecosystem services: Classification for valuation. Biol. Conservation, 141, 1167-1169.

Fraisse D., Carnat A., Viala D., Pradel P., Besle J.M., Coulon J.B., Felgines C., Lamaison J.L, 2007. Polyphenolic composition of a permanent pasture: Variations related to the period of harvesting. J. Sci. Food Agric., 87, 2427-2435.

Frappat B., Lusson J.M., Beauchamp J.J., 2014. La prairie vue par les éleveurs, les conseillers et les futurs éleveurs en France : quelques pistes pour faciliter l'accès à des systèmes valorisant mieux la prairie. Fourrages, 218, 147-155.

Galliot J.N., Hulin S., Bonsacquet E., Carrere P., 2019. Apprécier les compromis entre services à travers la typologie multifonctionnelle des prairies du Massif central. Fourrages, 237, 67-74.

Galliot J.N., Hulin S., Le Hénaff P.M., Farruggia A., Seytre L., Perera S., Dupic G., Faure P., Carrère P., 2020. Typologie multifonctionnelle des prairies du Massif central. Edition Sidam-AEOLE, 284p. https://projets.cbnmc.fr/uploads/downloads/meadow/massif_central_typology/TMPMC_2020_BD_telechargement.pdf

Gauly M., Bollwein H., Breves G., Brugemann K., Danicke S., Das G., Demeler J., Hansen H., Isselstein J., Konig S., Loholter M., Martinsohn M., Meyer U., Potthoff H., Sanker C., Schroder B., Wrage N., Meibaum B., Von Samson-Himmelsjerna G., Stinshoff H., Wrenzycki C., 2013. Future consequences and challenges for dairy cow production systems arising from climate change in Central Europe – a review. Animal, 7, 5, 843-859. https://doi.org/10.1017/S1751731112002352

Gomas A.L., Laurent M., Rubin B., 2008. Alternatives au maïs ensilage : freins et perspectives dans les élevages bovins laitiers du sud des Deux-Sèvres. Fourrages, 196, 490-494.

Graulet B., Piquet M., Duriot B., Pradel P., Hulin S., Cornu A., Portelli J., Martin B., Farruggia A., 2012. Variations des teneurs en micronutriments de l'herbe de prairies de moyenne montagne et transfert au lait. Fourrages, 209, 59-68.

Grime J.P., 1977. Evidence for existence of 3 primary strategies in plants and its relevance to ecological and evolutionary theory. American Naturalist, 111, 982, 1169-1194.

Grime J.P., Hodgson J.G., Hunt R., 1979. Comparative plant ecology: a functional approach to common British species. London: Unwin Hyman.

GIEC, 2018. Résumé à l'intention des décideurs, Réchauffement planétaire de 1,5 °C, Rapport spécial du GIEC sur les conséquences d'un réchauffement planétaire de 1,5 °C par rapport aux niveaux préindustriels et les trajectoires associées d'émissions mondiales de gaz à effet de serre, dans le contexte du renforcement de la parade mondiale au changement climatique, du développement durable et de la lutte contre la pauvreté. Masson-Delmotte V., Zhai P., Pörtner H.O., Roberts D., Skea J., Shukla P.R., Pirani A., Moufouma-Okia W., Péan C., Pidcock R., Connors S., Matthews J.B.R., Chen Y., Zhou X., Gomis M.I., Lonnoy E., Maycock T., Tignor M., Waterfield T. (Eds). Organisation météorologique mondiale, Genève, Suisse, 32p.

Habib G., Khan NA., Sultan A., Ali M., 2016. Nutritive value of common tree leaves for livestock in the semi-arid and arid rangelands of Northern Pakistan. Livest. Sci., 184, 64-70. https://doi.org/10.1016/j.livsci.2015.12.009

Herrero M., Wirsenius S., Henderson B., Rigolot C., Thornton P., Havlík P., De Boer I., Gerber P.J., 2015. Livestock and the environment: What have we learned in the past decade? Annu. Rev. Environ. Resour., 40, 177-202, https://doi.org/10.1146/annurev-environ-031113-093503

Hofer D., Suter M., Haughey E., Finn J.A., Hoekstra N.J., Buchmann N., Luscher A., 2016. Yield of temperate forage grassland species is either largely resistant or resilient to experimental summer drought. J. Appl. Ecol., 53, 4, 1023-34. https://doi.org/10.1111/1365-2664.12694

Hopkins A., 1986. Botanical composition of permanent grassland in England and Wales in relation to soil, environment and management factors. Grass Forage Sci., 41, 237-246.

Hoste H., Gaillard L., Le Fibreux Y., 2005. Consequences of the regular distribution of sainfoin hay on gastrointestinal parasitisme with nematodes and milk production in dairy goats. Small Rum. Res., 59, 265-271

Huang D., Ou B., Prior R.L., 2005. The chemistry behind antioxidant capacity assays. J. Agric. Food Chem., 53, 1841-1856.

Hubert F., Pierre P., 2003. Guide pour un diagnostic prairial. Une méthode pour faire le diagnostic de vos prairies. Chambres d'agriculture Pays de Loire, pp235.

Huguenin-Elie O., Delaby L., Le Clec'h S., Moreno G. M., Teixeira R.F.M., Schneider M.K., 2018. Optimising ecosystem services provided by grassland systems. Grass. Sci. Europe, 23, 520-534.

Hulin S., Farruggia A., Carrère P., 2012. Valorisation de la diversité des prairies au sein des systèmes fourragers : une approche appliquée pour les territoires AOP du Massif Central. Innov. Agron., 25, 71-84.

Hulin S., Galliot J.N., Carrere P., Le Henaff P.M., Bonsaquet E., 2019. Les prairies naturelles du Massif central : l'expression d'un terroir au service de produits de qualité. Fourrages, 239, 223-229.

INRA, 2018. INRA Feeding System for Ruminants, Wageningen Academic Publishers, Wageningen, The Netherlands, 643p.

Institut de l'Élevage, 2019. Résultats économiques des fermes laitières de l'ouest : des repères pour se situer 2018/2019. 12p.

Jeangros B., Schmid W., 1991. Production et valeur nutritive des prairies permanentes riches en espèces. Fourrages, 126, 131-136.

Jeangros B., Troxler J., Conod D., Scehovic J., Bosset J.O., 1997. Relations entre les caractéristiques de l'herbe et celles du fromage. Présentation et premiers résultats d'une étude pluridisciplinaire. Fourrages, 152, 437-443.

Jeannin B., Fleury P., Dorioz J.M., 1991. Typologie des prairies d'altitude des Alpes du Nord : méthode et réalisation. Fourrages, 128, 379-396.

Klimas E., Balezentiene L., 2008. Fertilization impact on natural and sown grassland floristic improvement. Zemes ukio Mokslai, 15, 2, 41-45.

Klimek S., Kemmermann A.R.G., Hofmann M., Isselstein J., 2007. Plant species richness and composition in managed grasslands: The relative importance of field management and environmental factors. Biol. Conservation, 134, 559-570.

Knapp A.K., Briggs J.M., Koelliker J.K., 2001. Frequency and extent of water limitation to primary production in a mesic temperate grassland. Ecosystems, 4, 19-28.

Koplan P., Bond C., Merson M., Reddy S., Rodríguez M., Sewankambo N., Wasserheit J., 2009. Towards a Common Definition of Global Health. The Lancet, 373, 1993-1995. https://doi.org/10.1016/S0140-6736(09)60332-9

Lacroix K., Gifford R., 2019. Reducing meat consumption: identifying group-specific inhibitors using latent profile analysis. Appetite, 138, 233-241. https://doi.org/10.1016/j.appet.2019.04.002

Laisse S., Baumont R., Dusart L., Gaudré D., Rouillé B., Benoit M., Veysset P., Rémond D., Peyraud J.L., 2018. L'efficience nette de conversion des aliments par les animaux d'élevage : une nouvelle approche pour évaluer la contribution de l'élevage à l'alimentation humaine. In : Ressources alimentaires pour les animaux d'élevage. Baumont R. (Ed). Dossier, INRA Prod. Anim., 31, 269-288.

Lasseur R., Vannier C., Leverbre J., Longaretti P.-Y, Lavorel, S., 2018. Landscape-scale modeling of agricultural land use for the quantification of ecosystem services. J. Appl. Remote Sensing, 12, 4. https://doi.org/10.1117/1.JRS.12.046024

Launay F., Baumont R., Plantureux S., Farrie J.P., Michaud A., Pottier E., 2011. Prairies permanentes : des références pour valoriser leur diversité, Institut de l'Élevage, 128p.

Lavorel S., Grigulis K., Lamarque P., Colace M.P., Garden D., Girel J., Pellet G., Douzet R., 2011. Using plant functional traits to understand the landscape distribution of multiple ecosystem services. J. Ecol., 99, 135-147.

Lee J.M., Hemmingson N.R., Minnee E.M.K., Clarck C.E.F., 2015. Management strategies for chicory (Cichorium intybus) and plantain (Plantago lanceolata): impact on dry matter yield, nutritive characteristics and plant density. Crop Pasture Sci., 66, 2, 168-183. https://doi.org/10.1071/CP14181

Lemaire G., Carvalho P.C.D.F., Kronberg S., Recous S., 2019. Agroecosystem diversity: reconciling contemporary agriculture and environmental quality. Elsevier, Academic Press, 464 p.

Liagre F., 2007. Les haies rurales : rôles, création, entretien. France Agricole Éditions. 290p.

Likkesfeldt J., Svendsen O., 2007. Oxidants and antioxidants in diseases: oxidative stress in farms animals. Vet. J., 173, 502-511.

Lima M.A., Paciullo D.S.C., Morenz J.F., Gomide C.A.M., Rodrigues R.A.R., Chizzotti F.H.M., 2019. Productivity and nutritive value of Brachiaria decumbens and performance of dairy heifers in a long-term silvopastoral system. Grass Forage Sci., 74, 1, 160-170. https://doi.org/10.1111/gfs.12395

Litrico I., Barkaoui K., Barradas A., Barre P., Beguier V., Birouste M., Bristiel P., Crespo D., Deléglise C., Durand JL., Fernadez L., Gastal F., Ghesquiere M., Godinho B., Hernandez P., Julier B., Louarn G., Meisser M., Mosimann E., Picon-cochard C., Roumet C., Volaire F., 2016. Utiliser les mélanges fourragers pour s'adapter au changement climatique : opportunités et défis. Fourrages, 225, 11-20.

Lusson J.M., Coquil X., Frappat B., Falaise D., 2014. Itinéraires vers des systèmes herbagers : comprendre les transitions pour mieux les accompagner. Fourrages, 219, 213-220.

Maire V., 2009. Des traits des graminées au fonctionnement de l'écosystème prairial : une approche de modélisation mécaniste. PhD thèses, Université Blaise Pascal, Clermont Ferrand, France.

Martin B., Graulet B., Uijttewaal A., Ferlay A., Coppa M., Rémond D., 2019. Contribution des produits laitiers aux apports nutritionnels selon la nature des fourrages distribués aux vaches laitières. Fourrages, 239, 193-202.

Martin G., Felten B., Duru M., 2011. Forage rummy: a game to support the participatory design of adapted livestock systems. Environ. Model. Software, 26, 1442-1453.

Mathieu A., 2004. Conceptions des agriculteurs et modèles agronomiques. Le pâturage des vaches laitières dans le Jura. Natures Sci. Soc., 12, 4, 387-399.

Mauchamp L., Gillet F., Mouly A., Badot PM., 2013. Les prairies : biodiversité et services écosystémiques. CNAOL-UFC. Presses universitaires de Franche-Comté, Pratiques et Techniques, 134p, <hal-00768735>.

Mee J.F., Boyle L.A., 2020. Assessing whether dairy cow welfare is "better" in pasture-based than in confinement-based management systems, N.Z. Vet. J., https://doi.org/10.1080/00480169.2020.1721034

Meilhac J., Durand J.L., Beguier V., Litrico I., 2019. Increasing the benefits of species diversity in multispecies temporary grasslands by increasing within-species diversity. Ann Bot., 123, 5, 891-900.

Michaud A., Havet A., Matthieu A., 2008. Reverting to grazing: farmer's conception. In: Proc. 22rd Gen. Meet. Eur. Grass. Fed., Uppsala: Sweeden: Biodiversity and animal feed.

Michaud A., Andueza D., Picard F., Plantureux S., Baumont R., 2011. The seasonal dynamics of biomass production and herbage quality of three grasslands with contrasting functional compositions. Grass Forage Sci., 67, 64-76. https://doi.org/10.1111/j.1365-2494.2011.00821.x

Michaud A., Carrère P., Farruggia A., Jeangros B., Orth D., Pauthenet Y., Plantureux S., 2013. Construire des typologies pour évaluer le potentiel des prairies à rendre des services agro-environnementaux. Fourrages, 213, 35-44.

Michaud A., Plantureux S., Pottier E., Baumont R., 2014. Links between functional composition, biomass production and forage quality in permanent grasslands over a broad gradient of conditions. J. Agricult. Sci., 153, 891-906. https://doi.org/10.1017/S0021859614000653

Millenium Ecosystem Assessment, 2005. Ecosystems and Human Well-Being. Synthesis. In: A report of the Millenium Ecosystem Assesment, pp. 219. Island Press, Washington.

Miller J.K., Brzezinska-Slebodzinska E., Madsen F.C., 1993. Oxidative stress, antioxidants, and animal function. J. Dairy Sci., 76, 2812-2823.

Minh B.R., Barry T.N., Tattwood G.T., McNabb W.C., 2003. The effect of condensed tannins on the nutrition and health of ruminants fed fresh temperate forages: a review. Anim. Feed Sci. Technol., 106, 3-19.

Mosimann E., Deléglise C., Demenga M., Frund D., Sinaj S., Charles R., 2013. Recherche agronomique suisse 4 (11+12), 468-475.

Mottet A., Teillard F., Boettcher P., De'Besi G., Besbes B., 2018. Domestic herbivores and food security: current contribution, trends and challenges for a sustainable development. Animal, 12, 2, 188-198.

Mulligan F.J., Doherty M.L., 2008. Production diseases of the transition cow. Vet J., 176, 3-9.

Niki E., 2010. Assessment of antioxidant capacity in vitro and in vivo. Free Radical Biol. Med., 49, 503-515.

Nozière P., Graulet B., Lucas A., Martin B., Grolier P., Doreau M., 2006. Carotenoids for ruminants: From forages to dairy products. Anim. Feed Sci. Technol., 131, 418-450.

O'Donovan M., Delaby L., 2016. Grazed grass in the dairy cow diet – how this can be achieved better! In: 26. Gen. Meeting Eur. Grassland Fed., (EGF). Wageningen Academic Publishers.

Paillard S., Dorin B., Treyer S., 2010. Agrimonde. Scénarios et défis pour nourrir le monde en 2050. Éditions Quae, Versailles, France, 296p.

Pakeman R., Leps J., Kleyer M., Lavorel S., Garnier E., the VISTA consortium, 2009. Relative climatic, edaphic and management controls of plant functional trait signatures. J. Veget. Sci., 20, 148-159.

Peeters A., Beaufoy G., Canals R.M., De Vliegher A., Huyghe C., Isselstein J., Jones G., Kessler W., Kirilov A., Mosquera-Losada M.R., Nilsdotter-Linde N., Parente G., Peyraud J.L., Pickert J., Plantureux S., Porqueddu C., Rataj D., Stypinski P., Tonn B., Van Den Pol – Van Dasselaar A., Vintu V., Wilkins R., 2014. Grassland term definitions and classifications adapted to the diversity of European grassland-based systems. 25th Gen. Meet. Eur. Grassland Fed. Aberystwyth, Wales, 8-11 septembre 2014.

Petit S., Vansteelant J.Y., Plaige V., Fleury P., 2004. Les typologies de prairies : d'un outil agronomique à un objet de médiation entre agriculture et environnement. Fourrages, 179, 369-382.

Petit T., Martel G., Vertès F., Couvreur S., 2019. Long-term maintenance of grasslands on dairy farms is associated with redesign and hybridisation of practices, motivated by farmers' perceptions. Agricult. Sys., 173, 435-448.

Pickworth C.L., Loerch S.C., Kopec R.E., Schwartz S.J., Fluharty Y.F.L., 2012. Concentration of pro-vitamin A carotenoids in common beef cattle feedstuffs. J. Anim. Sci., 90, 1553-1561.

Picon-Cochard C., Bloor J., Zwicke M., Duru, M., 2013. Impacts du changement climatique sur les prairies permanentes. Fourrages, 214, 127-134.

Pierik M.E., Gusmeroli F., Della Marianna G., Tamburini A., Bocchi S., 2017. Meadows species composition, biodiversity and forage value in an Alpine district: relationships with environmental and dairy farm management variables. Agriculture, Ecosystems and Environment, 244, 14-21. https://doi.org/10.1016/j.agee.2017.04.012

Plantureux S., Bonischot R., Guckert A., 1993. Classification, vegetation dynamics and forage production of permanent pastures in Lorraine. Eur. J. Agron., 2, 11-17.

Ponisio L.C., M'Gonigle L.K., Mace K.C., Palomino J., De Valpine P., Kremen C., 2014. Diversification practices reduce organic to conventional yield gap. Proc. R. Soc., 282, 1799.

Pottier E., Delaby L., Agabriel J., 2007. Adaptations de la conduite des troupeaux bovins et ovins aux risques de sécheresse. Fourrages, 191, 267-284.

Pottier E., Roumiguie A., Jacquin A., Fougère M., 2017. Les nouvelles technologies au service de la prairie. In Journées AFPF : Le pâturage au cœur des systèmes d'élevage de demain. 21-22 mars 2017.

Poutaraud A., Michelot-Antalik A., Plantureux S., 2017. Grasslands: A Source of Secondary Metabolites for Livestock Health. J. Agric. Food Chem., 65, 6535-6553.

Reynaud A., Fraisse D., Cornu A., Farruggia A., Pujos-Guillot E., Besle J.M., Martin B., Lamaison J.L., Paquet D., Doreau M., Graulet B., 2010. Variation in content and composition of phenolic compounds in permanent pastures according to botanical variation. J. Agric. Food Chem., 58, 5485-5494.

Rockström J., Steffen W., Noone K., Persson A., Chapin F.S.I., Lambin E.F., Lenton T.M., Scheffer M., Folke C., Schellnhuber H., 2009. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecol. Soc., 14, 2, 1-32.

Roukos C.,Koutsoukis C., Akrida-Demertzi K., Karatassiou M., Demertzis G.P., Kandrelis S., 2017. The effect of altitudinal zone on soil properties, species composition and forage production in a subalpine grassland in northwest Greece. Appl. Ecol. Environ. Res., 15, 1, 609-626. https://doi.org/10.15666/aeer/1501_609626

Rubin B., Perrot C., Quenon J., 2017. Coûts de production et place du pâturage dans les systèmes fourragers bovins laitiers en France et chez nos compétiteurs. Fourrages, 230, 97-100.

Rychen G., Jurjanz S., Toussaint H., Feidt C., 2008. Dairy ruminant exposure to persistent organic pollutants and excretion to milk. Animal: an international J. Anim. Biosci., 2, 2, 312.

Ryschawy J., Dumont B., Therond O., Donnars C., Hendrickson J., Benoit M., Duru M., 2019. Review: An integrated graphical tool for analysing impacts and services provided by livestock farming. Animal, 13, 1760-1772.

Saatkamp H.W., Vissers L.S.M., Van Horne P.L.M., De Jong I.C., 2019. Transition from Conventional Broiler Meat to Meat from Production Concepts with Higher Animal Welfare: Experiences from The Netherlands. Animals, 9, 483, 2-11. https://doi.org/10.3390/ani9080483

Sanchez-Sabate R., Sabate J., 2019. Consumer attitudes toward environment concerns of meat consumption: a systematic review. Int. J. Environ. Res. Public Health, 16, 7, 1220. https://doi.org/10.3390/ijerph16071220

Simon J.C., Leconte D., Vertès F., Le Meur D., 1997. Maîtrise de la pérennité du trèfle blanc dans les associations. Fourrages, 152, 483-498.

Shalloo L., O'Donovan M., Leso L., Werner J., Ruelle E., Geoghegan A., Delaby L., O'Leary N., 2018. Review: Grass-based dairy systems, data and precision technologies. Animal, 12, 2, 262-271.

Soussana J.F., Teyssonneyre F., Picon-Cochard C., Casella E., Besle J.M., Lherm M., Loiseau P., 2002.

Impacts des changements climatiques et atmosphériques sur la prairie et sa production. Fourrages, 169, 3-24.

Stassart P.M., Baret P., Grégoire JC., Hance T., Mormont M., Reheul D., Stimlant D., Vanloqueren G., Vissser M., 2012. L'agroécologie : Trajectoire et potentiel pour une transition vers des systèmes alimentaires durables. Agroécol. Entre Prat. Sci. Soc., 25-51.

Steinfeld H., Gerber P., Wassenaar T.D., Caste V., De Haan C., 2006 Livestock's Long Shadow: Environ. Issues Options; Food Agricult. Organization: Rome, Italy, pp390.

Sulpice P., Manteaux J.P., Michaud A., Fauriat A., Ollivier A., Otz P., Longfellow H., 2019. Quels effets bénéfiques du pâturage sur la santé animale ? Première approche à partir de suivis d'élevages bovins laitiers par des vétérinaires conventionnés. Fourrages, 238, 133-138.

Theau J.P., Pauthenet Y., Cruz P., 2017. Une typologie des espèces non graminéennes pour mieux caractériser la diversité et la valeur d'usage des prairies permanentes. Fourrages, 232, 321-329.

Theau J.P., Malvoisin T., Faugeroux F., Pauthenet Y., 2018. Dialog'Alpes : Un outil pour valoriser la diversité des prairies permanentes dans les exploitations d'élevage bovin laitier. Fourrages, 234, 131-142.

Therond O., Tichit M., Tibi A., Accatino F., Biju-Duval L., Bockstaller C., Bohan D., Bonaudo T., Boval M., Cahuzac E., Casellas E., Chauvel B., Choler P., Constantin J., Cousin I., Daroussin J., David M., Delacote P., Derocles S., De Sousa L., Domingues J.P., Dross C., Duru M., Eugene M., Fontaine C., Garcia B, Geijzendorffer I.R., Girardin A., Graux A.I., Jouven M., Langlois B., Le Bas C., Le Bissonnais Y., Lelievre V., Lifran R., Maigne E., Martin G., Martin R., Martin-Laurent F., Martinet V., Mclaughlin O., Meillet A., Mignolet C., Mouchet M., Nozieres-Petit M.O., Ostermann O., Paracchini M.L., Pellerin S., Peyraud J.L., Petit Michaut S., Picaud C., Plantureux S., Pomeon T., Porcher E., Puech T., Puillet L., Rambonilaza T., Raynal H., Resmond R., Ripoche D., Ruget F., Rulleau B., Rush A., Salles, J.M., Sauvant D., Schott C., Tardieu L., 2017. Biens produits par l'écosystème. In: EFESE, services écosystémiques rendus par les écosystèmes agricoles, 693-894, https://prodinra.inra.fr/record/421319.

Tichit M., Dumont B., 2016. L'agroécologie : origines, bases scientifiques et déclinaisons en élevage. In L'agroécologie. Du nouveau pour le pastoralisme. Éditions INRA, AgroPArisTech, pp106.

Tornambé G., Ferlay A., Farruggia A., Chilliard Y., Loiseau P., Pradel P., Graulet B., Chauveau-Duriot B., Martin B., 2010. Influence of the botanical diversity and development stage of mountain pastures on milk fatty acid composition, carotenoids, fat-soluble vitamins and sensory properties. In: Proc. 23rd General Meet. Eur. Grassland Fed., 589-591. Kiel, Germany: Grassland in a changing world.

Tuba Z., Kaligaric M., 2008. Grassland ecology in changing climate and land use. Community Ecol., 9, 3-12.

Tuomisto H.L., Hodge I.D., Riordan P., Macdonald D.W., 2012. Does organic farming reduce environmental impacts?–A meta-analysis of European research. J. Environ. Management, 112, 309-320.

Valnet J., 1972. Phytothérapie : traitement des maladies par les plantes. Editions Vigot, 639p.

Vandermeulen S., Ramirez-Restrepo C.A., Beckers Y., Claessens H., Bindelle J., 2018. Agroforestry for ruminants: a review of trees and shrubs as fodder in silvopastoral temperate and tropical production systems. Animal Production Science, 58, 5, 767-777. https://doi.org/10.1071/AN16434

Volaire F., Norton MR., Lelievre F., 2009. Summer drought survival strategies and sustainability of perennial temperate forage grasses in mediterranean areas, Crop Science, 49, 2386-2392.

Volaire F., Ahmed L.Q., Barre P., Bourgoin T., Durand J.L., Gutiérrez A.E., Fakiri M., Ghesquière M., Julier B., Kallida R., Louarn G., Morvan-Bertrand A., Picon-Cochard C., Prud'homme P., Shaimi N., Zaka S., Zouhri L., Zwicke M., 2016. Quelle est la variabilité intra-et interspécifique des caractères d'adaptation des espèces prairiales pérennes aux variables du changement climatique ? Fourrages, 225, 1-9.

Volaire F., Lens F., Cochard H., Xu H., Chacon-Doria L., Bristiel P., Balashowski J., Nick R., Violle C., Picon-Cochard C., 2018. Embolism and mechanical resistances play a key role in dehydration tolerance of a perennial grass Dactylis glomerata L. Ann. Botany, 122, 325-336.

Wang F.Y., Basso F., 2019. « Animals are friends, not food » : antropomorphism leads to less favorable attitudes toward meat consumption by inducing feelings of anticipatory guilt. Appetite 138, 153-173. https//doi.org/10.1016/j.appet.2019.03.019

Zeiler E., Sauter-Louis C., Ruddat I., Martin R., Mansfeld R., Knubben-Schweizer G., Zerbe H., 2010. Influence of vitamin E and selenium on udder health – a meta-analysis. Reprod. Domestic Anim., 61, 60-61.

Zwicke M., Alessio GA., Thiery L., Falcimagne R., Baumont R., Rossignol, N., Soussana J.F., Picon-Cochard C., 2013. Lasting effects of climate disturbance on perennial grassland above-ground biomass production under two cutting frequencies. Global Change Biol., 19, 3435-3448.

Zwicke M., Picon-Cochard C., Morvan-Bertrand A., Prud'homme M. P.,Volaire F., 2015. What functional strategies drive drought survival and recovery of perennial species from upland grassland? Ann. Botany, 116, 1001-1015.

Abstract

Given the crisis that livestock farming is experiencing, with society is calling it into question, permanent and temporary grasslands could help provide a positive and recognised response for ruminant farming (cattle, sheep and goats). This article assesses innovative knowledge and tools for managing grassland in temperate areas, in light of the changing issues associated with livestock farming. Knowledge about grassland functioning and management has progressed significantly in recent years, especially for permanent grasslands, which are more complex to manage. Grasslands have many environmental benefits, which give them real advantages. In addition, they have strong advantages for animal health and the nutritional and organoleptic quality of animal products, which influence human health, and interesting potential to increase the resilience of production systems in the face of climatic and economic hazards. Beyond their economic benefits, grasslands, as ecosystem components, should be able to consolidate their place in ruminant production systems of tomorrow that are sustainable and acceptable to society.

Résumé

Les prairies, un richesse et un support d'innovation pour des élevages de ruminants plus durables et acceptables

Face aux crises que subit l'élevage et aux questionnements forts de la société vis-à-vis de celui-ci, les prairies permanentes et temporaires pourraient contribuer à fournir une réponse positive et reconnue pour l'élevage de ruminants (bovin, ovins et caprins). L'objet de cet article est de proposer un état des lieux des nouvelles connaissances et des innovations en termes d'outils de gestion des prairies en zone tempérée, au regard de l'évolution des enjeux associées à l'élevage. Les connaissances sur le fonctionnement des prairies et leur gestion ont fortement progressé ces dernières années et ont été particulièrement approfondies pour les prairies permanentes, surfaces prairiales plus complexes à gérer. Leurs intérêts environnementaux sont multiples et confèrent aux prairies de réels atouts. À ces éléments s'ajoutent de forts avantages au regard de la santé des animaux et de la *qualité nutritionnelle et organoleptique des produits animaux ayant un impact sur la santé humaine, mais aussi des perspectives intéressantes pour la résilience des systèmes de production face aux aléas climatiques et économiques. Au-delà de leur intérêt économique, ces éléments écosystémiques devraient permettre aux prairies de conforter leur place dans des élevages ruminants durables de demain et acceptables par la société.*

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https://doi.org/10.20870/productions-animales.2020.33.3.4543