Improving the use of natural and semi-natural grasslands in Mediterranean ruminant systems: issues, options and perspectives

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Improving the use of natural and semi-natural grasslands in Mediterranean ruminant systems: issues, options and perspectives

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Abstract. Mediterranean small-ruminant systems (MSRS) have undergone an intensification process triggered by local and global changes. Recent research suggests that such tendency should be reversed. This paper provides insight about how increasing the contribution of grasslands (including natural and semi-natural, improved or temporary grasslands) to the feeding system can improve MSRS' sustainability. Products from grazing animals are ethically appreciated and display good nutritional quality, specific organoleptic characteristics and possibly a longer shelf-life; they can be traced, and thus differentiated. The large surface area of natural and semi-natural grasslands (including areas with shrubs and trees) gives MSRS a head start in terms of carbon sequestration, which can be increased further by an appropriate grazing and feeding management. Technical options to increase grazed grass in MSRS include: (1) producing locally-adapted seed mixtures for grasslands; (2) increasing the proportion of legumes in grasslands; (3) managing grazing in order to maximize the amount and quality of intake; (4) matching the diversity of natural and semi-natural grasslands to animal requirements and/or providing strategic supplementation; (5) reconsidering the value of trees and the interest of foliage as forage. Digital technologies can help to improve farmers' working conditions and build the ecological knowledge necessary to implement adaptive management strategies. At a socio-political level, it is important to recognize the peculiarities of silvopastoral systems, value the ecosystem services provided, foster collective management solutions and facilitate interconnection with other activities.

Keywords. Forage – Grasslands – Feeding system – Management – Animal performance – Product quality – Ecosystem services.

Améliorer l'utilisation des pâturages dans les systèmes d'élevages méditerranéens de petits ruminants : enjeux, leviers d'action et perspectives

Résumé. *Les systèmes d'élevage méditerranéens de petits ruminants (SEMPR) se sont intensifiés sous l'influence de changements locaux et globaux. De récentes recherches suggèrent d'inverser la tendance. Cet article explore comment une contribution accrue des pâtures (naturelles et semi-naturelles, améliorés ou temporaires) aux systèmes d'alimentation peut améliorer la durabilité des SEMPR. Les produits d'animaux pâturant sont éthiquement appréciés et se caractérisent par une bonne qualité nutritive, des spécificités organoleptiques et une durée de conservation accrue ; ils sont traçables, donc différenciables. Les vastes surfaces de pâtures naturelles et semi-naturelles (dont les surfaces boisées ou embroussaillées) sont un atout en termes de séquestration de carbone, qu'une conduite appropriée du pâturage et de l'alimentation peut améliorer. Les leviers techniques pour augmenter le pâturage dans les SEMPR sont : (1) produire des mélanges de graines fourragères adaptés aux conditions locales ; (2) augmenter la proportion des légumineuses dans les pâtures ; (3) conduire le pâturage pour optimiser quantité et qualité ingérées ; (4) faire correspondre diversité des pâtures et besoins des animaux et/ou complémenter de manière stratégique ; (5) reconsidérer la valeur de l'arbre et l'intérêt fourrager des feuillages. Les technologies numériques peuvent contribuer à améliorer les conditions de travail des éleveurs, et à construire les savoirs écologiques nécessaires aux conduites adaptatives. Au niveau socio-politique, il est important de reconnaître les particularités des systèmes sylvopastoraux, valoriser les services rendus, encourager les solutions de gestion collective et faciliter l'interconnection avec d'autres activités.*

Mots-clés: *Fourrage – Pâtures – Système d'alimentation – Conduite – Performances zootechniques – Qualité des produits – Services écosystémique.*

I – Introduction

Pastoral and silvopastoral farming systems, especially when they involve small ruminants, play a major role on both sides of the Mediterranean basin, due to their acknowledged contribution to the preservation of natural resources and the socio-economic development of rural areas (De Rancourt *et al*., 2006; Boughalmi *et al*., 2015). Their feeding system relies, at least for part of the year, on the spontaneous vegetation grazed by the flock in natural and semi-natural grasslands, which may include woody species (shrubs, trees)[1]. These areas are also a reservoir of biodiversity, with ecological issues related to the pastoral activity (Hadjigeorgiou *et al*., 2005; Mahyou *et al*., 2010). Natural resources, under a Mediterranean climate, are subjected to strong seasonal variations and, at given moments of the annual production cycle, they cannot fully satisfy the animal feeding requirements (in qualitative or quantitative terms). Thus, the farmers need either to move their flock (transhumance) or to resort to temporary grasslands or conserved feed (often purchased, at an additional cost) in order to ensure adequate animal production levels. Silvopastoral systems traditionally use small ruminants (often of autochthonous breeds), which are adapted to such variable and extensive rearing conditions (Cosentino *et al.*, 2014) and apply local know-how to make the best use of the available resources in each territory (PASTOMED, 2008).

In the last decades, Mediterranean small ruminant farming systems (MSFS) have been confronted to major challenges at a global level, related to the increasing uncertainty in markets, policies, climate or changes in socio-cultural trends and consumer concerns (Nori and Scoones, 2019). When farms respond to these challenges with an intensification of their management system in search of higher animal productivity, a concomitant reduction in the contribution of natural and semi-natural grasslands and on-farm resources to animal diets is often observed (example in France: Aubron *et al*., 2016; in Italy: Vagnoni and Franca, 2017; in Morocco: Chattou, 2014). Yet, an increased dependency on purchased feed does not always result in improved economic return or efficiency, as Ripoll-Bosch *et al.,* demonstrated, because self-sufficiency is key to farm resilience, especially when facing uncertain and volatile markets. Furthermore, it certainly fails to exploit the ability of ruminants to convert natural vegetation and human-inedible feedstuffs into high-quality edible protein, which gives them a comparative advantage over other livestock as regards global food security (Herrero *et al.,* 2013).

Today, MSRS are characterized by contrasting intensification levels (Porqueddu *et al*., 2017), due to factors such as geographical location of farms, contingent market conditions and other external factors such as public incentives or local markets trends (Biala *et al.,* 2007). Alarmingly, Riedel *et al.,* found that intensification was more frequent in farms owned by younger and more innovative farmers, whereas the chances of continuity were critical in those who relied more on grazing resources and applied the most environmentally desirable management strategies. Pastoral farms are generally owned by older farmers, with few or no options for succession (). Besides this intensification process, the population of sheep and goats, most adapted to pastoral environments in Mediterranean areas, has changed significantly in the last decades, decreasing in European countries by more than 25% between 2000 and 2017 (according to FAOstat), mostly due to decreasing consumption trends and low economic profitability, and increasing in Northern Africa mostly due to agricultural policies aimed at improving animal production to meet the growing local demand (Alary and El Mourid, 2005). These trends have led to a degradation of the forage resource on the natural and semi-natural grasslands, either by the combined effect of drought and over-grazing (Morocco: Bechchari *et al*., 2014) or by shrub encroachment (Southern Europe: Bernués *et al*., 2011). Although Mediterranean grasslands have proven to be resilient under different stocking densities and grazing regimes, flexible management systems should be implemented to prevent overgrazing/undergrazing, in a climate change context where their amount and quality will be increasingly unpredictable.

1. The terminology used in this paper is based on Peeters *et al*. (2014).

In order to enhance the development of efficient and sustainable MSRS, research and policies should address the balance between delivering animal products and environmental services, while considering also other challenges such as public health, food security, social equity and animal welfare (Mottet *et al*., 2018). We hypothesize that using more or better natural and semi-natural grasslands in MSRS could be an interesting option to answer and reconcile the three major issues of (i) ensuring the [economic / social / ecological] sustainability of sheep and goat farms, (ii) providing animal products in line with consumers' demand, and (iii) mitigating climate change. The objective of the current paper is to provide insight about how and on what conditions, increasing the contribution of Mediterranean natural and semi-natural grasslands in the feeding systems can be an interesting option for small ruminant farms. The topic is analyzed at animal / paddock, farm and country scales, with an interdisciplinary approach considering agronomic, zootechnical, management and social factors.

II – More grazed grass in the diet: expected outcomes

1. Why extensive grassland-based systems could be more sustainable than intensive ones?

A very large diversity of ruminant farming systems is observed across the Mediterranean area, and while extensification is characteristic of marginal, less-favoured areas relying mostly on natural resources, intensification is common in lowlands where farms have access to forage and grain crops for their flocks (Bernués *et al*., 2011, Porqueddu *et al*., 2017). However, there is also a wide variety of systems within each region, with large differences in the use they make of natural and semi-natural grasslands. Lasseur indicated that the management practices implemented in natural grasslands in French mountain areas depended on the technical, environmental and social concerns of the farmers. In this study, farms specialized as lamb producers differed from those more oriented to pastoral management in aspects as diverse as grassland type (semi-natural vs temporary), grazing management (shepherding vs. fencing), lambing season, lamb fattening system and animal productivity. Similarly, in Spanish meat sheep farms Riedel *et al.* (2007) described in a mountain region the co-existence of intensive production systems (in terms of reproduction rates and indoor feeding) with extensive farms with a large proportion of semi-natural grasslands and, finally, agricultural farms with mixed sheep-crop systems. The latter exploit the complementarity among the available feeding resources (grasslands, forage crops), and allow for a product diversification within the farm that may improve their resilience under uncertain political and socio-economic environments.

Recent studies on key aspects for MSRS' sustainability pointed out the advantages of grassland-based systems. Gutiérrez-Peña *et al.,* analysed the strengths and weaknesses of traditional dairy goat farms and concluded that their viability could be improved: (1) by optimizing the use of grazeable resources, *i.e.* improving semi-natural grasslands, cultivating locally-adapted forage crops and designing year-round feeding schedules to account for forage seasonality; (2) by adopting commercialization strategies linked to the quality of grassland-based products to retain the potential added value. A modelling study on extensive sheep farming predicted higher economic (+40% income) and ecological performance (-29% use of non-renewable energy) for grassland-oriented management strategies (Jouven *et al.*, 2011). Application of the changes tested in an experimental farm resulted in a substantial increase in feed self-sufficiency (Jouven *et al*., 2015a). Feed self-sufficiency seems to be an effective way to increase farm sustainability, mainly in less-favoured areas. An agro-ecological survey carried out by Thénard *et al.* (2016) showed that farmers could improve farm self-sufficiency through different strategies, as a result of a trade-off between production, purchases and the use of local resources. In any case, each self-sufficiency pattern should be assessed in relation to environmental issues. Agroecological transition requires a good knowledge of the practices required to face the constant disruptions of the system (climatic hazards, predation, …) and reduce environmental impacts. Adequately managed livestock can also be a tool for the efficient management of areas with high natural value, sustaining at the same time a viable economic activity and providing differentiated products that fulfill societal demands for quality and environmentally-friendly production.

2. What can be expected out of a diet of Mediterranean forage in terms of product quality?

The effects of a grassland-based diet depend on a variety of factors such as the physiological status of the animal, the type of forage (main species, maturity, chemical composition) and feeding management (grazing vs. preserved, stocking rate, availability of supplements), among others.

High rates of forage inclusion in ruminant diets may result in a different product quality in terms of chemical composition. Ruminant products are usually low in fat but have a higher proportion of saturated fatty acids than other animal species, because dietary fat is partially biohydrogenated by ruminal microorganisms while they cannot synthetize polyunsaturated fatty acids (PUFA), the main source of which is green forage. Therefore, the fat composition of end products depends on the fat composition of the ingested diet and the rate of ruminal biohydrogenation, which can be partially inhibited by plant secondary metabolites. Cabiddu *et al.,* found that the forage species and its phenological phase influenced the concentration of fatty acids with beneficial effects on human health in the milk and cheese of dairy sheep (mono- and poly-unsaturated fatty acids, conjugated linoleic and vaccenic acid). Higher concentrations of those fatty acids were found for ewes grazing pure legumes or grass-legume mixtures than for ewes grazing pure grass swards, especially in the vegetative (rather than in the reproductive) stage. Similarly, Joy *et al.,* found that grazing improved the contents of conjugated linoleic and vaccenic acid and the PUFA n-6/n-3 ratios in sheep, compared to a hay-based diet. This was observed both in the milk produced by the ewes and in the meat of their suckling lambs, since young lambs are functionally non-ruminants and dietary fatty acids are transferred into their tissues in their original, non-biohydrogenated form. These differences in meat quality were even used as a basis to accurately discriminate among different feeding systems.

Grazing can also affect sensorial properties of ruminant products. In the case of dairy animals, higher PUFA contents in milk reduce fat melting point, resulting in cheeses of a softer, more melting texture. Some grassland components as terpenoids (abundant in forbs) and carotenoids (which decline with herbage maturation) are directly transferred from herbage to milk. The former are responsible for cheese odours and aromas, and the latter for its yellow colour. In the case of meat, comparisons between grassland-based and concentrate-based feeding systems generally show a more yellowish fat, due to the deposition of grass carotenoids, and a darker meat colour in grassland-fed animals, due to factors such as ultimate-pH, intramuscular fat content and composition. These colour traits can be used as markers for the traceability of grassland-feeding (Blanco *et al*., 2011), although the accuracy of classification can be limited if animals are finished indoors after grazing, because of their intermediate meat and carcass characteristics (Casasús *et al*., 2016). A pastoral flavour originates mostly in the oxidation of grass linolenic acid in the case of cattle and the deposition of skatole in sheep (Priolo *et al*., 2001), the ruminal biosynthesis of which can be limited by dietary tannins. These phenolic compounds, together with other secondary metabolites like saponins or essential oils, can also influence meat flavour or oxidative stability, by reducing discoloration and extending meat shelf life. In this sense, Lobón *et al.,* indicated that meat lipid oxidation was lower in lambs raised with their dams at pasture than in lambs raised indoors, especially when ewe-lamb pairs grazed on sainfoin rather than on alfalfa temporary grasslands. This was associated to the higher ! -tocopherol and condensed tannin contents of sainfoin as compared to alfalfa, which resulted in a meat shelf-life 4 to 6 days longer.

In the food market, consumers care about production chain sustainability, authenticity and responsibility, personalisation and health & wellness (Poore and Nemecek, 2018). Ruminant systems based on a high use of grazed forages and legumes benefit from the effects on sensorial and instrumental quality traits of the meat and milk obtained in these conditions. A quality-based differentiation together with the strong territorial link of these products, very important for consumers, could be the basis of specific product differentiation schemes. These programs add value to animal production and increase its marketability, making them attractive for all stakeholders within the supply chain, from farmers and retailers to consumers.

3. What is the potential of grassland-based systems in terms of climate change mitigation?

The greening process of agriculture and livestock sectors is supported by EU climate change policies and driven by the increasing demand of environmental-friendly agri-food products. Reduction of greenhouse gas (GHG) emissions from ruminant farming systems in order to mitigate climate change can be done either by increasing carbon (C) sequestration or by reducing carbon emissions in the form of methane (CH_4). The Mediterranean livestock supply chain is a good example for exploring the relationship between small ruminants farming and climate change (Marino *et al*., 2016).

Grazing management and the total surface area of natural and semi-natural grasslands (including areas with shrubs and trees) are the characteristics that affect potential soil C sequestration the most (Bernués *et al*., 2017). Correct agronomic practices may increase soil C sequestration, especially in extensive small ruminant farms, where permanent grasslands plays an important role as C sink (Hopkins and Del Prado, 2007). Natural and semi-natural grasslands improve soil C stock with respect to arable crops, due to a higher stability of C returning to the soil and to an increased residence time of C in the absence of soil tillage (Soussana *et al.,* 2004). Grasslands cannot sequester C indefinitely in time. Thus, grazing management can improve soil C sequestration, by regulating the grazing pressure both in overgrazing/undergrazing conditions (Vigan *et al.,* 2017). However, the effect of grazing regimes on the GHG emissions is still unclear. At farm scale, increasing the contribution of natural and semi-natural grasslands in small ruminant systems might have other positive side-effects, such as improvement of the overall environmental performance, with a better eco-efficiency due to less mechanized operations and to a lower use of inputs, thus reducing eutrophication, acidification, GHG emissions and non-renewable energy use (Rotz *et al.,* 2010; Soteriades, 2016; Vagnoni and Franca, 2017).

Dietary mitigation strategies, through the increase of diet digestibility, are crucial to mitigate CH_4 emissions. Methane emissions can be limited by increasing forage quality, either by feeding ruminants high quality forages such as legumes, and/or by adopting grazing management techniques aimed at securing a high quality of grazed forage (LEAP, 2019). Though, increasing forage digestibility is no trivial matter, since digestibility varies among forage species and plant parts and changes depending on standing herbage mass, phenology, cultivation techniques and grazing management. Usually, legumes are more digestible and ingested in higher amount than grasses at an equal growth stage (Rochon *et al.,* 2004). Legume and forb species may differ significantly in the digestive CH_4 and nitrogen (N) release due to differences in the content of bioactive compounds such as tannins and saponins (Waghorn *et al*., 2002; Archimede *et al* 2011). Also, grasses and legumes with high content of water-soluble carbohydrates may contribute to the reduction of CH_4 emission, having the potential to reduce ammonia escape from the rumen and to increase intake and performance (Lee *et al.,* 2001; Jones *et al*., 2014). Grazing management may be a relevant mitigation strategy when adopting specific grazing management solutions, such as rotational grazing, in order to limit the digestibility decay related to herbage mass accumulation - or a part-time afternoon grazing that may enhance ruminant intake and performance, through a more efficient rumen N incorporation (Gregorini, 2012; Molle *et al*., 2016). The options reported in this paragraph are easier to implement in temporary grasslands, but they could also find applications in pastoral systems, where flock mobility can enable to “follow forage quality and availability in space and time". The high heterogeneity observed in the effectiveness of mitigation strategies (Veneman *et al*., 2016) calls for a deeper knowledge about the technical applicability of strategies within specific production systems and about the economic implications of their implementation.

III – Technical options to increase grazed grass in Mediterranean feeding systems

1. Innovations to improve the amount and quality of forage production in grasslands

The agrarian landscape in the European Mediterranean regions appears as a complex mosaic of feed resources, animal species and local breeds, as an effect of the local socio-cultural traditions (Porqueddu *et al.,* 2016a). Grazed forage crops represent a relevant portion of this mosaic (EIP-AGRI Focus Group on "Permanent grasslands", 2014). The influence of climate change is expected to lead to large reductions in Mediterranean crop productivity with increased water demand, hastened maturation and reduced yields for spring crops and geographically variable effects for autumn crops (Maracchi *et al.*, 2005; Rötter and van de Geijn, 1999). Innovation aimed at improving forage productivity, compatibly with the eco-sustainability of animal production, needs to face such climatic trend. Also, farmers increasingly ask for locally-produced feeds adapted to the particular soil and climate conditions of each area, especially if they can be used under direct grazing systems and have long vegetative periods. This interest concerns especially forages, but also local grains, oil seeds and pulses as an alternative to reduce the dependency on soybean imports.

Regarding temporary grasslands, annual forage crops such as traditional mixtures of annual forage legumes (common vetch, woolly pod vetch, Persian clover, crimson clover and berseem clover) and winter cereals (oats, barley and triticale) or grasses (especially Italian ryegrass: *Lolium multiflorum Lam.* ssp. *italicum* and ssp. *westerwoldicum*) are used for short-term forage crops on arable lands (Porqueddu *et al*., 2017). They are usually grazed up to the end of winter and left ungrazed for all the final growth cycle in spring, when they are cut for hay production. Mixtures based on annual self-reseeding legumes and winter cereals have been introduced to extend the duration of temporary grasslands to two or three years. Among perennial forage crops, alfalfa represents the primary temporary grassland species for neutral and alkaline soils, while other perennial legumes as red clover and birdsfoot trefoil are less frequently sown. A renewed interest is growing for sulla and sainfoin (Re *et al.,* 2014). A few varieties of perennial grasses, particularly cocksfoot (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.) and bulbous canary grass (*Phalaris aquatica* L.), are sown in higher rainfall areas with deeper soils and they are generally included in seed mixtures with annual or perennial legumes.

Regarding semi-natural grasslands, the species and varieties of legumes and grasses to be used in mixtures sown at the establishment of the sward should be accurately chosen. Traditionally, self-reseeding annual legumes, in particular subterranean clover and annual medics, have been used for the improvement of semi-natural grasslands in many European Mediterranean areas. However, these cultivars are often poorly suited to the climatic conditions and management systems of southern Europe (Sulas, 2005; Porqueddu *et al*., 2010). In more recent years, some innovative annual legume species suitable for soil types and farming systems not suited to annual subterranean clover and medics have been developed. Among these, biserrula, yellow serradella, French serradella, balansa clover, arrowleaf clover, bladder clover and Persian clover (Nichols *et al*., 2007).

Innovation for forage productivity necessarily needs multidisciplinary investigations on the different types of grazed forage crops and plant species components related to the quality and value of livestock products. Self-sufficiency in high-protein feeds is a challenge (Porqueddu *et al.,* 2016b). A successful development of legume species and varieties well-adapted to Mediterranean habitats is needed, both for temporary and permanent grasslands. The available seeds for temporary grasslands are selected and multiplied in various countries including Central Europe, Denmark and New Zealand. Seed production also occurs in Italy and France but is mainly restricted to alfalfa (Huyghe *et al.,* 2014). Annual legumes for the improvement of semi-natural grasslands are selected, multiplied and imported mainly from Australia. The seed market of such varieties thus mainly relies on Australian seed companies (Loi *et al.,* 2008). However, these varieties show often poor adaptability to the variable climatic and management conditions of southern Europe (Sulas, 2005; Porqueddu *et al*., 2010). Thus, there is a need to develop local seed production in the Mediterranean basin.

2. Feeding and grazing management to improve animal performance

Grassland-based feeding is often associated with lower animal performance compared to stall-feeding. The main reasons for this would be a lower quality of the feed ingested, a variable availability of the pastoral resource and a higher energy expenditure for walking and regulating body temperature. Recent research suggests that these arguments are not always true, depending on the seasons and local conditions, and points out possible solutions to improve animal performance at pasture.

Mediterranean legume-based grasslands, particularly those containing moderate levels of condensed tannins, like sainfoin (*Onobrychis sativa*), sulla (*Hedysarum coronarium*), chicory (*Cichorium intybus*) or birdsfoot trefoil (*Lotus corniculatus*) have been reported to improve sheep performance. This benefit has been ascribed to increased intake and N retention, reduced methane emissions and improved resilience to digestive parasites, among others. A combination of these forages with annual grasses can provide an adequate protein:energy ratio in grazing dairy sheep, that could be fully balanced with fibrous concentrates in some phases of lactation (Molle *et al*., 2008). Accordingly, Gutiérrez-Peña *et al*. (2016) indicated that concentrate supplementation for dairy goats grazing on semi-natural grasslands and forage crops could contribute as much as 57% of the total annual herd energy requirements, in order to compensate for forage seasonality and to obtain optimum milk yield. In the case of meat sheep in Mediterranean mountain areas, Gonzàlez-Garcìa *et al.* (2014) reported that suckling *Romane* ewes grazing natural grasslands in spring performed fairly well, with an average daily gain around 200g/day for twins and 250g/day for singleton lambs, and no loss in body condition score for ewes, apart for multiparous ewes suckling twins (-0,2 points /5). Joy *et al.,* showed that lamb performance was improved when their dams grazed on natural grasslands compared to when they received indoors hay from similar canopies (0.26 vs. 0.22 kg/day). However, due to the seasonality of forage growth in these conditions, this management could only be applied during the vegetative period in spring and for a short period on the autumn regrowth.

In order to overcome seasonal drops in grazeable resources, integration of forages with longer vegetative growth periods such as alfalfa (*Medicago sativa*) in the grazing plans has been proposed. Alvarez-Rodríguez *et al.,* described that light lambs reared by their mothers on alfalfa with creep-fed concentrate supplement until slaughter had similar gains to weaned lambs fed with *ad libitum* concentrates in feedlot conditions (0.24 vs. 0.26 kg/day, NS). The long growth period of alfalfa would allow for this management for ewes lambing in spring and summer. Similarly, Blanco *et al.,* indicated that rotational grazing of young bulls on *Medicago sativa* supplemented with 1.8 kg DM barley/day provided an interesting alternative to feedlot concentrate feeding. This system allowed for a 165-day grazing period with daily gains similar to those obtained at the feedlot (1.36 vs. 1.52 kg/day, NS) but at a lower economic cost per kg gained. Other studies, however, found lower growth rates in cattle fed forage-based diets, maybe due to a higher energy expenditure at pasture or to a suboptimal nutrient synchrony (carbohydrate:protein) in absence of adequate supplements.

In practice, if natural grasslands (including areas with shrubs and trees) usually meet the low requirements of dry females, high-quality rations are needed for dairy ewes or lambs. Those can be obtained either by grazing high-quality, immature swards of natural or semi-natural grasslands in spring or autumn, by introducing improved grasslands in the forage plan (or in the daily grazing circuit in case of shepherded flocks), or by strategic supplementation at pasture. In all cases, a fine-tuning in the choice of the grasslands and of the supplements is needed in order to fulfill the animal requirements while maximizing the intake at pasture and thus minimizing feeding costs.

3. Management options to make the best use of natural and semi-natural grasslands

Natural grasslands provide low-cost grazed forage in many MSRS, and sometimes have a very high contribution in the feeding system. Jouven *et al.* (2015b) found, based on farm surveys, that natural grasslands could provide up to 80% of the feed ingested by young horses and mares in Endurance and Camargue farms of southern France. A better use of natural grasslands is thus a key to improve the technical and economic performance of MSRS. This implies an optimum integration in the grazing calendar, either by grazing them in the periods where their yield and quality is at its highest, or by using them in other phases with animals of limited nutritional requirements. Tuning the dynamics of animal requirements and forage availability will sometimes require adapting animal management in terms of calving and weaning dates.

Taking advantage of the diversity of natural grasslands and of the complementarities between natural and temporary grasslands is another key point. In dry mountain areas of Spain, autumn-calving cow-calf herds could graze throughout the year in a combination of wooded and dry grasslands, supplemented in periods of scarcity with forage (winter) and forage crops (summer). Brosh *et al.,* described that when adequate supplements were provided at given periods, pregnant, lactating and dry beef cows could meet 80% of their energy requirements in Mediterranean wooded grasslands, where browse constituted up to 60% of the diet in periods of low grass availability. Shrubby vegetation plays a major role as forage resource for small ruminants during the summer drought, although the intake of foliage can be limited for many Mediterranean plant species due to the presence of secondary compounds which may impair animal health. These effects can be counteracted by supplementing animals with additives that decrease their absorption and/or increase their elimination. For eastern Morocco, Gobindram *et al.* (2018) reported a strategic utilization of natural grasslands, wooded grasslands and cereal stubble depending on the season and on their local availability; where wooded grasslands were common, farmers would keep more goats in the flock in order to take best advantage of the available foliage. At smaller scales, experienced shepherds would offer a diversity of feeding sites during the daily grazing circuit, as previously reported by Meuret and Provenza (2015). In fact, the diversity of feed items, both in terms of quality (Silue *et al*., 2016) and in terms of bite size (Agreil and Meuret, 2004), makes it possible for the animals to adjust their feeding choices and secure the amount and quality of their intake. In order to do this, the domestic herbivores need to learn, especially in their young age and by observing the behaviour of their mother, the nutritional interest of plant parts and associations of those plant parts (Meuret and Provenza, 2015). Thus, replacement females should be raised at pasture, ideally with their mother.

Making a sustainable use of natural grasslands implies ensuring the renewal of the pastoral resources on the long term, and thus controlling vegetation dynamics. Grazing by both sheep (Riedel *et al.,* 2013) and cattle has proven to affect vegetation dynamics on Mediterranean natural and wooded grasslands. However, although they consumed herbage biomass and maintained a stable cover through the years, stocking rates may not be high enough to prevent shrub encroachment and its detrimental effects on environmental risks (loss of diversity, fire hazard). This would call for specific actions either through enhanced grazing management or by means of prescribed fire and mechanical removal for controlling shrub invasion. The efficiency of these methods for the recovery of grasslands will depend on the biology of the dominant species and the establishment of an adequate grazing pressure afterwards that can ensure both grass seed dispersal and shrub regrowth control. In Southern Mediterranean areas, where natural grasslands tend to be overgrazed, different strategies have been recommended to reduce grazing pressure and foster rehabilitation. Among them, Ates *et al.,* proposed the use of natural grasslands with fodder crops, by introducing forage legumes into rotations with cereal crops or by intercropping fodder trees or shrubs in the fields, and the optimization of grazing rotations on *wadis* and lowlands to enhance their productivity and nutritive value for livestock.

Rangelands are economically interesting for the farmer not only as a forage resource but also because they allow to minimize mechanized operations; though, they usually require fencing or shepherding, which can be costly and tough to implement. Besides, grazing the flock on large areas with bushes and trees might increase the predation risk (Nozières-Petit *et al.*, 2017). The conservation of open pastoral areas by extensive livestock systems provides a wide range of ecosystem services, each influenced, to a different extent, by numerous agricultural practices. Fire prevention is the most publicized ecosystem service in North Mediterranean areas, and several wildfire prevention programs include extensive grazing in forests or specifically on fuel breaks, often under payment schemes based on a long-term commitment of farmers and public administrations. A payment system based on farmers' agricultural practices and their associated benefits extended to other services would ensure that farmers are fairly rewarded from society for their contributions, and motivate them further to use natural grasslands.

4. Efficient and sustainable management of silvopastoral systems

Silvopastoralism indicates the association, in the same piece of land, of silviculture and livestock grazing. Silvopastoral systems cover a total of approximately 20 million ha in the EU27 (4.7%) and about 10.8% of the Mediterranean biogeographical region. Silvopastoral systems involve grazed wooded grasslands and are particularly relevant in Mediterranean countries: Dehesas in Spain and Montados in Portugal occupy about 7 million ha; Greek Phrygana, a maquis managed by grazing and occasional fires, concerns more than 1 million ha; in Italy, 1.3 million ha (10% of the utilised agricultural area) integrates trees with livestock production (Riguiero-Rodríguez *et al.*, 2009; Moreno *et al.*, 2014; Paris *et al.*, 2019). Silvopastoral systems have an exceptional ecological value as a result of their contribution to biodiversity at a landscape level, their dynamic character, and their role as a repository of genetic resources (Plieninger *et al.*, 2015). They also enable to increase the total production on a given surface area, thus contributing to the ecological intensification of agriculture, and have an important socio-economic role, providing rural employment and a range of ecosystem services (Seddaiu *et al.,* 2013; Rossetti *et al.,* 2015). In a context of serious risk of inland abandonment, silvopastoral systems require a new management approach in order to enhance and value their multiple functions.

Trees and livestock can be combined with semi-natural grasslands to form an integration of animal husbandry, silviculture, and forage crops, defined as "silvopasture" (Sharrow *et al.*, 2009). The innovative management practices associated to silvopastures are related to grazing regimes and forage production. Traditional grazing management practices often involve an intense grazing pressure, which may compromise tree regeneration (Moreno *et al.*, 2014). In the framework of the LIFE Project REGENERATE (www.regenerate.eu), adaptive multi-paddock grazing management is being tested. The principle is to take into account ecosystem complexity to plan the distribution of grazing over time, across landscapes and plant communities, using a series of paddocks (Teague and Barnes, 2017). In addition, multi-species grazing tries to optimize the complementarities among the feeding behaviour of sheep, goats and cattle in the framework of rotational grazing.

The needs of silvopastoral farmers were assessed with a survey in the framework of the AGFORWARD Project (www.agforward.eu). Priority was given to enhancing the availability of forage resources in the understory layer, to improving the valuation of grassland resources, and to increasing grassland productivity and quality (Pisanelli *et al.,* 2014, Camilli *et al.*, 2018). In non-arable lands, such as natural or wooded grasslands in the mountain areas, livestock usually graze extensively, mainly during spring-autumn months, when fodder resources in the plain are scarce. For deep enough and arable soils, a more intensive management could be possible in silvopastures, with the sowing of high quality forage species and a targeted mineral fertilization, especially in terms of phosphorus, which enables to extend the period of grass growth and thus the length of the grazing season and favours the development of legumes which improve the nutritive quality of grazed forage. In silvopastures with shrubby vegetation, mechanical clearing can be associated with fertilization and, if necessary, over-sowing of adapted pasture species with techniques of minimum tillage or sod-seeding. In case of degradation of the herbaceous layer with invasive species, overseeding and fertilization can help restoring the sward, provided the seed mixtures are adapted to the local environment (annual self-reseeding clovers and medics in dry areas, perennial grasses and clovers in soils with high water retention capacity). Unfortunately, the seed market does not provide specific shade-tolerant pasture species. Recently, a research aimed at selecting shade tolerant pasture legume species for silvopastoral farms was carried out by Franca *et al.* (2018). The preliminary results indicated *Trifolium subterraneum* L. var. Campeda, *Ornithopus sativus* Brot. var. Cadiz, *T. vesiculosum* Savi and *Medicago polymorpha* L. var Anglona are the most promising species.

Although silvopastoral systems have proven to be sustainable, and efficient management practices are being designed, they suffer from a poor recognition by the EU Common Agricultural Policy (CAP), which considers them as a specific agroforestry practice only since about ten years. Until now, the application of specific measures supporting silvopastoralism in EU countries has failed. Thus, each member state should contribute to the effective application/adoption of the existing measures, in order to account for the peculiarities of the silvopastoral systems in each country.

IV – Social, technological and territorial perspectives

1. Social factors determining an efficient and sustainable utilization of natural grasslands

As a consequence of livestock systems' intensification, the function of natural grasslands (including areas with shrubs and trees) in the feeding systems has changed: often, they are no more the main feed resource, but instead they are viewed and used: (a) in Northern Mediterranean areas, as a security in case of climatic hazards or as a low-cost forage resource for animals with low feed requirements (Jouven *et al*., 2010) or (b) in Southern Mediterranean areas, as a place where the flock can have access to a water point (Bechchari *et al*., 2014; Gobindram *et al.,* 2018). In both cases, the management practices implemented are not aimed at conserving the pastoral resource anymore, but rather at taking advantage of a low-cost source of [low quality] forage.

The status of natural grasslands determines the interest and implication of users for their sustainable utilization. In South Mediterranean areas, natural grasslands are community lands, traditionally governed by tribal rights. The addition of colonial and post-colonial rules created a confusion in the user rights, paving the way to an opportunistic utilization, incompatible with the long-term renewal of pastoral resources (Bourbouze and Gibon, 1999). The richest farmers, who own trucks and can easily move their flock around, and the most influential social fractions, exploit intensively the best pastoral resources (Bechchari *et al.,* 2014). In France, the Pastoral Law of 1972 created a favourable legal context for the development of pastoralism, with 3 complementary tools (Charbonnier, 2012): the multiannual pastoral convention (CPP, a contract between land owner and pastoral farmer for a seasonal utilisation), the pastoral group (GP, an association of pastoral farmers using a given area of rangeland) and the land pastoral association (AFP, an association of land owners putting together their land for a given pastoral use). As a consequence, two situations co-exist in terms of access to rangeland (Gava *et al.*, 2018): (a) in lowland areas where livestock activities had until recently almost disappeared and land speculation is common, farmers have a precarious access to natural grasslands (oral or no agreement with the [private] land owner), making it difficult to obtain CAP subsidies and reducing the investments in pastoral developments; (b) in upland areas, where extensive livestock systems have always existed and ecological and recreational issues are associated with grazing, farmers have a secured access to natural grasslands (ownership, agricultural lease, CPP with public body), often associated with collective bodies (AFP, GP) which make it possible to implement pastoral developments and hire shepherds. In Mediterranean areas, there is a need for legal tools, co-constructed with the local populations, which can regulate the utilization of natural grasslands and encourage the user communities to co-construct and implement a sustainable grazing management (Ait-Alhayane, 2016). Since mobility and cooperation are vital for the resilience of pastoral systems, collective management solutions are to be preferred.

The contribution of natural grasslands to the feeding system (in terms of % of forage consumed by the flock) is widely influenced by two factors: on the one hand, the available surface area of natural grassland and the vegetation diversity; on the other hand, the global production strategy of the farmer, and especially his willingness to feed animals with high requirements on natural grasslands. Lasseur (2005) classified French Mediterranean sheep farms into three classes: (a) the "lamb producers", with a controlled and more intensive production of lambs fattened indoors, who only use rangelands to feed dry ewes, a few months a year; (b) the local pastoral farmers, whose typical agro-pastoral systems are based on improved forage and who use alpine grasslands through transhumance, but also locally available natural grasslands when improved forage resources are unavailable; (c) new pastoral farmers, grazing all the flock on natural grasslands, through frequent mobility and shepherding. Jouven *et al.* (2015b) classified horse pastoral farms in Southern France on the basis of the contribution of natural grasslands to the feeding system; the most pastoral farms were those who had a secure access to large surface areas of natural grasslands and who grazed all animal categories there (from young horses to lactating mates), with little or no supplementation. Generally, farmers who supplement systematically grazing animals lack confidence in the ability of natural grasslands to provide the necessary nutrients. Such farmers also tend to keep indoors the animals deemed as "fragile", such as lambs and young replacement females, thus preventing them from learning to forage (and more generally behave) in a diversified and variable environment.

The efficient use of natural grasslands implies adapting a wide range of management practices in order to make the best use of animal and plant diversity, and to compensate for the unpredictable environmental changes. Such adaptive management is based on a close monitoring of the system, associated with a good knowledge of grassland ecology and of grazing animals' behaviour (Meuret and Provenza, 2015). Traditionally, such local ecological knowledge (LEK) was acquired by observing (while shepherding) the state of the grasslands and the behaviour of the flock, their changes during the days and seasons, and their response to new management practices. With the decline of shepherding (less shepherds + depreciation of the job), the amount of LEK held by farmers is decreasing (Gobindram *et al.,* 2018). A challenge is thus to value LEK and find new ways to pass it from one generation to the next, but also enhance it with individual experiences and scientific knowledge.

2. Technologies to overcome cognitive and informational obstacles

In less favoured areas, farm viability not only depends on technical and economic efficiency, but also on environmental and societal dimensions. Concerning the social pillar, despite extensive farmers are reasonably satisfied with their job, other issues are more controversial, *e.g.* there is a clear lack of generational turnover, probably linked to the low attractiveness of the job for young farmers, the arduous work and living conditions in rural areas or the lack of acknowledgement of their role by society. In order to maintain farming and population in rural areas, increasing the job attractiveness along with farmers' income should be a priority for policy makers. Technologies related to smart precision farming can help promote the activity in marginal areas.

Precision livestock farming (or "smart farming") uses information technologies and algorithms to improve the efficiency of livestock farming (Berkmans, 2016). In extensive farms, the issue is mainly to manage better diversity and variability, for heterogeneous animal groups operating in large, diverse areas of rangeland (Bocquier *et al.,* 2016). While in intensive farms, precision livestock farming enables to replace the farmer by automated devices for a number of operations, this is not possible/advisable in agro-pastoral systems, due to the complexity of the environment and to the multiple functions associated with natural and semi-natural grasslands (Bocquier and Jouven, 2016). Current research for grassland-based farming focuses on the development of virtual fences to facilitate the control of free-ranging livestock without shepherding or physical barriers, or the use of unmanned aerial vehicles combined with a variety of animal-born sensors to determine their location and health status.

In MSRS, technological packages mainly aim at providing farmers with information enabling them to gain a better understanding of the system and thus implementing an adequate adaptive management. Recently, the CLOchèTE project (http://idele.fr/reseaux-et-partenariats/clochete.html) studied the possible applications of GPS and accelerometer technologies to assist French pastoral farmer in their grazing management and shepherding activity. Based on individual interviews and focus groups with farmers, 4 main applications were identified (Guinamard *et al*., 2018): (1) Real-time localisation of flocks grazing free in large areas of natural grasslands, or in case of flock splitting; (2) alert on the farmer's cell phone if the flock crosses certain geographical limits, or in case of panic movements possibly related with predation; (3) knowledge of animal grazing circuits; (4) monitoring of animal activities in time and space. The last two applications were mentioned mainly by farmers who did not practice shepherding. Both for those farmers and for the shepherds who change often flock and place, such information would be very useful to build or update LEK about flock behaviour. Another means by which to improve LEK is sharing it and discussing it with peers. The Pastoral Rummy (Zapata *et al.,* 2017) is a serious game based on a physical board and cards, and on a computer simulator; groups of farmers or students design pastoral systems on the board, and discuss the performance of the system based on simulation results. Again, technologies make it possible to produce quantitative information, difficult to access directly, but very useful to understand the functioning of pastoral systems.

The diversity of pastoral situations and the difficulty to measure the state of the system in heterogeneous conditions and large surface areas, limit the amount of scientific knowledge on the subject. In the future, the deployment of sensors (even as simple as embarked GPS) in pastoral farms will produce large amounts of data. Gathering such data and analysing large, heterogeneous datasets would boost research about the ecological functioning and the management of pastoral systems.

3. Reconnecting livestock farming to other activities in a "land-sharing" perspective

The last century has been characterized by urbanization and desertification of pastoral areas, mostly human desertification in Southern Europe and ecological desertification in Northern Africa (Ait-Alhayane, 2016). Industrialization created a gap between urban and rural areas. In rural areas, the specialization of farms and sometimes of whole geographical regions encouraged a spatial separation between agricultural and livestock activities. In the 1990s, the development of agri-environmental measures in the CAP introduced in Europe the idea of multiple functions associated with agriculture, and especially with extensive livestock farming. More recently, long lists of ecosystem services provided by livestock farming systems have been identified (Ryschawy *et al*., 2015), although only a few are paid to the farmers through agri-environmental schemes, diversification of activities or higher prices for agricultural products.

Mediterranean pastoral areas are associated with biodiversity conservation issues, traditional products, cultural landscapes and tourism. In Europe, the LIFE programme counted among its objectives to establish the best farming practices to maintain or enhance the natural value of Natura 2000 sites and generate examples of success stories, in order to provide a sound basis for policy making (Silva *et al.,* 2008). A couple of recent examples are: (1) the LIFE Montserrat project (https://lifemontserrat.eu/en/) that aimed at achieving biodiversity conservation and forest fire prevention through integrated silvopastoral management and (2) the LIFE+ Mil'Ouv project (http://idele.fr/reseaux-et-partenariats/life-milouv.html), aimed at improving the utilization of agro-pastoral habitats through the dissemination of skills, information, methods and relevant advice to the various stakeholders. In a number of rural areas, farming activities coexist with different forms of nature-related tourism. Although there may be some trade-offs (namely, competition for land and labour) many synergies among both sectors can be exploited. Value chains can be developed for farm products which incoming tourists associate with a particular area and production system (Renting *et al*., 2003; Aubron *et al*., 2014). On the other hand, touristic activities can benefit from the existence of farms in a given area (Van Huylenbroeck *et al.*, 2006) or directly from livestock grazing, such as ski stations located on alpine grasslands where livestock grazing in the summer ensures the stability of the snowpack in the winter (Casasús *et al*., 2014).

The recent awareness of the negative impacts of input-based agriculture and the opportunities offered by agroecology have encouraged stakeholders to re-associate livestock farming to perennial cropping, silviculture, or even areas devoted to recreation or energy production. Such associations usually imply combining livestock periodical grazing with other utilizations of the resources available on the land. Wooded areas are re-considered and identified as potential providers of bedding (from wood), forage trees and fruit used as concentrate for livestock (see: AGROSYL project, http://idele.fr/no_cache/recherche/publication/idelesolr/recommends/presentation-du-projet-agrosyl.html). The limitations in terms of herbicide use in vineyards and orchards encourage farmers to resort to livestock grazing to keep the herbaceous layer short and thus control the competition for water with permanent crops. Such practice is also beneficial to livestock farming, since it provides alternative and complementary forage resources (Napoleone *et al.,* 2019). Non-agricultural stakeholders such as municipalities or photovoltaic park operators increasingly envisage to resort to grazing to manage the grasslands within their responsibility; this practice, known as "eco-pasture", is rapidly developing (Delfosse *et al*., 2016). Such promising options in terms of land sharing in the Mediterranean basin require mutual understanding from the stakeholders involved, the adaptation of their individual practices and a favorable legal framework. Specific tools can also be developed, for example to support targeted grazing (Nobrega *et al*., 2017).

V – Conclusion

Grassland-based MSRS benefit from a positive image, a specific quality of the animal products and – if an appropriate grazing management is implemented – of a positive environmental footprint. Technical options to increase the contribution of grasslands to MSRS exist, but they need to be associated with social and technological developments, since they cannot solve all the problems. The challenges which Mediterranean grassland-based systems have to face are summarized in table 1, together with their consequences, the potential solutions to secure farm sustainability discussed in this paper and the research and development perspectives identified by the authors. Such research perspectives imply leading interdisciplinary projects, which connect plant and animal sciences (to "optimize animal production at pasture"), agronomic (*s.l.*) sciences and information technologies (to "produce IT-based tools") or, more often, agronomic (*s.l.*) and social sciences, possibly in the framework of participatory research. Various projects have already started tackling these questions. Further research is needed to investigate the diversity of existing situations (in terms of seasons, physical environment, social context, type of system, …), but also to find, among such diversity, the common features that can be used as a basis to design efficient agroecosystems, product differentiations, grassland-oriented agricultural policies and development schemes.

Table 1. Grassland-based livestock farming systems (LFS) in Mediterranean areas: from global/local challenges to research and development perspectives

Challenges	Climate change	Market trends	Agricultural policies	Social trends
Drivers of change	• ↘ Forage production • ↗ Unpredictability	• ↗ Quality standards • ↗ (S) or ↘ (N) in quantitative demand	• ↗ Environmental concern but poor recognition of ES	• ↘ Attractiveness of the job (farmer, shepherd) • Changes in access to land
Impact on (silvo)pastoral LFS	• ↘ Self sufficiency • ↗ Intensification	• Difficult to fit main standards	• Policies *de facto* unfavourable to extensive grazing	• Lack of generational turnover • Complex grazing management
Potential solutions	• Plant mixtures and cultivars adapted to local conditions • Diversification of grazing areas	• Differentiate the products from (silvo)pastoral LFS • Direct sale of products	• Pay for the ES provided by grassland-based LFS • Take into account the peculiarities of silvopastoral LFS	• Collective management of large pastoral areas • Improve working conditions
Research and development perspectives	• Produce the seeds locally • Optimize animal production at pasture	• Reconnect farmers and consumers • Connect LFS and other activities	• Quantify the ES provided • Objectivize the specific features of silvopastoral LFS	• Produce IT-based tools to facilitate LEK-building and grazing management.

S: south Mediterranean countries / N: Nord Mediterranean countries / ES: Escosystem Services / LEK: local ecological knowledge.

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