Animal (2010), **4:10**, pp 1746–1757 © The Animal Consortium 2010
doi:10.1017/S1751731110000996

Rangeland utilization in Mediterranean farming systems

M. Jouven[1,2†], P. Lapeyronie[1,2], C-H. Moulin[1,2] and F. Bocquier[1,2]

[1]*Montpellier SupAgro, MPRS, UMR ERRC, 2 place Pierre Viala, F-34060 Montpellier, France;* [2]*INRA, PHASE, UMR868, 2 place Pierre Viala, F-34060 Montpellier, France*

(Received 18 May 2009; Accepted 26 March 2010; First published online 21 May 2010)

In the countries surrounding the Mediterranean basin, most of the semi-natural grazing lands are covered by rangelands. Rangelands can be defined as highly heterogeneous natural vegetation communities with high conservation value, growing in harsh environments (poor soils, unfavourable climatic conditions). In the recent socio-economic context, traditional livestock grazing practices that enabled one to reconcile rangeland preservation and animal production no longer apply, especially because they require labour that has become scarce and costly. The consequence is rangeland degradation, due to underutilization in Southern Europe, and overutilization in Northern Africa. We analysed issues raised by rangeland utilization in livestock farming systems of the Mediterranean basin. Based on a review of the scientific literature about rangeland utilization in this area, we argue that the best way to reconcile animal production and rangeland preservation would be to promote management practices allowing animals to express their adaptative capacities in feeding behaviour and productive response. In order to propose management practices adapted to extensive and simplified systems, we conclude that research efforts should focus on: (i) proposing a functional characterization of vegetation heterogeneity at the scale of the vegetation community, (ii) validating the criteria determining animals' foraging behaviour on Mediterranean rangelands, (iii) developing and using simulation models to test management strategies against seasonal and long-term variability in climatic conditions and (iv) evaluating the potential of modern technologies for improving rangeland utilization.

Keywords: rangeland, grazing management, feeding behaviour, ruminant

Implications

Rangelands are an important forage resource for Mediterranean farming systems, providing cheap forage and a reservoir of biodiversity. In the last few decades, grazing practices have changed, causing rangeland degradation. Today, the challenge is to propose management practices that take into account the diversity of rangeland vegetations and cope with the variable forage availability while maximizing feed intake and animal performance with minimum farm labour. This article reviews studies about rangeland utilization in the Mediterranean basin, and points out where further research is needed in order to answer this challenge and thus secure agro-pastoral farming systems in the Mediterranean basin.

Introduction

In the countries surrounding the Mediterranean basin, most of the grazing lands are rangelands (Bounejmate *et al*., 2004; Hadjigeorgiou *et al*., 2005; Ruiz *et al*., 2009). Rangelands can be defined as highly heterogeneous natural vegetation communities with high conservation value, growing in harsh environments (poor soils, unfavourable climatic conditions) and characterized by high heterogeneity in the spatial and temporal distribution of the forage resource. Because their forage production is usually of low quality and cannot be easily controlled, rangelands have been less valued in the last few decades than cultivated or fertilized grasslands: their use has mainly been restricted to very extensive systems or to limited periods of the year where animals have low nutrient requirements. A major issue today is how to manage rangeland utilization by the herd or flock to secure both animal production and the renewal of natural feed resources, at various spatiotemporal scales. In the present socio-economic context of the Mediterranean basin, traditional practices that proved to be efficient years ago no longer apply, especially because they require labour that is not available any more. A challenge for research is therefore to propose management practices adapted to extensive and simplified systems, which reconcile short-term system profitability and long-term preservation of the forage resource and biodiversity associated to rangelands (Hadjigeorgiou *et al*., 2005).

† E-mail: jouven@supagro.inra.fr

In Southern Europe, rangelands are becoming under-exploited, which causes shrub encroachment, increased fire risk and reduction in floristic diversity (Zarovali *et al*., 2007). The main reasons for this are the abandonment of farmland and the specialization of farming systems (Bouju, 2000). Increasingly, farms tend to raise large numbers of animals with little financial and human means. Therefore, management strategies are kept as simple as possible, especially for large areas such as rangelands, while cultivated land provides most of the feed resources. In general, the more the systems are intensified, the less the number of grazing animals and the duration of the grazing period on rangelands (Riedel *et al*., 2007). Traditional practices known as favourable to rangeland utilization, such as mixed species herds and collective organization of grazing management, have almost disappeared (Bourbouze and Gibon, 1999). Recently, rangelands have regained farmers' interest because, on the one hand, they represent an opportunity to extend farms with little investment, and on the other European Union agricultural policies, through agri-environmental schemes, have secured the utilization of rented land and subsidized pastoral developments such as fences (Léger, 1999).

In Northern Africa, rangelands are often overexploited, which reduces vegetation cover, modifies floristic composition with a decrease in the abundance of perennial species, causes degradation of soil water reserves and fertility and increases erosion (Nedjraoui, 2004). Such intensive utilization of rangelands can be explained by the low profitability of animal production, which encourages farmers to minimize financial and labour efforts and to develop complementary activities (Bouju, 2000). Therefore, herds or flocks are moved less and are fed almost exclusively on rangelands, where they range freely or are watched by women or children. Traditional rules regulating the use of collective pastoral resources such as seasonal preservation ('Agdal') are no longer enforced. Bourbouze (2000) explains that where rangeland resources have not been taken over by individual farmers, their utilization no longer responds to collective decisions and conservation objectives, but to the private interests of farmers who are increasingly settled. In the last few decades, the frequency of draughts has increased. Consequently, exceptional subsidies for buying feed have become almost normal and have led to feeding systems increasingly based on conserved forage, concentrate and agricultural by-products (Bourbouze and Gibon, 1999; Cialdella *et al*., 2004). Resorting to purchasing feed means that larger numbers of animals can be kept on restricted areas of rangeland, which in turn may further increase the grazing pressure. Fortunately, the opportunity for such a strategy varies between countries and with time, depending on the relative prices of meat and cereals and on possible subsidies (Bourbouze, 2000).

The objective of this article is to review studies about rangeland utilization in the context of the Mediterranean basin. We focus on the biological and management components of rangeland utilization on paddock to farm scale. For simplicity, we do not consider the socio-economic factors such as dependence on subsidies, cost of specific equipment, such as fences or electronic devices and other factors, which can play a role in Mediterranean systems, such as land status (Bourbouze and Gibon, 1999) or protection against predators (wolves: Ciucci and Boitani, 2005; Lapeyronie and Moret, 2007). When Mediterranean references were not available, we chose to discuss the applicability to Mediterranean systems of references obtained in controlled conditions, or very different farming systems (i.e. huge herds or flocks free-ranging in large open landscapes in the USA and Australia).

This article considers four issues, all in line with the general objective of managing rangeland utilization in order to secure both animal production and the renewal of natural feed resources: (i) characterize vegetation diversity, (ii) feed the herd or flock on rangeland, (iii) cope with the seasonal and year-to-year variability in forage production and (iv) minimize human intervention and farm work. In this article, we first analyse these issues and later summarize the current knowledge about animal and herd behaviour in Mediterranean farming systems. Finally, we describe management tools that should help answer these issues based on the knowledge of foraging behaviour.

Issues related to rangeland utilization in the Mediterranean basin

Characterize the diversity of rangeland vegetations

Mediterranean rangelands are made up not only of natural vegetation communities including a variety of grass and forb species, but also often of shrubs and trees, which produce multi-dimensional heterogeneity at the scales of the landscape or large paddock, of the vegetation community and of the feeding station (Figure 1). The presence of ligneous species radically changes the forage value of the vegetation community and its dynamics, and consequently the diet selected by the animals. Characterizing vegetation diversity with variables related to animal intake and resource dynamics is necessary to answer the questions of when and how to use a given vegetation community in order to take

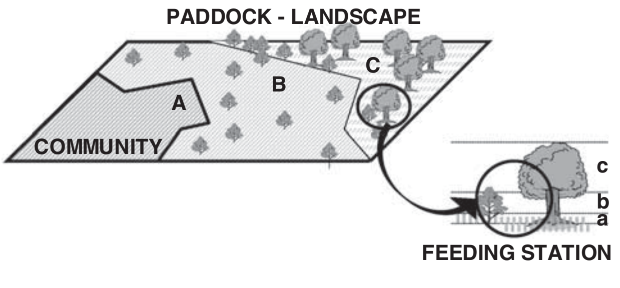

Figure 1 Rangeland spatial heterogeneity at various spatial scales. The *landscape* or large paddock comprises different *vegetation communities* (A, B, C), which are made of assemblages of herb, shrub and tree species, which are in abundance and whose state may vary from one *feeding station* to another. The forage resource is also distributed vertically, with grass and fallen fruit on the ground (a), and leaves and fruit on the branches of bushes and trees (b, c).

the best out of it without spoiling it in the long term. While interesting classifications based on functional approaches of grass species have been proposed for grasslands (Duru *et al.*, 2009), little has been done to our knowledge for shrubland and woodland communities. The main Mediterranean shrubland communities are *maquis* (dense shrub communities on siliceous soils), *garrigue* (open shrub communities on calcareous soils) and *phrygana* (open, dwarf shrub communities on friable soils); the main woodland communities are dense coniferous woodlands, dense broadleaved woodlands and sparse silvopastoral woodlands (Papanastasis *et al.*, 2008).

Vegetation diversity in rangeland is supported by physical, biotic and human factors. Ouled Belgacem and Papanastasis (1995) found that up to 60% of the vegetation heterogeneity in western Crete rangelands could be attributed to distance from watering points, while the remaining 40% could be attributed to soil and topographical factors. In the Mediterranean basin, shelters providing water, supplementation and a resting place for the night act as focal points. Papanastasis *et al.* (2009) observed that in the vicinity of shelters (0 to 50 m), vegetation communities were dominated by herbaceous and annual species (*Capsella bursa-pastoris* and *Poa bulbosa*), while far from the shelters (200 to 800 m), shrubs (*Quercus coccifera*) and perennials (*Dactylis glomerata*) were most abundant. Such a vegetation gradient might be explained not only by grazing factors, such as increased defoliation, faeces deposition and trampling near the focal point, but also sometimes by human factors such as increased shrub clearing with fire (Ouled Belgacem and Papanastasis, 1995).

Maximize feed intake and animal performance on rangeland

A problem raised by the utilization of rangeland in Mediterranean countries is often the limited consumption of potentially invasive shrubs, due to their low nutritive value or high content in secondary compounds. Low organic matter digestibilities for Mediterranean browse species (0.50 to 0.55 measured *in vitro*) are reported and explained by the high content in secondary compounds such as tannins (Papanastasis *et al.*, 2008). Tannins are a group of substances (comprising hydrolysable and condensed forms) that bind to proteins in the rumen and can have either positive or negative effects on intake and digestion depending on the animal species and experience, the proportion in the diet and the absorption of feed additives (for a comprehensive review, see Makkar, 2003). For Mediterranean browse species, 0% to 24% condensed tannins in dry matter (DM) are reported (Cabiddu *et al.*, 2000; Landau *et al.*, 2000a; Frutos *et al.*, 2002), with usually higher values measured in summer on mature vegetation compared to spring or winter. Species with medium to high condensed tannin content reported by these authors, such as *Quercus ilex* (3% to 8% DM), *Erica arborea* (27% to 30% DM), *Myrtus comunis* (12% to 15% DM) and *Pistacia lentiscus* (10% to 24% DM), are typical of *maquis* communities. The more open *garrigue* and *phrygana* also include a sizeable proportion of herbaceous species, which contain little or no tannins (Barroso *et al.*, 2001).

Foraging on rangelands usually produces acceptable animal performance for dry or pregnant females, but poor performance for lactating ones. In French lamb-producing systems, the utilization of rangelands for grazing dry or pregnant ewes in winter spared 40% to 60% of the conserved forage needed for the winter period, without a dramatic fall in animal performance (Gautier and Moulin, 2004). Osoro *et al.* (2000) observed that in rangeland dominated by *Calluna vulgaris*, dry ewes were able to increase their live weight and body condition, while ewes suckling lambs exhibited poor performance. Henkin *et al.* (2005) observed acceptable animal performance (20% lower calf weight at weaning than for conventional systems) for a silvopastoral cow–calf system based on rangeland utilization, with supplementary feeding introduced in summer and winter periods. Molénat *et al.* (2005) obtained satisfactory lamb growth (230 to 250 g daily weight gain) for ewes and lambs grazing at low stocking density on native Causse rangeland at the end of the lactation period, without any supplementation, because lactation occurred in spring when the herbaceous vegetation was most abundant and green.

Cope with seasonal and year-to-year variability of forage production on rangeland

The forage resources provided by rangelands are highly variable between seasons and years. Chemmam *et al.* (2009) reported significant differences in herbage abundance and quality between seasons in a 2-year study of a natural pasture in Algeria. They measured 1.5t DM/ha (DM) available biomass and 15% crude protein (CP) in spring, but only 1.2t DM/ha and 9% CP in summer. The seasonal and yearly variations in biomass production and net energy for lactation of a natural pasture community in the French Causse rangeland are reported in Table 1. These features illustrate the importance of seasonal dynamics and fluctuations between years for biomass production, which contrasts with the relative stability of the nutritive value.

When rangelands include shrubs or trees, the seasonal availability of their sprouts, leaves, flowers and fruit may smooth the variations in the total amount of edible matter. Papanastasis *et al.* (2008) report that shrublands are more productive than grasslands in similar conditions and that their forage production depends mainly on shrub density and height. Shrubs contribute to the total forage production, but limit the production of the herbaceous layer. Herbaceous and woody species not only differ in the amount and quality of biomass production, but also most interestingly in the period when they are available for grazing: winter and spring for herbaceous species, summer and autumn for shrubs and trees (Papanastasis *et al.*, 2008).

Seasonal variability of rangeland production is rarely in line with the nutritional requirements of the flock or herd. In meat production systems, the energy requirements of lactating females are multiplied by 1.6 for cattle and 2.3 for sheep compared with dry females (Institut National de la Recherche Agronomique (INRA), 2007), but if the young are kept in the farm and graze when their mothers are dry, these differences are smoothed. Getting the periods of highest theoretical biomass production and highest animal requirements to coincide

Table 1 *Seasonal variations in the forage characteristics of a natural pasture community in the French Causse rangeland*

	Season		
	Spring (April to May)	Summer (June to July)	Autumn (September to October)
Biomass (t DM/ha)			
Mean	1.0	0.4	0.2
s.d./mean	24%	49%	32%
Minimum to maximum	0.6 to 1.3	0.0 to 0.8	0.1 to 0.4
Net energy for lactation (MJ/kg DM)			
Minimum to maximum	5.3 to 6.1	4.8 to 6.3	4.4 to 5.6

DM = dry matter.
Above-ground DM biomass production refers to Molénat *et al.* (2005) for the period 1990 to 2003; nutritive value measured in net energy for lactation refers to G Molénat (unpublished result) for the period 1996 to 2002.

is advisable but rarely sufficient to secure the feeding system, due to year-to-year variations in rangeland production.

Minimize human intervention and farm work

The easiest way to control the foraging behaviour of a herd or flock is to put it under the guidance of a shepherd (Najari *et al.*, 2004). The shepherd guides the feeding choices of the animal group and produces a sequence of synergic phases where the utilization of rangeland diversity is aimed in some phases at stimulating animal motivation to eat and in others at promoting the intake of the coarsest resources (Meuret, 1997). The sequence of locations grazed might be adjusted either to animal behaviour (e.g. hunger) or to specific environmental objectives (e.g. limit shrub encroachment) (Meuret, 1996). In a study comparing the feeding behaviour of sheep free-ranging or shepherded, Rochon *et al.* (2009) showed that the guidance of a shepherd increased the distance walked by the flock (2 km instead of 1.6 km/day), which foraged in a closer group and consumed more shrubs. Shepherding does not attract young people anymore because of the harsh working conditions. Besides, farmers might not have the financial means to hire a shepherd.

In the last few decades, traditional pastoral systems have been increasing the proportion of cultivated and purchased feed, both in Northern Africa and Southern Europe. Therefore, rangeland utilization should be considered in the global context of a feeding system including pastoral and cultivated resources (Bourbouze and Lazarev, 1991). In the feeding system, feed crops can be used to provide: (i) conserved forage for the periods unfavourable to grazing (winter, summer, etc.), (ii) concentrate feed for supplementation at pasture or (iii) high-quality grazed herbage. Feed crops and forage conservation require a considerable amount of work, which leaves less time for grazing management. In Northern Africa, access to and ownership of plots in the cropping zone influences the timing and intensity of rangeland utilization, which happens for Bedouin flocks (Dutilly-Diane *et al.*, 2006). In Southern Europe, rangeland utilization is often restricted to free-ranging dry females in unfavourable seasons or climatic years, especially in farms with high production objectives (Lasseur, 2005; Quétier *et al.*, 2005). When a herd or flock free-ranges, both the distribution of the grazing pressure and the daily intake depend on the vegetation communities visited during the day. The latter results from the knowledge the animals have of the environment, feeding preferences and social interactions. The question is, how to achieve an 'optimal' rangeland utilization with little or no direct human intervention?

Animal and herd behaviour in Mediterranean rangelands

In grassland environments, the mechanisms directing selective intake have been extensively studied (see reviews of Bailey *et al.*, 1998; Baumont *et al.*, 2000; Rutter, 2006). It is generally accepted that feeding choices of plants or feeding stations are a compromise between the abundance and quality of vegetation and the effort that is needed to seize it. Animal feeding choices would be aimed at maximising their nutrient intake rate. When offered different plant types (e.g. grass and legume species or herbaceous and shrub species), ruminants select mixed diets. Higher intake rates are achieved when plant types are offered separately or successively, which is usually interpreted as the result of a lower selection cost. The accumulation of experimental work has allowed the development of a number of simple models predicting daily intake at pasture (see e.g. Avondo *et al.*, 2002; Baumont *et al.*, 2004; Jouven *et al.*, 2008), usually according to the abundance and digestibility of the available herbage.

In rangeland environments, such models developed for grassland environments might not apply, because (i) the ranking criteria for determining foraging behaviour may be different and might include searching costs for travelling and sorting out plant parts, (ii) morphological and physiological abilities of animals and their previous foraging experience might modify the foraging behaviour on rangelands and (iii) the animals might adapt their physiology to the harsh environment.

Vegetation and landscape characteristics that modify foraging behaviour of animals

Mediterranean rangelands usually include woody vegetation with mechanical and chemical defences against browsing. As discussed by Papachristou *et al.* (2005), browse consumption introduces new criteria for predicting diet selection, such as the presence of thorns or concentration of potentially toxic secondary compounds (e.g. tannins, terpenes). Spinescence is aimed at decreasing leaf and shoot losses for the plant. It reduces the bite size and intake rate and increases the total handling time, especially for large herbivores, by forcing the animals to select the parts without thorns (Cooper and Owen-Smith, 1986). In experimental trials involving penned animals, a depressive effect of tannins on intake was observed and related mainly to reduced palatability of feed due to tannin astringency (Landau *et al*., 2000b).

The daily intake measured for small ruminants grazing rangeland vegetation can be up to 2-fold higher than that predicted for models based on the average organic matter digestibility of the vegetation, suggesting that rumen fill constraints might be overcome (Agreil *et al*., 2006). Direct observations of intake dynamics during a meal and during the grazing down of paddocks suggest that feeding choices on rangeland might be driven by the objective of stabilizing intake rather than maximizing it (Agreil *et al*., 2005). As a secondary objective, ruminants might also choose to mix feeds in order to optimize their intake of nutrients and to neutralize toxins (Provenza *et al*., 2003).

In situations of extensive grazing, feeding preferences for plants or feeding stations vary with the spatial distribution of the vegetation: animals will select a more preferred resource if it is aggregated (Dumont *et al*., 2002). This might result both from individual spatial memory, which is higher for aggregated resources and small paddocks (Dumont and Petit, 1998), and from conspecific attraction, which reduces individual spatial exploration (modelling study by Dumont and Hill, 2001). Aggregation also reduces searching and travelling costs.

While water availability is a criterion for selection on the scale of the vegetation community, topography seems to influence the choice of feeding stations and resting areas (Bailey *et al*., 1996). Research studies on rangeland grazing by cattle show that they usually prefer gentle slopes and avoid travelling long horizontal and vertical distances from water (Bailey, 2005). Lapeyronie (2001) observed for gregarious species such as *Merino* sheep that geomorphology modifies the shape of the grazing flock: animals tend to be sparse in convex areas and tightly packed in concave areas; in open areas, flock shape tends to be symmetric. The importance of water availability and topography may vary depending on the associated biotic factors. For example, Bailey *et al*. (2001) compared the individual grazing patterns of beef cows differing in breed, age and nutritional status. They found that dry cows travelled further from water (+15% vertical distance from water) than lactating ones, and that the breed originating from mountainous terrain (*Tarentaise*) used the whole area better than the breed developed in gentler topography (*Hereford*). Climatic variability, and especially heat during the summer, may also interfere with the abiotic factors mentioned before. In a preliminary study, Thomas *et al*. (2008) observed in Australian rangelands that during hot days sheep travelled less, stood closer to water points and modified their preferences for feeding sites, probably in relation to shade availability.

Animal characteristics and experiences that determine the ability to forage on rangelands

Research studies converge in showing that sheep, goats and cattle exhibit complementary feeding behaviour. On this subject, published results are available for animals and vegetation communities typical of the Mediterranean basin. In contrast to sheep and cattle, which are primarily grass feeders, goats are intermediate feeders that tend to select a wide range of plants in their diets, and opportunistic feeders that adapt their diet to the vegetation offered. Nolan and Nastis (1997) studied diet selection of cattle, sheep and goats co-grazing Mediterranean rangeland. They observed that cattle exhibited a fixed foraging strategy between seasons and years, while small ruminants exhibited a more versatile behaviour and were able to extend the range of plants consumed in the dry season when overall vegetation availability was low. Papachristou (2000) and Yiakoulaki *et al*. (2009) measured individual choices of sheep and goats grazing shrubland or woodland. Their results converge: goats ate more browse (60% to 90% of the diet) and a wider array of plants than sheep, which in contrast selected herbaceous species (50% to 100% of the diet). Experimental trials of Rogosic *et al*. (2006) involving penned sheep and goats offered Mediterranean shrubs suggest that goats are physiologically better suited to use shrubs. The ability of goats to forage in rangelands containing high proportions of shrubs can be explained by their bipedal stance, which gives them better access to leaves and fruit, to their good digestion of lignified items, and to the ready adaptation of their rumen microflora to changes in diet composition (Nastis, 1997). Silakinove (1997) illustrates how goats raised in harsh environments are able to reduce their metabolism, adapt their digestive efficiency and neutralize the negative effects of tannins. Physiological adaptations to digest tannin-rich feed include salivary proteins that bind to tannins, faster ruminal degradation of hydrolysable tannins and, maybe, more efficient liver detoxification (Makkar, 2003). Similar to species, breeds may also differ in their ability to exploit rangelands, and especially browse (Brand, 2000). Usually, the effect of breed is less evident than the effect of species (Rook *et al*., 2004).

Individual feeding preferences are the result of interactions between genetically inherited morphological and physiological characteristics and foraging experiences, which are particularly critical in early life. When herbivores are confronted with a diversity of plants differing in their nutrient and toxin content, they need to learn how to mix their diet in order to avoid aversive effects. In the context of mixed diets, aversive effects may be modified by nutrient–nutrient, toxin–nutrient and toxin–toxin interactions, and herbivores may optimize their intake of nutrients and toxins on the basis of their experience of the mix of foods offered (see reviews of Provenza, 1996; Provenza *et al*., 2003). The social environment in a group of foraging animals enhances the learning efficiency in such complex situations because each animal no longer needs to discover everything by itself (Provenza, 2007). In groups of gregarious animals, movements from one patch or vegetation community to another are initiated by leaders, which are usually the elder animals of the group or the ones with the greatest experience of the foraging environment (Bailey *et al*., 1998).

Domestic ruminants develop their ability to exploit a given habitat if they are regularly confronted with it in the farming system where they are reared. Lécrivain *et al*. (2004) observed that sheep feeding behaviour differed depending on the strategic importance attributed to rangelands in the farming system: sheep from a pastoral farm exploited much more the shrub component than sheep from an intensive lamb producing farm, which concentrated their grazing pressure on grass. Similarly, Aharon *et al*. (2007) compared two goat production systems differing in breed purposes (milk/meat) and supplementation. They showed that each system induced a different utilization of rangeland vegetation by the flock, in terms of grass/shrub ratio intake, proportion of ligneous species ingested and consumption of undesirable species.

Animal behavioural and physiological adaptations to cope with seasonal forage availability

Diet selection of free-ranging ruminants varies between seasons, especially for goats that as discussed earlier, can readily adapt their digestive physiology. On daily time scales, ruminants may compensate for lower intake rates by longer feeding times and lower sward quality by higher selectivity in order to maintain the necessary level of energy intake (Prache and Peyraud, 2001). Evidence of changes in feeding behaviour and composition of goat intake with time are mostly based on direct observations (Dumont *et al*., 1995; Perevolotsky *et al*., 1998; Kyriazopoulos *et al*., 2009). For example, free-ranging goats grazing Greek shrublands selected mostly *Phillyrea latifolia* in April, *Pistacia lentiscus* in August and their preference was distributed between *Olea europea*, *Phillyrea latifolia* and *Pistacia Lentiscus* in December (Kyriazopoulos *et al*., 2009). At landscape scale, Ganskopp and Bohnert (2009) observed that free-ranging cattle distribution in US rangeland pastures was significantly correlated with forage quality (high CP content and DM digestibility, low neutral detergent fibre content), and speculate that landscape-level nutritional dynamics may at least partly explain the seasonal changes in cattle distribution.

When the herd or flock has to face alternative periods of low and high feed availability, the production cycle is secured by two well-known mechanisms: the mobilization and reconstitution of body reserves and the adjustment of animal performance, milk production for the lactating females or growth rate for the young (Blanc *et al*., 2006). In Lebanese *Baladi* dairy goats, each time the feed availability increases (i.e. each time they are moved from rangeland to crop residues), milk production and body condition are improved (Kharrat and Bocquier, 2010). Under unfavourable feeding conditions, reproduction is delayed. For example, *Barbary* ewes in Tunisia become pregnant only when they reach a sufficient body condition score (Atti *et al*., 2001). For growing animals, compensatory growth allows recovery from a period of low feed availability and restricted growth by accelerating growth rates when feed availability increases again (Ryan, 1990).

Management practices for rangeland utilization in the Mediterranean basin

Table 2 summarizes, for each rangeland utilization issue discussed in this paper, the management practices or tools that can help answer it and the related features of animal behaviour. In the following paragraphs, these management practices or tools are discussed in the context of the Mediterranean basin.

Well-known management practices to improve the utilization of rangeland diversity

Differences in foraging behaviour between sheep, goats and cattle are such that matching the livestock species to the type of rangeland is the first step towards reconciling animal

Table 2 *Management practices or tools, which can help answering the issues about rangeland utilization in the Mediterraean basin and features of animal behaviour on which they rely*

Issue	Management practices or tools	Related features of animal behaviour
Characterize vegetation diversity	Indicators of feeding value at community scale*	Criteria for diet selection and intake on rangelands*
Feed the animals on rangeland	Choice of adapted species	Species' foraging abilities
	Early exposure to rangelands	Learning from peers and foraging experience*
	Adapted supplementation	
Cope with climatic variability	Grazing plan based on rangeland diversity and including flexible items	Changes in diet composition
		Compensatory mechanisms for animal performance
	Simulation models*	
Minimize human intervention and farm work	Position of focal points	Criteria for patch selection
	Fencing based on or combined with electronic devices*	Behavioural response to positive or negative stimuli*
		Ability to learn and memorize*

*Indicate the main points that need further research.

production and rangeland preservation. In Portuguese pastoral systems, farmers choose the species (goat *v.* sheep) and breed in relation to topography (slope, altitude) and shrub density (Pacheco, 1999). Since they have similar nutrient and management requirements, co-grazing of sheep and goats can be an efficient way to take advantage of their different foraging abilities (Animut and Goetsch, 2008). Mixed grazing of cattle, sheep and goats produces a higher overall capture of vegetation resources, provided the diversity and spatial distribution of vegetation communities is such that the animals can exhibit complementary feeding behaviour (Nolan and Nastis, 1997). In mono-species flocks or herds, the diversity of individual preferences can play a similar role, but with much smaller effects (Provenza and Papachristou, 2009). In spite of this, mixed flocks are becoming rare because they increase labour requirements (Pacheco, 1999).

In free-ranging management, the human factor is weak compared to the feeding and moving behaviour of the flock. Nevertheless, farmers may control the spatial distribution of grazing by modifying the position and availability of feed, shelters and water. The distribution of supplementary feed (e.g. feed blocks) can be a way to increase the appeal of a vegetation community and thus the grazing pressure on it. Water development has proved to be an effective strategy to encourage uniform distribution of cattle across the landscape, especially if the position of water tanks follows seasonal changes in the vegetation cover (Del Curto *et al.*, 2005). Ganskopp (2001) was able to modify long-term grazing distribution of cattle in rangeland by changing the position of water tanks, while moving salting areas had only short-term effects.

Within a vegetation community, a number of plants or plant parts may be rejected or very little consumed by the animals either due to a high fibre content or to the presence of secondary compounds. It is well known that supplementation with concentrate or other nutrient-rich feed can significantly increase the consumption of coarse forage resources (Ben Salem and Smith, 2008). In order to avoid negative effects of secondary compounds, animals can be administrated nutrient supplementation to help detoxification or feed additives inactivating secondary compounds, such as polyethylene glycol (PEG), that bind with tannins (Rogosic *et al.*, 2008). As seen before, even without human intervention, ruminants might be able to adapt their feeding behaviour (smaller eating bouts) and digestion (higher salivation and higher microbial synthesis efficiency) to tannin-rich diets (Landau *et al.*, 2000b). Rogosic *et al.* (2008) reported experiments where 1, 2, 3 or 6 shrub species were fed to goats or sheep, which received different feed additives (PEG or activated charcoil). The results show a positive and significant effect of feed additives on intake when only a few shrub species were offered. When six shrub species were offered simultaneously, the overall intake was higher and no effect of the feed additive was observed. This suggests that offering a diversity of foods is the most simple and convenient way to improve intake and performance.

Indicators to support grazing management decisions in heterogeneous rangelands

The simplest indicator traditionally used for grazing management is stocking density. High stocking densities are necessary to force the animals to diversify their diet (Provenza, 2007) and eat less palatable items, for example, to get sheep to browse some *Quercus coccifera* (Etienne and Rigolot, 2004). Stocking density might be simplistic for Mediterranean rangelands, where intake depends on the mix of species offered and on the relative availability and palatability of the coexisting species (Nolan and Nastis, 1997).

When the animals graze small paddocks ($<$10 ha) or when grazing is managed by a shepherd, indicators of vegetation state are needed to (i) choose the vegetation community or paddock to be grazed at a given time of the year and (ii) decide when to leave for another community or paddock to avoid either a fall in animal performance or degradation of the vegetation. Usually, sward height is used as an indicator to plan the time and duration of grazing in homogeneous grassland paddocks. Recently, indicators based on functional traits of grass species have been proposed (Duru *et al.*, 2009). Mediterranean rangelands including high proportions of shrubs or trees require specific indicators.

An example of indicators for Mediterranean rangelands is proposed by Agreil *et al.* (2004). These authors adopt the animal point of view, and categorize plants or plant parts on the basis of their acceptability (edible or not for the animal species considered) and the bite size they induce. Based on numerous field observations on sheep, goat and heifers grazing *garrigue* rangeland, Agreil and Meuret (2004) show that ruminants eat alternately 'big items' (i.e. edible vegetation items producing big bites and a high intake rate) and 'small items' during a meal, the first being most important to stabilize daily intake. When only 'small items' are available, the intake rate falls sharply, and the cost of foraging becomes very high. Besides, a total consumption of 'big items' might damage the plants producing them and thus their presence in the following seasons or years. The amount of 'big items' (e.g. tall grass for sheep or dense shrubs for goats) could be used as an indicator of the likelihood that a given vegetation state might induce sufficient biomass intake. Agreil's methodology, which requires close monitoring of the state of vegetation, could also be used to characterize the foraging potential of a community or paddock. Unfortunately, it does not fully address the problem of vegetation degradation, since the long-term consequences of grazing might depend on the type of vegetation community and the season of utilization.

Grazing plans based on the complementarity between forage resources to cope with the variability of forage production

In grassland-based systems, a number of management practices have been identified as important for the balance between animal performance and rangeland preservation. They include especially: characterizing each paddock by its function in the feeding system (Fleury *et al.*, 1996), applying moderate stocking densities (Dumont *et al*., 2007) and adjusting the residual sward height to overall forage availability on farm scale (Duru *et al*., 2002).

In agropastoral systems, the complementarity between cultivated and natural vegetations has been extensively studied with systemic approaches, especially by French scientists. Given the diversity of Mediterranean rangelands, the complementary nature of different rangeland vegetations could be exploited similarly. A simple and straightforward way to classify rangelands depending on their forage potential could be to consider the percentage of shrub or tree cover. This variable, in fact, is highly correlated with species composition, production dynamics and quality of herbaceous vegetation (Zarovali *et al*., 2007). Another variable of interest would certainly be the dominant shrub species, which can either be eaten or rejected by the animals (depending sometimes on the animal species) and can therefore contribute or not to the forage resource. Rangeland types could be further differentiated on the basis of their seasonal forage potential.

Functions and utilization objectives can be attributed to rangeland paddocks according to vegetation type, environmental objectives, animal production cycle and distance from livestock buildings (Guérin and Gautier, 2004). In order to cope with the unpredictable climatic conditions, such grazing plans should be flexible, with rules modifying the utilization objectives on the basis of vegetation or flock state at key periods of the year (Guérin *et al*., 2001). For each type of rangeland, it would be most interesting to simulate the impact of different utilization dynamics through the year to determine which management strategies should be supported by agri-environmental schemes.

Simulation models of agro-pastoral systems to investigate grazing dynamics in rangelands and evaluate management practices

A few simulation models have tackled the problem of intake in highly heterogeneous vegetations, either by empirically introducing a shrub component (Armstrong *et al*., 1997a and 1997b) or by considering a wider array of plant species (Freer *et al*., 1997). In both cases, the abundance and digestibility of the plant material were the main criteria for diet selection. As far as we know, no mechanistic model of selective intake has ever been designed for, or even tested on, Mediterranean rangelands. Agreil and Meuret (2004) proposed predicting feeding choices on *garrigue* rangeland from a functional description of the vegetation, which they divide into items inducing 'big bites' and items inducing 'small bites'. Their conceptual model contrasts with some previous models, which predicted that the animals would first graze the best vegetation items, either the top layer of the sward (Baumont *et al*., 2004) or the most digestible plant parts (Freer *et al*., 1997). On a daily time scale, it is thought compatible with the model of Jouven *et al*. (2008), which predicts selective intake according to 'biomass $\times$ digestibility^{s}' of edible plant parts. In fact, in this model, 'big items' would be selected due to their high biomass, and 'small items' due to their usually higher digestibility. Differences between animal species or breeds in their feeding choices can be introduced with the selectivity coefficient 's' as a power of digestibility. This model will soon be tested against field data for Mediterranean rangelands, but its validity might be restricted if the concentration of secondary compounds in plants is high and becomes the major criterion of diet selection.

Recently, many dynamic models of grassland-based feeding systems have been developed (cow–calf systems: Jouven and Baumont, 2008; Martin *et al*., 2009; dairy cow systems: Andrieu *et al*., 2007). In these models, paddock utilization is chosen by the user or simulated as a function of vegetation type, topography and distance from the cowshed; the exact timing and duration of grazing on each paddock is flexible and depends on the current state of the vegetation on the paddock and on the total forage availability on the farm. Model predictions suggest that feeding strategies based on the complementarities between grassland types secure forage self-sufficiency against climatic variability and that management practices favourable to forage self-sufficiency in the long term (10 years or more) also preserve grassland floristic diversity. Unfortunately, to our knowledge, none of the published models on the scale of the feeding system have been designed or adapted for Mediterranean agro-pastoral systems.

Automated devices to assist grazing management and reduce farm labour

Automated devices for grazing management are promising tools to minimize human intervention in grazing management and farm work. They can be used for two main tasks: (i) to gain information on the state of the system (vegetation state, herd or flock geographical position) and (ii) to apply management decisions.

Modern technologies can greatly assist the study of rangeland spatial utilization by free-ranging ruminants. Global Positioning Systems (GPS) and Geographical Information Systems can be used efficiently to gather data on flock or herd spatial behaviour (Barbari *et al*., 2006) and are currently the most popular tool for studying the distribution of grazing pressure on rangeland. Recently, research has also investigated the potential of virtual fencing to control animal distribution in extensive grazing systems. Combining GPS with a collar delivering a message (stimulus) to the animal can be used to keep livestock within a restricted perimeter (cattle: Anderson, 2001; goats: Fay *et al*., 1989). The basic principle is to train animals to change direction when they receive (through a collar) an audio stimulus (warning), followed, if necessary, by an electric stimulation (punishment). The stimulus can be activated either by the vicinity of an electromagnetic field or by the geographic position, which may be less precise. Virtual fencing with electromagnetic fields carried by a simple electric wire on the ground has recently been tested experimentally on small groups of cattle (each equipped with a collar) in an alley (Bishop-Hurley *et al*., 2007), but still needs to be tested on small ruminants and in extensive conditions (large flocks, large surfaces). In large flocks, the issue would be to take advantage of group cohesion in order to equip only a limited number of animals. Obviously, the adoption of such technologies is constrained by their cost in already economically marginal farming systems.

Sorting animal groups and managing them separately is a time-consuming practice. Combining individual electronic identification and selective gates between paddocks would offer the opportunity to automatically sort the animals and give them access to different resources depending on their requirements or on the production objectives. The control of animal movements and their grazing targets on the territory would be fundamentally based on the knowledge of their behavioural response to positive and negative stimuli (Laca, 2009). Maton *et al.* (2008) describe automated sorting and geolocalizing devices, which could interestingly be adapted to grazing management.

Conclusion

In the future, rangeland utilization in the Mediterranean basin will need to reconcile animal production and rangeland preservation. In order to achieve this objective, further research is needed to answer the following issues.

Characterize the diversity of rangeland vegetations
For herbaceous vegetations, approaches based on the functional traits of grass species can be an interesting way to characterize communities, provided the functional traits studied can be easily related to variables determining animal intake. For shrublands and woodlands, there are still research efforts to make as to our knowledge only one simple but controversial approach has been proposed.

Maximize feed intake and animal performance on rangeland
The utilization of rangeland diversity on paddock and farm scale is optimized by complementarities between breeds, animal categories and individuals. Individual foraging efficiency may be improved by sharing experience with peers, especially between more experienced older animals and younger animals. If the farming system is organized in such a way as to enable animals to learn to use the diversity of rangeland resources, the farmer can rely on their ability to select and ingest a diet adapted to their requirements (but not necessarily to high production objectives). Given the current knowledge of animal and flock behaviour, favourable points in the farming system would be giving access to rangeland vegetation in the early life, mixing experienced and inexperienced animals, adapting supplementation and applying high stocking densities to 'force' them to test and eat a diversity of plants. Scientific knowledge about feeding behaviour still needs to be refined for complex environments such as rangelands. A better understanding of the criteria determining foraging behaviour in Mediterranean rangelands is needed in order to propose specific management options.

Cope with the seasonal and year-to-year variability in forage production
Rangeland heterogeneity in space and time, which at first can seem a disadvantage compared to the controlled production of grasslands, is in fact an interesting feature of Mediterranean farming systems. On a farm scale, the diversity of rangeland vegetation communities is an advantage due to their complementary production dynamics: different communities can support different utilizations in terms of timing and intensity of grazing. On a paddock or landscape scale, the diversity of species smoothes out the seasonal variations in forage quality and, for shrublands and woodlands, in forage production: rangeland utilization is thus much more flexible than grassland utilization. On the scale of the feeding station, the diversity of vegetation items stimulates animal motivation to eat and enables each individual to select the most suitable diet. Planning a suitable utilization of such diversity is difficult. Simulation models will be needed as decision aids or to test management strategies against seasonal and long-term variability in climatic conditions and rangeland heterogeneity.

Minimize human intervention and farm work
The adoption of automated and electronic devices for grazing management, in the framework of precision livestock farming, could minimize human intervention and labour at farm scale. The implementation of such tools is based not only on the knowledge of animal feeding and social behaviour but also on animal learning and memorial capacities. To develop cost-effective systems, knowledge about these aspects needs to be refined. The new tools also need to be evaluated on the field, taking into account sanitary issues, traceability, protection against predators, compatibility with environmental issues and recreational uses of rangelands. The sustainability of their cost for small farms as can be found in the Mediterranean basin remains, of course, the major criteria.

Acknowledgements

We would like to thank the anonymous reviewers for their useful comments on the manuscript.

References

Agreil C and Meuret M 2004. An improved method for quantifying intake rate and ingestive behaviour of ruminants in diverse and variable habitats using direct observation. Small Ruminant Research 54, 99–113.

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

Agreil C, Fritz H and Meuret M 2005. Maintainance of daily intake through bite mass diversity adjustment in sheep grazing on heterogeneous and variable vegetation. Applied Animal Behaviour Science 91, 35–56.

Agreil C, Meuret M and Fritz H 2006. Adjustment of feeding choices and intake by a ruminant foraging in varied and variable environments: new insights from continuous bite monitoring. In Feeding in domestic vertebrates: from structure to behaviour (ed. V Bels), pp. 302–325. CAB International, Wallingford, UK.

Aharon A, Henkin Z, Ungar ED, Kababya D, Baram H and Perevolotsky A 2007. Foraging behaviour of the newly introduced Boer goat breed in a Mediterranean woodland: a research observation. Small Ruminant Research 69, 144–153.

Anderson DM 2001. Virtual fencing – a prescription range animal management tool for the 21st century. In Proceedings of the conference "tracking animals with GPS" (ed. AM Sibbald and IJ Gordon), pp. 85–94. The Macaulay Institute, Aberdeen, Scotland.

Andrieu N, Poix C, Josien E and Duru M 2007. Simulation of forage management strategies considering farm-level land diversity: example of dairy farms in the Auvergne. Computers and Electronics in Agriculture 55, 36–48.

Animut G and Goetsch AL 2008. Co-grazing of sheep and goats: benefits and constraints. Small Ruminant Research 77, 127–145.

Armstrong HM, Gordon IJ, Grant SA, Hutchings NJ, Milne JA and Sibbald AR 1997a. A model of the grazing down of hill vegetation by sheep in the UK. I- The prediction of vegetation biomass. Journal of Applied Ecology 34, 166–185.

Armstrong HM, Gordon IJ, Hutchings NJ, Illius AW, Milne JA and Sibbald AR 1997b. A model of the grazing down of hill vegetation by sheep in the UK. II- The prediction of offtake by sheep. Journal of Applied Ecology 34, 186–207.

Atti N, Thériez M and Abdennebi L 2001. Relationship between ewe body condition at mating and reproductive performance in the fat-tailed Barbarine breed. Animal Research 50, 135–144.

Avondo M, Bordonaro S, Marletta D, Guastella AM and D'Urso G 2002. A simple model to predict the herbage intake of grazing dairy ewes in semi-extensive Mediterranean systems. Livestock Production Science 73, 275–283.

Bailey DW 2005. Identification and creation of optimum habitat conditions for livestock. Rangeland Ecology and Management 58, 109–118.

Bailey DW, Gross JE, Laca EA, Rittenhouse LR, Coughenour MB, Swift DM and Sims PL 1996. Mechanisms that result in large herbivore grazing distribution patterns. Journal of Range Management 49, 386–400.

Bailey DW, Dumont B and WallisDeVries MF 1998. Utilization of heterogeneous grasslands by domestic herbivores: theory to management. Annales de Zootechnie 47, 321–333.

Bailey DW, Kress DD, Anderson DC, Boss DL and Miller ET 2001. Relationship between terrain use and performance of beef cows grazing foothill rangeland. Journal of Animal Science 79, 1883–1891.

Barbari M, Conti L, Koostra BK, Masi G, Sorbetti Guerri F and Workman SR 2006. The use of global positioning and geographical information systems in the management of extensive cattle grazing. Biosystems Engineering 95, 271–280.

Barroso FG, Martìnez TF, Paz T, Parra A and Alarcòn FJ 2001. Tannin content of grazing plants of southern Spanish arid lands. Journal of Arid Environments 49, 301–314.

Baumont R, Prache S, Meuret M and Mohrand-Fehr P 2000. How forage characteristics influence behaviour and intake in small ruminants: a review. Livestock Production Science 64, 15–28.

Baumont R, Cohen-Salmon D, Prache S and Sauvant D 2004. A mechanistic model of intake and grazing behaviour in sheep integrating sward architecture and animal decisions. Animal Feed Science and Technology 112, 5–28.

Ben Salem H and Smith T 2008. Feeding strategies to increase small ruminant production in dry environments. Small Ruminant Research 77, 174–194.

Bishop-Hurley GJ, Swain DL, Anderson DM, Sikka P, Crossman C and Corke P 2007. Virtual fencing applications: implementing and testing an automated cattle control system. Computers and Electronics in Agriculture 56, 14–22.

Blanc F, Bocquier F, Agabriel J, D'Hour P and Chilliard Y 2006. Adaptive abilities of the females and sustainability of ruminant livestock systems. A review. Animal Research 55, 489–510.

Bouju S 2000. Evolution des systèmes d'élevage de part et d'autre de la Méditerranée: une difficile conciliation avec des objectifs de développement durable. Options Méditerranéennes Série A 39, 145–158.

Bounejmate M, Norton BE, El Mourid M, Khatib A, Bathikha N, Ghassali F and Mahyou H 2004. Partnership for understanding land use/cover change and reviving overgrazed rangeland in Mediterranean areas: ICARDA's experience. Cahiers Options Méditerranéennes 62, 267–283. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Bourbouze A 2000. Pastoralisme au Maghreb: la révolution silencieuse. Fourrages 161, 3–21.

Bourbouze A and Lazarev G 1991. Typologie dynamique des systèmes pastoraux en Méditerranée. Proceedings of the 4th International Rangeland Congress, 22–26 April 1991, Montpellier, France, pp. 729–733.

Bourbouze A and Gibon A 1999. Ressources individuelles ou ressources collectives? L'impact du statut des ressources sur la gestion des systèmes d'élevage des régions du pourtour méditerranéen. Options Méditerranéennes Série A 38, 289–309. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Brand TS 2000. Grazing behaviour and diet selection by Dorper sheep. Small Ruminant Research 36, 147–158.

Cabiddu A, Decandia M, Sitzia M and Molle G 2000. A note on the chemical composition and tannin content of some Mediterranean shrubs browsed by Sarda goats. Cahiers Options Méditerranéennes 52, 175–178. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Chemmam M, Moujahed N, Ouzrout R and Guellati MA 2009. Seasonal variations of chemical composition, intake and digestibility by ewes of natural pasture in the south-eastern regions of Algeria. Options Méditerranéennes Série A 85, 123–127. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Cialdella N, Genin D and Ouled Belgacem A 2004. Pacages et parcours en situation de sécheresse: réponses des agropasteurs pour l'alimentation des petits ruminants dans le sud tunisien. Cahiers Options Méditerranéennes 62, 207–210. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Ciucci P and Boitani L 2005, Conflitto tra lupo e zootecnia in Italia: stato delle conoscenze, ricerca e conservazione. In Grandi Carnivori e Zootecnia tra conflitto e coesistenza (ed. P Ciucci, C Teofili and L Boitani). Biologia e Conservazione della Fauna 115, pp. 26–51.

Cooper SM and Owen-Smith N 1986. Effects of plant spinescence on large mammalian herbivores. Oecologia 68, 446–455.

Del Curto T, Porath M, Parsons CT and Morrison JA 2005. Management strategies for sustainable beef cattle grazing on forested rangelands in the Pacific Northwest. Rangeland Ecology and Management 58, 119–127.

Dumont B and Petit M 1998. Spatial memory of sheep at pasture. Applied Animal Behaviour Science 60, 43–53.

Dumont B and Hill DRC 2001. Multi-agent simulation of group foraging in sheep: effects of spatial memory, conspecific attraction and plot size. Ecological Modelling 141, 201–215.

Dumont B, Meuret M and Prud'hon M 1995. Direct observation of biting for studying grazing behaviour of goats and llamas on garrigue rangelands. Small Ruminant Research 16, 27–35.

Dumont B, Carrère P and D'Hour P 2002. Foraging in patchy grasslands: diet selection by sheep and cattle is affected by the abundance and spatial distribution of preferred species. Animal Research 51, 367–381.

Dumont B, Rook AJ, Coran C and Röver K-U 2007. Effects of livestock breed and grazing intensity on biodiversity and production in grazing systems. 2. Diet selection. Grass and Forage Science 62, 159–171.

Duru M, Fiorelli J-L, Peyre D, Roger P and Theau J-P 2002. La hauteur d'herbe au pâturage: une mesure simple pour faciliter sa conduite, un indicateur pour caractériser des stratégies. Fourrages 170, 189–201.

Duru M, Al Haj Khaled R, Ducourtieux C, Theau JP, de Quadros FLF and Cruz P 2009. Do plant functional types based on leaf dry matter content allow characterizing native grass species and grasslands for herbage growth pattern? Plant Ecology 201, 421–433.

Dutilly-Diane C, Saint-Macary C, Tiedeman J, Arab G, Batikha N, Ghassali F and Khoudary E 2006. Mobility and feeding strategies in the pastoral systems of the Syrian Badiah. Options Méditerranéennes Série A 78, 85–90. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Etienne M and Rigolot E 2004. Pâturage et débroussaillement des garrigues à chêne kermès en France méditerranéenne. Cahiers Options Méditerranéennes 62, 407–410. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Fay PK, McElligott VT and Havstad KM 1989. Containment of free-ranging goats using pulsed-radio-wave activated shock collars. Applied Animal Behaviour Science 23, 165–171.

Fleury P, Duboeuf B and Jeannin B 1996. Forage management in dairy farms: a methodological approach. Agricultural Systems 52, 199–212.

Freer M, Moore AD and Donnelly JR 1997. GRAZPLAN: decision support system for Australian grazing enterprises – II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. Agricultural Systems 54, 77–126.

Frutos P, Hervas G, Ramos G, Giraldez FJ and Mantecon AR 2002. Condensed tannin content of several shrub species from a mountain area in northern Spain, and its relationship to various indicators of nutritive value. Animal Feed Science and Technology 95, 215–226.

Ganskopp D 2001. Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. Applied Animal Behaviour Science 73, 251–262.

Ganskopp DC and Bohnert DW 2009. Landscape nutritional patterns and cattle distribution in rangeland pastures. Applied Animal Behaviour Science 116, 110–119.

Gautier D and Moulin CH 2004. Intérêts du pâturage hivernal sur parcours pour les exploitations ovines: exemples des Préalpes du Sud. INRA Productions Animales 17, 275–286. Available online at: http://www.inra.fr/internet/Produits/PA/index.php

Guérin G and Gautier D 2004. Le pastoralisme: gérer une diversité de végétations. Le cas des systèmes pastoraux méditerranéens. Fourrages 178, 233–243.

Guérin G, Bellon S and Gautier D 2001. Valorisation et maîtrise des surfaces pastorales par le pâturage. Fourrages 166, 239–256.

Hadjigeorgiou I, Osoro K, Fragoso de Almeida JP and Molle G 2005. Southern European grazing lands: production, environmental and landscape management aspects. Livestock Production Science 96, 51–59.

Henkin Z, Gutman M, Aharon H, Perevolotsky A, Ungar ED and Seligman NG 2005. Suitability of Mediterranean oak woodland for beef herd husbandry. Agriculture Ecosystems and Environment 109, 255–261.

Institut National de la Recherche Agronomique (INRA) 2007. Alimentation des bovins, ovins et caprins. QUAE editions, Versailles, France.

Jouven M and Baumont R 2008. Simulating grassland utilization in beef suckler systems to investigate the trade-offs between production and floristic diversity. Agricultural Systems 96, 260–272.

Jouven M, Agabriel J and Baumont R 2008. A model predicting the seasonal dynamics of intake and production for suckler cows and their calves fed indoors or at pasture. Animal Feed Science and Technology 143, 256–279.

Kharrat M and Bocquier F 2010. Adaptive responses at the whole lactation scale of Baladi dairy goats according to feed supply and level of body reserves in agro-pastoral feeding system. Small Ruminant Research 90, 120–126.

Kyriazopoulos AP, Sklavou P, Nastis AS and Papanastasis VP 2009. Interactions between grazing behaviour and plant community structure in shrubland and their consequences on desertification. Options Méditerranéennes Série A 85, 91–97.

Laca EA 2009. Precision livestock production: tools and concepts. Revista Brasileira de Zootecnia 38, 123–132.

Landau S, Perevolotsky A, Bonfil D, Barkai D and Silakinove N 2000a. Utilization of low quality resources by small ruminants in Mediterranean agro-pastoral systems: the case of browse and aftermath cereal stubble. Livestock Production Science 64, 39–49.

Landau S, Silakinove N, Nitsan Z, Barkai D, Baram H, Provenza FD and Perevolotsky A 2000b. Short-term changes in eating patterns explain the effects of condensed tannins on feed intake in heifers. Applied Animal Behaviour Science 69, 199–213.

Lapeyronie P 2001. Gestion des habitats naturels par l'élevage: généralisation de règles spontanées ou induites sur l'occupation de l'espace et l'utilisation des végétations par les herbivores domestiques. Compte-rendu du troisième séminaire INRA-CIRAD, Verrières, France, pp. 33–48.

Lapeyronie P and Moret A 2007. Protection des troupeaux et impacts environnementaux. In Loup Elevage, s'ouvrir à la complexité (ed. L Garde), pp. 202–211. Edition CERPAM, Manosque, France.

Lasseur J 2005. Sheep farming systems and nature management of rangeland in French Mediterranean mountain areas. Livestock Production Science 96, 87–95.

Lécrivain E, Lasseur J and Armand D 2004. Diversité des systèmes d'élevage ovin et diversité de comportement des troupeaux sur parcours: un atout pour la gestion des milieux hétérogènes. Options Méditerranéennes Série A 61, 161–169. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Léger F 1999. Valoriser les territoires pastoraux: une voie d'avenir pour les systèmes d'élevage ovins viande du Sud de la France. Options Méditerranéennes Série A 38, 157–161. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Makkar HPS 2003. Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds. Small Ruminant Research 49, 241–256.

Martin G, Hossard L, Theau JP, Therond O, Josien E, Cruz P, Rellier JP, Martin-Clouaire R and Duru M 2009. Characterizing potential flexibility in grassland use. Application to the French Aubrac area. Agronomy for Sustainable Development 29, 381–389.

Maton C, Montagnac D, Viudes G, Bouquet PM and Bocquier F 2008. Les applications de l'identification électronique des petits ruminants au service de l'élevage biologique. Innovations Agronomiques 4, 67–71.

Meuret M 1996. Organizing a grazing route to motivate intake on coarse resources. Annales de Zootechnie 45, 87–88.

Meuret M 1997. How do I cope with that bush? Optimizing less palatable feeds at pasture using the MENU model. Options Méditerranéennes Série A 34, 53–57. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Molénat G, Foulquie D, Autran P, Bouix J, Hubert D, Jacquin M, Bocquier F and Bibe B 2005. Pour un élevage ovin allaitant performant et durable sur parcours: un système expérimental sur le Causse du Larzac. INRA Productions Animales 18, 323–338. Available online at: http://www.inra.fr/internet/Produits/PA/index.php

Najari S, Khaldi G, Jaouad M, Ben Hammouda M and Djemali M 2004. Conduite traditionnelle des petits ruminants dans les régions arides tunisiennes: savoir-faire du berger et exploitation durable des ressources pastorales. Cahiers Options Méditerranéennes 62, 249–253. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Nastis A 1997. Feeding behaviour of goats and utilisation of pasture and rangelands. Cahiers Options Méditerranéennes 25, 39–45.

Nedjraoui D 2004. Evaluation des ressources pastorales des régions steppiques algériennes et définition des indicateurs de dégradation. Cahiers Options Méditerranéennes 62, 239–243. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Nolan T and Nastis A 1997. Some aspects of the use of vegetation by grazing sheep and goats. Options Méditerranéennes Série A 34, 11–25. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Osoro K, Olivan M, Celaya R and Martinez A 2000. The effect of Calluna vulgaris cover on the performance and intake of ewes grazing hill pastures in Northern Spain. Grass and Forage Science 55, 300–308.

Ouled Belgacem A and Papanastasis V 1995. Impact of grazing practices on rangeland vegetation of western Crete. Cahiers Options Méditerranéennes 12, 209–212. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Pacheco F 1999. Les conséquences des pressions environnementales sur la conduite des troupeaux et l'organisation du travail dans les élevages utilisateurs de parcours. Options Méditerranéennes Série A 38, 371–380. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Papachristou TG 2000. Dietary selection by goats and sheep in kermes oak shrublands of Northern Greece: influence of shrub cover and grazing season. Cahiers Options Méditerranéennes 52, 161–164. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Papachristou TG, Dziba LE and Provenza FD 2005. Foraging ecology of goats and sheep on wooded rangelands. Small Ruminant Research 59, 141–156.

Papanastasis VP, Yiakoulaki MD, Decandia M and Dini-Papanastasi O 2008. Integrating woody species into livestock feeding in the Mediterranean areas of Europe. Animal Feed Science and Technology 140, 1–17.

Papanastasis VP, Ghossoub R and Scarpelo C 2009. Impact of animal sheds on vegetation configuration in Mediterranean landscapes. Options Méditerranéennes Série A 85, 49–54. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Perevolotsky A, Landau S, Kababia D and Ungar ED 1998. Diet selection in dairy goats grazing woody Mediterranean rangeland. Applied Animal Behaviour Science 57, 117–131.

Prache Sand and Peyraud JL 2001. Foraging behaviour and intake in temperate cultivated grasslands. In Proceedings of the XIX International Grassland Congress, Brazil, pp. 309–319.

Provenza FD 1996. Acquired aversions as the basis for varied diets of ruminants foraging on rangelands. Journal of Animal Science 74, 2010–2020.

Provenza FD 2007. Social organization, culture and use of landscapes by livestock. Options Méditerranéennes Série A 74, 307–315. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Provenza FD and Papachristou TG 2009. Behavior-based management of ecosystems. Options Méditerranéennes Série A 85, 13–28.

Provenza FD, Villalba JJ, Dziba LE, Atwood SB and Banner RE 2003. Linking herbivore experience, varied diets and plant biochemical diversity. Small Ruminant Research 49, 257–274.

Quétier F, Marty P and Lepart J 2005. Farmers' management strategies and land use in an agropastoral landscape: Roquefort cheese production rules as a driver of change. Agricultural Systems 84, 171–193.

Riedel J-L, Casasùs I and Bernuès A 2007. Sheep farming intensification and utilization of natural resources in a Mediterranean pastoral agro-ecosystem [Abstract]. Livestock Science 111, 153–163.

Rochon JJ, Duval M and Goby J-P 2009. Effect of the environment of a flock of sheep when free-ranging or under the guidance of a shepherd. Options Méditerranéennes Série A 85, 61–65.

Rogosic J, Pfister JA, Provenza FD and Grbesa D 2006. Sheep and goat preferences for and nutritional value of Mediterranean maquis shrubs. Small Ruminant Research 64, 169–179.

Rogosic J, Estell RE, Ivankovic S, Kezic J and Razov J 2008. Potential mechanisms to increase shrub intake and performance of small ruminants in Mediterranean shrubby ecosystems. Small Ruminant Research 74, 1–15.

Rook AJ, Dumont B, Isselstein J, Osoro K, WalliesDeVries MF, Parente G and Mills J 2004. Matching type of livestock to desired biodiversity outcomes in pastures – a review. Biological Conservation 119, 137–150.

Ruiz FA, Mena Y, Castel JM, Guinamard C, Bossis N, Caramelle-Holtz E, Contu M, Sitzia M and Fois N 2009. Dairy goat grazing systems in Mediterranean regions: a comparative analysis in Spain, France and Italy. Small Ruminant Research 85, 42–49.

Rutter SM 2006. Diet preference for grass and legumes in free-ranging domestic sheep and cattle: current theory and future application. Applied Animal Behaviour Science 97, 17–35.

Ryan WJ 1990. Compensatory growth in cattle and sheep. Nutrition Abstracts and Reviews – Series B 60, 653–664.

Silakinove N 1997. Why goats raised on harsh environments perform better than other domesticated animals. Options Méditerranéennes Série A 34, 185–194. Available online at: http://www.ciheam.org/publications/options-mediterraneennes._5_40027_.php

Thomas DT, Wilmot MG, Alchin M and Masters DG 2008. Preliminary indications that Merino sheep graze different areas on cooler days in the Southern Rangelands of Western Australia. Australian Journal of Experimental Agriculture 48, 889–892.

Yiakoulaki MD, Zarovali MP and Papanastasis VP 2009. Foraging behaviour of sheep and goats grazing on silvopastoral systems in Northern Greece. Options Méditerranéennes Série A 85, 79–84.

Zarovali MP, Yiakoulaki MD and Papanastasis VP 2007. Effects of shrub encroachment on herbage production and nutritive value in semi-arid Mediterranean grasslands. Grass and Forage Science 62, 355–363.