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Sustainable intensification of grass-based ruminant production

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Abstract

The sustainable or ecological intensification of grass-based food production systems provides an opportunity to align the ever increasing global demand for food with the necessity to re-green ruminant production. The challenge for production scientists now is to find innovative ways to improve grass-based production processes to maximize resource use-efficiency based on improved management practices. The objective of this paper is, firstly, to outline the potential opportunities to enhance the yield and quality of grasslands for grazing and conserved forages paying particular attention to species diversity and legumes. Subsequently, the paper addresses the necessity to choose appropriate animals and management practices to improve productive and reproductive performance within such systems. Finally, the paper reports experimental results from dairy cow and sheep production systems that succeeded in combining high animal performance with low environmental impacts.

Keywords: grass yield, quality, legumes, animal productivity, grazing, dairy cow, sheep

Introduction

Global food demand, climate change, urbanization and bio-fuel production will increase competition for agricultural land use between crop and herbivore production. Consequently, it is expected that ruminant production will have to be concentrated on non-arable lands (permanent grasslands) and on arable lands where it would be the most profitable system of production.

European grass-based ruminant production systems face a threefold challenge: i) to meet the rapidly changing demand for food within a resource-constrained environment; ii) to do so in an environmentally and socially sustainable manner for consumers and producers; and iii) to ensure that the products produced meet the highest standards of quality and nutritional value for increasingly discerning consumers. Producing more food from the same land area, while reducing environmental impacts, requires what has been referred to as 'sustainable intensification' (Pretty, 1997) or 'ecological intensification' (Griffon, 2013) of agricultural production. This is based on new innovative blueprints of production based on increased herbage production and quality, and improved utilization under grazing.

The aim of the present contribution is to propose a framework of sustainable intensification in grass-based ruminant production. The definition and challenges of sustainable intensification in grass-based ruminant production will first be outlined. Then specific aspects, including grass production and quality, the type of animals and management practices will be addressed.

Sustainable intensification: definition and challenges

Since the 1970s, and the growing environmental concern over industrial agriculture and livestock production, there has been a consensus in society and the scientific community on the necessity to re-green agriculture. However, the best approach to achieve re-greening is still a matter for much debate among production scientists, legislators and other public stakeholders, and numerous concepts can be found in the literature (Griffon, 2013): 'sustainable agriculture', 'conservation agriculture', 'agro-ecology', 'organic farming', 'high nature-value agriculture', 'ecological or sustainable intensified agriculture' *etc.*

Ecological intensification of agricultural systems was recently defined by Hochman *et al.* (2013) as producing more food per unit of resource used, while minimizing the impact on the environment. Griffon (2013) stated that ecological intensification contrasts with chemical and energy use for crop production and with the use of feed and drugs for animal production. Thus, ecological intensification relies more heavily on the use of natural resources and the functionality (or ecosystem services) they provide and it places less emphasis on the use of external inputs. The challenge for such systems is to improve the efficiency of natural resource use in order to increase food production from existing farmland while minimizing pressure on the environment.

The literature on ecological intensification and agro-ecology in animal production is scarce. Recently, Dumont *et al.* (2013) proposed the development of ecology-based alternatives for animal production by adopting management practices to improve animal health, decreasing the inputs needed for production, decreasing pollution by optimizing the metabolic functioning of farming systems and by adapting management practices to enhance biological diversity and strengthen the resilience within animal production systems.

Grass-based systems have been shown to be beneficial to the environment (Jankowska-Huflejt, 2006; Peyraud *et al.*, 2010) and to be economically successful by reducing total costs of food production (Dillon *et al.*, 2005). However, systems based on increased mobilization of services provided by natural resources (low supplementary feed input or organic systems) have to cope with more variability in relation to plants, animals, climate and bio-aggressors. Such systems therefore require plants and animals that are robust and easy to manage. The production performance of grassland is dependent on the yield of utilizable energy and protein in the grass grown. This means that increasing the yield and stability of high quality grass growth is imperative to ensure the robustness of the overall system. The animal required for efficient grassland-based production systems must be robust, autonomous and 'easy care', and capable of high levels of performance from a predominantly grazed pasture diet. Finally, the management of such systems has to maximize the utilization of a **renewable low cost resource without adverse effects on the environment over the long term.**

Achieving and maintaining optimum soil fertility is a prerequisite for high productivity grassland production systems. The topic of soil fertility is, however, outside the direct scope of this paper. In order to maximize nutrient-use efficiency within grass-based production systems, and to minimize environmental impacts, nutrient recycling must be improved by closely matching nutrient supply to grassland demand according to the climatic conditions.

Combining yield and quality of grasslands for grazing and conserved forages

Forage production and forage quality must be increased without increasing the negative effects on the environment. In recent years research efforts have moved from improving the production and quality of single-species swards through breeding and fertilization to focus on the role of diversity and thus multispecies sown and permanent swards.

The role of species diversity in sown and permanent swards

In a recent review of the literature, Huyghe *et al.* (2012) showed that a positive relationship between species diversity in sown swards and biomass production is frequently found in controlled environments. More so than the number of species, the functional diversity (type of grasses, legumes, forbs) has a positive effect on forage yield (Kirwan *et al.*, 2007), and the highest yields are often achieved with intermediate species diversity.

The relationship between species diversity and herbage feed value has received little attention. In an experiment reported by Huyghe *et al.* (2008) in which species diversity ranged from one to eight species, the negative relationship between forage yield and *in vitro* digestibility was not affected by the number of species nor by the number of functional groups. A notable advantage

of complex swards combining grasses and legumes was the more stable chemical composition across the year that allows more flexibility in sward utilization for grazing and harvesting.
The functional composition is also a key feature which explains variation in productivity and quality and their temporal patterns in permanent grasslands (Duru *et al.*, 2010). In a recent study in France on a set of 190 permanent grasslands representative of most pedo-climatic conditions from Atlantic to Alpine areas (Michaud *et al.*, 2014), feed value, both in early and late spring, was positively related to the proportion of legume species in the sward. A higher stability of forage quality in spring was related to high proportions of forbs and conservative grasses (Figure 1).

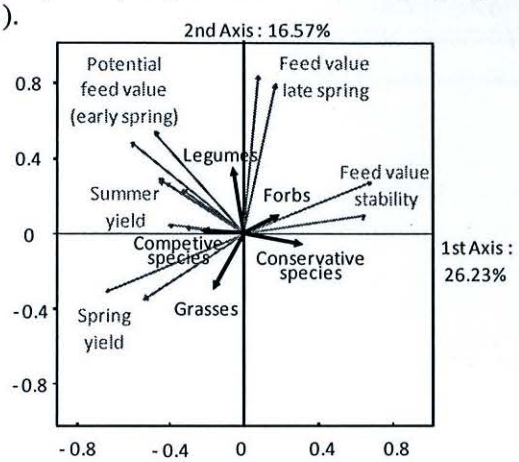

Figure 1. Principal component analysis of herbage yield, feed value and functional composition on a set of 190 permanent grasslands in France (from the data of Michaud *et al.*, 2014)

Species diversity may have a positive effect on voluntary food intake, as diversity offers a choice of herbage species and previous studies have reported that choice significantly increases intake at pasture in sheep (Cortes *et al.*, 2006) and indoors with conserved forages (Ginane *et al.*, 2002 with heifers, Bruinenberg *et al.*, 2003 with cows). It is not clear whether the variation in intake is a consequence of the diversity *per se* or of the choice situation, even though the experiments of Cortes *et al.* (2006) support the hypothesis of a true effect of diversity. In contrast, Soder *et al.* (2006) found no effect of species diversity on dairy cow intake, suggesting that the animal type could interact with the species diversity effect.

The specific role of legume species

Introducing legume species into conserved and grazed forages gives many advantages relating to feed value, animal performance and environmental impact.
White clover has a high digestibility and a high energy value; this is attributed to its low fibre concentration which reflects the absence of structural components such as stems and sheaths (Ayres *et al.*, 1998). A particular advantage of white clover is the reduced rate of decline in digestibility in the mid-season compared to perennial ryegrass (Ulyatt, 1970). Furthermore, white clover supports increased voluntary intake (Ribeiro Filho *et al.*, 2003). Increased production performance as a result of increasing the sward white clover proportion has been observed in dairy cows (Dewhurst *et al.*, 2003), beef steers (Thomas *et al.*, 1981) and sheep (Orr *et al.*, 1990). The results depend on the proportion of white clover in the sward. Egan *et al.* (2013) found that cows grazing a grass-clover sward (21.6% clover content) had higher milk yield and milk solids yield than cows grazing a grass-only sward, whereas Enriquez-Hidalgo *et al.* (2012) found no difference in milk yield and milk solids yield when the average sward clover content was only 13%.
When expressed on a proportion of gross energy intake or unit-intake basis, methane emissions are often lower for forage legume-fed animals than grass-fed animals (McCaughey *et al.*, 1999; Waghorn *et al.*, 2002). Beauchemin *et al.* (2008) proposed that this was due to the lower fibre content, higher dry matter intake, increased passage rate and presence of condensed tannins

(CTs) in certain legume species such as *Lotus corniculatus* or *Onobrychis viciifolia*. Although the effect of CTs on methane emissions has been found in several studies *in vitro* (e.g. Niderkorn *et al.*, 2011), it remains uncertain *in vivo*.

Condensed tannins are also important in reducing the degradation of forage proteins in the rumen, without reducing the amount of microbial protein which is synthesized, and in deactivating internal parasites (Min *et al.*, 2003). These features have positive implications for nitrogen excretion and the use of anthelmintic drugs respectively. Promising results were obtained with *Onobrychisv viciifolia*, with similar voluntary intake and digestibility as lucerne, but lower protein degradation in the rumen resulting in lower protein excretion in urine (Theodoridou *et al.*, 2010). Another interesting secondary compound is polyphenol oxidase, which is present in red clover and which was shown to inhibit proteolysis and lipolysis (Lee *et al.*, 2004). These properties could improve silage conservation, as CTs also do (Theodoridou *et al.*, 2012), and limit fatty acid hydrogenation in the rumen. A challenge for the future is to find positive associative effects between plants, relying on synergies between the different bioactive compounds (Niderkorn and Baumont, 2009; Aufrère *et al.*, 2012): e.g., could CTs from one plant bind with proteins from another plant? Recently, synergies between cocksfoot silage and red clover silage, and between ryegrass and chicory, were observed for DM and NDF intake and eating rate, with 50:50 being the optimal proportions. For the cocksfoot silage-red clover silage association, the synergistic effect was also observed on daily digestible organic matter intake (Niderkorn *et al.*, 2014).

Quality vs. quantity: biomass accumulation and stage of maturity

As biomass is accumulating with plant growth, sward quality in terms of net energy, protein content and potential voluntary intake is decreasing as a result of plant maturation. This is well documented for single-species swards of grasses and legumes, e.g. in the feed value tables used in France (Baumont *et al.*, 2007). A less mature plant contains a lower proportion of true stem and dead material and a greater proportion of leaf which is lower in fibre and highly digestible (Curran *et al.*, 2010; Beecher *et al.*, 2013). As the plant enters the reproductive stage, leaf proportion decreases and stem proportion increases, with negative effects on sward digestibility, crude protein concentration and voluntary intake.

Thus, harvesting and grazing management have to deal with the trade-off between forage quantity and quality. In spring, for conservation, the forage should be cut at the beginning of grass heading to maximize net energy and protein harvested per ha. The decrease in feed value between the beginning and end of heading will necessitate 2.5 kg/day more concentrate for a dairy cow to produce 30 kg of milk. At grazing, increased frequency of defoliation results in high quality but a decrease in net herbage accumulation whereas infrequent defoliation leads to greater herbage production, but decreased grass feed value (Hoogendorn *et al.*, 1992; Beecher *et al.*, submitted). High biomass yield (kg DM ha^{-1}) at grazing will limit animal performance through digestive constraints (low intake of poorly digestible matter), but high quality swards (low biomass yield) can also limit animal performance through behavioural constraints if the time required to graze the required quantity of grass is too great (Baumont *et al.*, 2004). The effect of biomass yield at grazing may also vary over the grazing season. Tunon (2013) found no effect of biomass yield up to 2,300 kg DM ha^{-1} (>4 cm) from April to July, but observed a reduction in milk fat plus protein yield compared to 1,000 and 1,500 kg DM ha^{-1} swards from July to October. McEvoy *et al.* (2010) found similar results. This agrees with work by Beecher *et al.* (submitted) who observed no difference in OM digestibility between swards with a biomass <1500 kg DM ha^{-1} and >2000 kg DM ha^{-1} in spring. In summer and autumn however, increasing biomass yield resulted in a significant decrease in OM digestibility and in digestible OM intake (Figure 2).

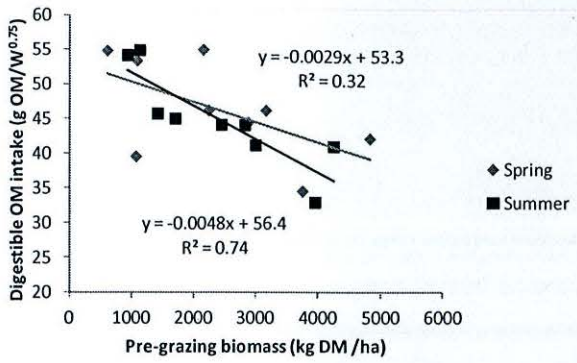

Figure 2. Effect of pre-grazing biomass on digestible dry matter intake measured in sheep (data from Beecher *et al.*, submitted)

Increasing grass quality via the use of less-mature grass also has positive implications for product quality (Hoogendorn *et al.*, 1992) and environmental measures. For example, biomass yield had no effect on enteric methane emissions in spring, but in summer, grazing swards of high biomass resulted in higher emissions (Wims *et al.*, 2010).

Finally, to manage the trade-off between quantity and quality, grazing consistently very low biomass yield swards (<1,200 kg DM ha^{-1}) should be avoided during the main grazing season as this can depress pasture regrowth rate. Diversified swards in which species have different growth and maturation rates and the use of late-heading cultivars could help manage the trade-off between quantity and quality by smoothing the biomass accumulation and the associated decline in feed value.

Choosing the appropriate animal for sustainable grass-based production

As only ~10% of the world's milk production comes from grazing systems, the majority of global ruminant livestock have not been selected for grazing systems. The long running scientific debate on the importance of genotype × environment interactions has been refuelled in recent years as the interest in grass-based systems in Europe has increased. Until recently, most experimental results have indicated little or no importance of such interactions (Holmes, 1995); however, increasingly diverse genotypes and/or production environments have increased the likelihood of such interactions (Falconer, 1990). There is now strong evidence to show that the animals that are genetically best suited to non-grazing systems, are not suited to grazing systems (Delaby *et al.*, 2010).

Animals for grass-based systems

Successful grazing systems require animals capable of achieving large intakes of forage relative to their genetic potential for production so that they can achieve their nutritional requirements almost entirely from grazing, with some conserved forage. As animal intakes at grazing are reduced relative to confinement systems, efficient animals within grazing systems have moderated feed requirements which are consistent with the feed supply capability of grazing. Consequently, such autonomous animals at grazing can achieve high milk production (and composition), retain optimal reproductive capacity and maintain adequate body reserves to avoid ill health within a restricted feed environment (Delaby *et al.*, 2009; Cutullic *et al.*, 2011). Additionally in the context of sustainable intensification, the necessity for more animals to be managed by individual farmers requires more robust autonomous livestock requiring less individual managerial assistance. Animals for grazing systems must also be able to graze effectively and to walk long distances, abilities that are not required in confinement systems.

The use of alternative breeds or crossbreeding to satisfy the specificities of an animal suited to the grass-based system is now being considered by farmers in many countries. Dual purpose or cross breed cows seem more flexible and better adapted to grazing and have improved health,

milk value, reproductive performance, feed efficiency and beef value. Recent studies have examined the suitability of alternative cow breeds for grass-based milk production systems in both France (Delaby *et al.*, 2014) and Ireland (Coleman *et al.*, 2009; Prendiville *et al.*, 2009). In France, an experiment run at the INRA experimental farm Le Pin-au-Haras (Normandy) evaluated the ability of different types of dairy cow to produce and to reproduce in response to two contrasting feeding strategies in a compact calving context (Table 1).

Table 1. Milk and reproductive performance of dairy cows according to breed and feeding strategy (from the INRA experiment in Le Pin-au-Haras; n=380 lactations)

Breed	Holstein		Normande	
Feeding strategy	High (1)	Low (2)	High (1)	Low (2)
Milk yield (44 weeks - kg)	8515	6022	6332	4798
Fat content (g/kg)	38.0	39.5	41.0	41.8
Protein content (g/kg)	32.1	31.0	34.9	33.3
Milk Solids (kg)	587	418	466	351
Body Condition Score change (pts)	-1.00	-1.25	-0.60	-0.90
First insemination success (%)	28	20	41	38
Recalving (%)	59	44	71	68

(1) The High feeding strategy had maize silage, grass silage, dehydrated alfalfa and concentrates in the indoor diet, a higher stocking rate, and supplementation with maize silage, grass silage and concentrate during the grazing season.
(2) The Low feeding strategy had grass silage and haylage in the indoor diet, a lower stocking rate, and supplementation with grass silage during the grazing season.

The high reactivity of the milk production in Holstein cows, as well as high body condition score loss and poor reproduction performance, makes the Holstein cow incompatible with the herbage system with no concentrate input and compact spring calving. In contrast, the Normande, a dual-purpose breed, appears less sensitive and better adapted to low input systems based on the maximization of grassland use for milk production. In Ireland, Prendiville *et al.* (2009) compared the biological efficiency of three genotypes (Jersey, Holstein-Friesian and Jersey × Holstein-Friesian) within grass-based systems. They reported higher milk production efficiencies among Jersey × Holstein-Friesian cattle compared to purebred Holstein-Friesian cattle. In comparison with purebred Holstein-Friesian dairy cattle, Jersey × Holstein-Friesian cattle achieved improved reproductive performance, a greater intake per kg of body weight at grazing and consequently, required 12% less grass to produce 1 kg of milk fat plus protein. Differences in intake and varying measures of feed conversion efficiency between dairy cows of various pure breeds have also been reported previously (for review, see Grainger and Goddard, 2004).

Animal management for grass-based systems

Grass-based systems of milk production require compact calving in spring to match feed supply and herd demand. This is based on achieving high rates of pregnancy within a short period of time following the start of breeding. Calving date is an important determinant of milk production and feed utilization in grass-based systems, through its impact on the alignment of feed demand with supply. Altering the mean calving date of the herd may have a role in reducing the reliance of grass-based farm systems on purchased feeds particularly at higher stocking rates. Both Dillon *et al.* (1995) and McCarthy *et al.* (2013) observed that delaying calving until March achieved a better alignment of dairy herd requirements and grass growth within Irish grass-based milk production studies, increased milk production from grazed grass, reduced the

requirement for purchased supplements and achieved a greater efficiency of energy utilization particularly at higher stocking rates.

In sheep production, high ewe productivity (number of lambs produced per ewe per year × mean lamb carcass weight) is a key indicator to ensure economic sustainability. In organic sheep production systems, where hormonal treatments are prohibited and the price of concentrate feed increases the pressure on production costs, increasing reproductive capacity could be used to increase ewe productivity without undue penalty for other technical or economic performance targets. Increasing ewe productivity by increasing ewe reproductive capacity was evaluated on a rustic breed (Limousine) over a four-year period. In the study, one lambing per ewe per year (*1/year*) (with 50% lambings in spring and 50% in autumn) was compared to three lambings over two years (*3in2*) (Benoit *et al.*, 2009). Ewe productivity in *1/year* (1.51) was slightly lower than in *3in2* (1.61), but with a lower between-year variability, lower lamb mortality and parasitism level and lower concentrate feed consumption per ewe. Lamb carcass conformation, fatness and fat colour were not different between systems, but carcass weight and subcutaneous dorsal fat firmness were lower in *3in2* lambs than in *1/year*. Intensification in an organic sheep system through increased reproduction rhythm therefore did not lead to better animal performance nor economic results and proved riskier, more variable and more difficult to manage, and thus less sustainable. The less intensive system (*1/year*) was highly efficient from the animal perspective and highly food self-sufficient (Benoit *et al.*, 2009).

Improving the efficiency of resource use in grazing systems

Grazed grass is the cheapest feed source (Finneran *et al.*, 2012) and commonly comprises 0.60 to 0.90 of ruminant animal diets within grass-based systems in Europe. Therefore, the production and utilization of increased quantities of higher quality grazed grass, coupled with the close alignment of grass production and animal requirements, has the potential to increase overall system productivity and contribute significantly to the sustainable intensification of agricultural production. Further research is therefore needed to develop management practices and technologies that will facilitate increases in milk and meat output from sustainable grass-based systems.

High stocking rates in grass-based dairy systems can be compatible with high environmental performance

Stocking rate (SR), traditionally defined as the number of animals per unit area of land used during a defined period of time, is widely acknowledged as the main driver of productivity from grazing systems and this applies across all grazing species (Rattray, 1987; Hoden *et al.*, 1991; Baudracco *et al.*, 2010; Crosson and McGee; 2011) due to its dominant effect on animal demand and hence pasture use. Increasing SR is usually associated with an increase in grazing severity (i.e., low post grazing residual sward height) and many studies have attributed the increased productivity of higher SR systems to an improvement in herbage utilization (McMeekan and Walsh, 1963). Penno (1999) suggested that the ideal stocking rate should balance the dual objectives of generous feeding to achieve high levels of production efficiency per animal and underfeeding to achieve high levels of pasture utilization to meet the overall objective of optimizing farm efficiency and profitability, while accounting for year-to-year variability in climate and grassland productivity. On that basis, intensified systems require grazing management practices that maximize pasture production and quality, which, in combination with increased stocking density, will result in increased overall system productivity (McEvoy *et al.*, 2009; Curran *et al.*, 2010; McCarthy *et al.*, 2013). A recent review of SR experiments reported a 0.20 increase in milk production per ha arising from a 1 cow ha^{-1} increase in SR, where no extra supplement was fed as SR increased (McCarthy *et al.*, 2011).

In addition to the economic and animal welfare benefits associated with grazing, grass-based ruminant livestock production systems provide an environmentally sustainable food production

model. In comparison with cropping, grassland is an important biological filter which reduces nutrient and chemical run off and supports biodiversity and carbon storage. Compared with arable land, grassland is associated with a better conservation of soil against erosion, and reduced runoff and leaching of nutrients into surface and ground water (Briemle and Elsasser, 1997; Jankowska-Huflejt, 2006). Grassland also acts as an important carbon sink for GHG emissions, due to its high organic matter content relative to arable land (Leip *et al.*, 2010). Notwithstanding these benefits, the efficiency of Nitrogen (N) use within grass-based systems is variable and can potentially result in nutrient loss to water resources by leaching. To comply with the Irish obligations pursuant to the EU Nitrate Directive (91/676/EEC), a long term study of the factors influencing nitrate loss beneath intensive dairy production systems in vulnerable soil types was undertaken at Curtins Farm, Teagasc Moorepark, in the south of Ireland over a 10-year period from 2001 to 2011. The Curtins Farm soil type is representative of the highest risk soils to nitrate leaching in Ireland. On the 48 ha site, cow numbers increased from 108 in 2001 to 138 in 2011, based on grazing management practices that increased grass growth and utilization which resulted in an increase in milk production from the site (Table 2).

Table 2. The effect of farm system characteristics on the biological efficiency of grass-based milk production at Curtins Farm (Teagasc, Ireland)

Year	2003	2005	2007	2009	2011
Stocking rate (cows/ha)	2.44	2.63	2.67	2.88	2.88
Grazing season (days)	293	295	306	287	285
Chemical N inputs (kg/ha)	289	331	313	248	249
Concentrate (kg/cow)	716	636	590	288	430
Milk volume ('000 L/ha)	15.6	15.5	14.6	14.4	15.3
Nitrate (NO_3-N mg/l)	11.1	13.3	12.4	9.7	6.6

Best nutrient management practices were used on the farm to increase slurry-use efficiency and reduce fertilizer N application to the levels stipulated by legislation. Based upon detailed field-scale knowledge of soil capacity for nutrient retention, improved timing and rate of organic fertilizer application, reduced reliance on chemical fertilizer and the adoption of minimum-till cultivation reseeding, the result of this strategy was a consistent improvement in N-use efficiency and a decline in nitrate concentrations in groundwater at the site during the study period (Table 2).

In future, the sustainable intensification of animal production from pasture necessitates that management practices on the farm must be increasingly tailored to achieve excellent nutrient management outcomes in addition to productivity improvement. The results of this study indicated that intensive dairy production systems based on improved nutrient management and agronomic practices can quickly improve groundwater quality and lead to high water quality standards even on highly vulnerable free draining soils.

Combining high animal productivity with high feed self-sufficiency in grassland-based organic sheep production systems

The aim of organic farming is to establish and maintain soil-plant-animal interdependence and to create a sustainable agro-ecosystem based on local resources. Feed self-sufficiency and particularly forage self-sufficiency is therefore one of the fundamentals of organic farming.

To ensure sustainability in organic sheep production, the aim of one of the experiments conducted in the INRA Redon experimental site with a rustic breed (Limousine) and semi-natural grasslands with a stocking rate of 0.8 livestock unit/ha, was to optimize both ewe

productivity and self-sufficiency. This optimization was managed by i) fitting the lambing distribution to the seasonal dynamics of the vegetation resources, with 65% of the lambings in spring and 35% in autumn and adapting stocking rate to resource potential, ii) fattening lambs at pasture together with controlling parasitism level, iii) ensuring the provision of young forage of high quality for animals with high requirements (with increased use of legumes in swards), iv) practicing winter grazing for animals with low requirements, and v) sowing mixtures of cereals (triticale, barley and oats) and peas to increase feed self-sufficiency, with the aim of producing 40% to 50% of concentrate feed requirements (Prache *et al.*, 2011). In this way, feed self-sufficiency reached 95% in the last 3 years of the experiment. Moreover, combining a low reliance on bought-in concentrate feed with no mineral fertilization led to a very low use of non-renewable energy (51.0 MJ/kg lamb carcass, estimated using a Life Cycle Assessment approach; Pottier *et al.*, 2009) and low net greenhouse gases emissions (11.1 kg eq-CO_2/kg carcass; Prache *et al.*, 2011).

Conclusion

Sustainable intensification of grass-based ruminant production must ensure that the increased global demand for food is met in an economically and environmentally sustainable manner, producing a product which is acceptable to increasingly discernible consumers from a quality, social and ethical perspective. In this paper we have given examples showing that sustainable intensification of grass-based ruminant production allows both economic and environmental performance improvement at the farm level. At a broader level, other environmental issues such as carbon storage, biodiversity and landscape, and cultural issues must also be considered.

The key point which must be addressed is improving the efficiency of the animal-grass dynamic with fewer inputs and in a long-term sustainable manner. Further research should address the trade-off between quantity and quality in grass production, the resilience of the resource and its persistency over time. More systemic research on the animal-grass dynamic is needed to select and manage animals for grass and grass for animals. Future research should also address animal self-sufficiency, animals which are easy to manage and which are resistant to climate variation and parasites. In terms of management, sustainable intensification means changing from a position where the emphasis is on controlling all the management parameters to a position focused on compromising with risks and searching for equilibrium. Finally we should not forget that the production system is managed by the farmer. Helping farmers with management decisions through appropriate tools that combine grass, animal and system issues is a challenge for the greater development of grass-based systems.

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