Effects of livestock breed and grazing intensity on biodiversity and production in grazing systems. 1. Nutritive value of herbage and livestock performance

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Summary

Reduction of grazing intensity and the use of traditional instead of commercial breeds has frequently been recommended to meet biodiversity and production goals in sustainable grazing systems in Europe. To test the impact of such practices across a range of contrasting grassland types, integrated measurements of foraging behaviour, agronomic production and botanical, structural and invertebrate biodiversity were made over three years on four sites in the UK, Germany, France and Italy. The sites in the UK and Germany were mesotrophic grassland with high productivity and low to moderate initial levels of plant diversity, and were grazed by cattle. The French site was a semi-natural, species-rich grassland grazed by cattle. The Italian site contained a wider range in plant diversity, from species-rich to mesotrophic grassland, and was grazed by sheep. The treatments were: MC, moderate grazing intensity with a commercial breed – this was designed to utilize herbage growth for optimum livestock production; LC, lenient grazing intensity with a commercial breed – this was designed to increase biodiversity by not fully utilizing herbage growth; and LT, lenient grazing intensity with a traditional breed – this was also designed to increase biodiversity. Neither fertilizers nor pesticides were applied. The nutritive value of the herbage and the performance of the livestock were measured. Mean stocking rates were proportionately 0·30–0·40 lower and mean sward heights and herbage mass on offer were 0·30–0·50 higher on the LC and LT treatments compared with the MC treatment. The proportion of live and dead material, and leaves and stems in the herbage, its chemical composition and nutritive value were little affected by the treatments. Individual livestock performance, measured as liveweight gain, showed no consistent response to treatment. In Germany, performance on the MC treatment was slightly lower than on the LC and LT treatments but no such difference was found on the sites in the other countries. Livestock breed did not have a strong effect on livestock performance. In the UK and France the traditional breeds had a lower performance but this was not the case in Germany or Italy. Livestock performance per ha of the LC and LT treatments was up to 0·40 lower than of the MC treatment. It is concluded that biodiversity-targeted extensive grazing systems have potential to be integrated into intensive livestock production systems because the individual livestock performance reaches a similar level compared to a moderate grazing intensity. Traditional breeds did not have a production advantage over commercial breeds on extensively managed pastures.

Keywords: grassland biodiversity, extensive grazing systems, herbage feeding value, livestock performance

Introduction

Grasslands in Europe make an important contribution to the total biodiversity of rural landscapes (Nösberger and Rodriguez, 1996). A considerable proportion of plant and animal species occur in grasslands and some are rarely found in other vegetation types. There is an increasing social awareness of the multifunctional character of grassland farming (Jeangros and Thomet, 2004; Lehmann and Hediger, 2004), as grassland provides multiple benefits to farmers and society and

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among these benefits biodiversity is of particular importance. During the last century, most of the semi-natural grassland in Europe was 'improved' and the management intensified. As a result, grasslands with a high species and community diversity were replaced by productive pastures with a low plant and animal diversity (Fuller, 1987; Green, 1990; Poschlod and Schumacher, 1998). In recent years, grassland management has seen a change due to changes in livestock production and in the Common Agricultural Policy of the European Union (CAP). In many countries, dairy cow performance has been increased by introducing highly digestible forages from arable land (e.g. maize) and concentrates into the rations, mainly at the expense of herbage from grassland. With a fixed milk quota, the proportion of milk being produced from grass herbage and forage is decreasing and less grassland is used for dairy production. If advances in technology continue to progress at current rates, the grassland area needed for dairy farming will further decrease in the future, unless the demand for dairy and beef products from the dairy herd increases significantly (Feehan *et al.*, 2005). Therefore, agriculturally improved grassland is increasingly available for other livestock such as beef or sheep. Such grassland is likely to be managed less intensively. Low-productivity grassland which is of particular interest in relation to biodiversity is increasingly at risk of being abandoned from agricultural use. As a main purpose of the CAP is to support the multiple functions of grassland, agri-environment schemes have been established to support these non-market functions of grassland farming. It is estimated that at least 0·20 of the agricultural area in the EU is managed under agri-environment schemes. It is expected that the importance of agri-environment schemes for the continuation of farming on de-intensified and unimproved species-rich grasslands will increase in the future (Rounsevell *et al.*, 2005) and will, therefore, be essential to maintain and enhance biodiversity. Given this situation, there is a need to develop grassland farming systems that meet both agronomic and biodiversity targets and that are based on the idea that relatively large grassland areas are to be managed with relatively little livestock (Rook *et al.*, 2004b). Current knowledge suggests that compatibility between biodiversity and production is most likely to be achieved using low-input systems employing grazing rather than cutting and forage conservation (Dorrough *et al.*, 2004; Isselstein *et al.*, 2005).

Low-input grazing systems have been shown to be generally effective in the maintenance of biodiversity of semi-natural grasslands (Bakker, 1994; Spatz, 1994; Stammel *et al.*, 2003). Evidence also shows the potential of grazing for restoring biodiversity on semi-natural unimproved grassland that had been abandoned from agricultural use for some years, and therefore had lost species (Pykala, 2003; Lindborg and Eriksson, 2004; Hellström *et al.*, 2005). Grazing is also considered to have potential for the restoration of biodiversity on agriculturally improved species-poor grasslands. However, the effects of changes following the onset of extensive grazing management are not well understood. The livestock species is likely to have an effect (Demment and Greenwood, 1988). In addition, livestock of different breeds may have different dietary choices and thus behave differently when grazing. This could have an effect on the structure of pastures and the related biodiversity (Rook and Tallowin, 2003). It has been hypothesized that traditional breeds might be better adapted to utilize grass pastures under extensive grazing (Rook *et al.*, 2004b). To investigate these aspects of extensive grazing, a Europe-wide, multi-site experiment on mesotrophic and semi-natural grasslands was set up to study the effect of a moderate grazing intensity with commercial breeds when compared with a lenient grazing intensity with either commercial or traditional breeds on biodiversity outcomes and on agricultural production (Rook *et al.*, 2004b). This paper reports the results of the agricultural performance of the different treatments. The hypotheses tested were as follows: (1) biodiversity-targeted grazing systems with a reduced stocking rate will lead to lower pasture productivity and nutritive value of herbage as well as animal performance; (2) traditional breeds of grazing livestock will better maintain the production level in biodiversity-targeted grazing systems; and (3) these effects will occur irrespective of country, livestock species and production system. Results from other aspects of the experiment are reported by Dumont *et al.* (2007), Scimone *et al.* (2007) and Wallis De Vries *et al.* (2007).

Materials and methods

Experimental sites and design

A 3-year grazing experiment was set up in spring 2002 on four sites in four European countries (Table 1). All sites were permanent pastures. The French (F) site was a semi-natural grassland with no known history of agricultural improvement. The pastures on the other sites had experienced a temporarily more intensive agricultural use in the last century with moderate fertilizer applications and stocking rates. From the start of the experiment no fertilizers or pesticides were applied. The pastures did not receive any cutting treatment or topping during the course of the experiment. The long-term mean climatic conditions during the growing period (April to October) and the corresponding values for each year of the experiment are shown in Table 1. In the first year, rainfall was higher

Table 1 Experimental sites, climatic conditions and experimental treatments.

	Country			
	United Kingdom (UK)	**Germany (D)**	**France (F)**	**Italy (I)**
Location	North Devon	Solling	Massif Central	Provincia di Pordenone
Geographical coordinates	50°N 4°W	52°N9°E	45°N3°E	46°N13°E
Altitude a.s.l. (m)	100	250	1100	400
Mean daily temperature (April to October) (°C)				
Long-term average	12·4	13·5	10·8	18·7
2002	12·2	13·1	11·1	18·3
2003	13·0	13·7	13·1	19·5
2004	12·8	12·8	11·5	18·2
Rainfall (summer April to October) (mm)				
Long-term average	497	488	699	971
2002	538	656	710	1340
2003	340	360	644	601
2004	582	437	739	992
Grassland type	Mesotrophic, species-poor	Mesotrophic, moderately species-rich	Semi-natural, species-rich	Semi-natural, moderately species-rich
Grazing system	Variable continuous stocking	Variable continuous stocking	Set stocking	Rotational grazing, 10-days grazing period, 20-days rest period
Grazing treatments				
MC, moderate grazing intensity with commercial breeds	Target herbage mass of 3000 kg DM ha^{-1}, breed Charolais × Friesian steers	Target compressed pasture height of 6 cm, breed Simmental steers	Moderate constant stocking rate (average value 1·4 LU ha^{-1}), breed Charolais heifers	Moderate constant stocking rate (average value 1·0 LU ha^{-1}), breed Finnish ewes
LC, lenient grazing intensity with commercial breeds	Target HM 4500 kg ha^{-1}, Charolais × Friesian steers	Target CSH 12 cm, Simmental steers	Reduced constant stocking rate (0·70 of MC), Charolais heifers	Reduced constant stocking r ate (0·60 of MC), Finnish ewes
LT, lenient grazing intensity with traditional breeds	Target HM 4500 kg ha^{-1}, Red Devon steers	Target CSH 12 cm, German Angus steers	Reduced constant stocking rate (0·70 of MC), Salers heifers	Reduced constant stocking rate (0·60 of MC), Karst ewes
Paddock size (ha)	1·5	1·0	3·6	0·4

Table 2 Mean live weights of the grazing livestock at the start of the grazing season and average stocking rates of livestock units (LU) over the season for treatments MC, LC and LT (see Table 1 for description of treatments).

	Treatments				Level of significance	
Country	MC	LC	LT	s.e.m.	Treatment	Treatment × country
Mean live weight of livestock at start of grazing (kg)						
UK	311	301	296	6·4	NS	*
D	288	296	322	11·1		
F	406	402	403	2·8		
I	48·2	49·3	51·1	1·6		
Average stocking rate (LU ha^{-1})						
UK	2·08^{a†}	1·40^{b}	1·27^{b}	0·17	***	NS
D	2·43^{a}	1·36^{b}	1·52^{b}	0·25		
F	1·44^{a}	1·02^{b}	1·02^{b}	0·03		
I	1·07^{a}	0·63^{b}	0·67^{b}	0·08		

The study was conducted on sites in the UK and Germany (D) with steers, in France (F) with heifers and in Italy (I) with ewes. Values are means over 3 years with standard errors of mean (s.e.m.).

†Data within the same line followed by a different letter are significantly different at $P < 0·05$, using Bonferroni test.

NS, not significant; *$P < 0·05$; ***$P < 0·001$.

than average whereas the second year was exceptionally dry during the summer months.

The same experimental design was applied on all sites. There were three treatments which were replicated three times. Treatment MC used a moderate grazing intensity with a commercial breed and was designed to utilize herbage growth for optimum livestock production. Treatment LC used a lenient grazing intensity with the same commercial breed but the herbage growth was not fully utilized to increase biodiversity. Treatment LT used the same lenient grazing intensity as LC but with a traditional breed. Actual grazing intensities used in the different countries were based on long-term experience at the particular sites. Grazing systems and breeds differed between countries to reflect local conditions. The paddock size was the same between treatments within countries and varied from 0·4 to 3·6 ha between countries (Table 1). The sites were grazed either by growing cattle, steers in the United Kingdom (UK) and Germany (D); heifers in F; or by sheep, ewes, either pregnant or after weaning in Italy (I). In UK and D continuously variable stocking was used with livestock numbers adapted to herbage availability. In F continuous stocking with fixed stocking rates was used. In I rotational grazing was used with a fixed number of sheep and with a grazing cycle of 30 days (Table 1). Although grazing conditions varied between countries, the relationship of the grazing intensity between MC on the one hand and LC and LT on the other was similar in all countries. In the LC and LT treatment the average stocking rates were reduced proportionately by 0·30–0·40 compared with the MC treatment. The livestock received no supplementary feed at pasture and no minerals were supplied. The commercial breeds were chosen according to their importance in livestock farming practice as high-performing animals. The traditional breeds have much smaller populations largely confined to specific regions. They were assumed to be less productive than the commercial breeds but better adapted to grazing extensive grassland.

The grazing season started between April and May and ended between September and November, depending on year and country. In 2003, animals had to be removed from the experimental paddocks in D, F and I for up to 2 months during the summer because of drought and cessation of grass growth. The mean live weights of the grazing livestock at the start of the grazing season are shown in Table 2. There was no significant overall treatment effect indicating that the treatments had the same initial conditions. The average stocking rate in the MC treatment varied between 1·1 and 2·4 livestock units ha^{-1}, depending on the site. In the extensive grazing treatments, the stocking rate varied between 0·7 and 1·5 livestock units ha^{-1} (1 LU = 600 kg live weight) (Table 2) with the stocking rate effect being significant in all countries.

Measurement of herbage production and nutritive value of herbage

The amount of herbage on offer was obtained employing a double-sampling method. Compressed pasture heights, measured using a rising plate meter according to Castle (1976), were taken at 7- to 10-day intervals throughout the grazing season with 50 random measurements per paddock at each time. In I, readings were made at the end of each grazing period of a grazing cycle. Every 4 weeks, four 30 cm × 30 cm quadrats per paddock were cut to ground level and the herbage mass of dry matter (DM), obtained by oven-drying at 85°C, was determined. Before cutting, the compressed pasture height in each quadrat was measured. The data were used to form local linear regression equations at each site and date relating compressed pasture height to herbage mass of DM. Values of R^2 of the equations ranged between 0·50 and 0·80 and the coefficient of variation for the standard error varied from 0·15 to 0·35. The equations were then used to calculate the herbage mass of DM on offer from the weekly compressed pasture height measurements. Therefore, the calibrations were used to interpolate between sampling dates. At the F site the double-sampling method was not applicable as compressed pasture height measurements gave poor results due to the tussocky structure of the sward. Therefore, herbage mass was determined by cutting five subplots per paddock of 0·5 m^2 size to ground level at three-weekly intervals.

Pasture composition was analysed by separating above ground herbage mass into live leaf and live stem, separately for grasses, legumes and other forbs, and into dead material. For grasses, laminae are referred to as 'leaves' and pseudostems are included in 'stems'. At three to five dates in the grazing period, herbage was cut to ground level in four quadrats (30 cm × 30 cm) per paddock and date. A sub-sample of at least 100 g DM was used for the separation into the components. The contribution of the different components was expressed as a proportion of the herbage mass of DM of the total sample or of the live material.

The nutritive value of the herbage was evaluated by two sampling techniques. The herbage on offer was assessed by taking hand-plucked samples from the grazed horizon designed to simulate grazing; these samples were intended to estimate the quality of the potentially grazable herbage. Sampling was done at monthly intervals during the grazing season. Four samples per paddock and sampling date, each of approximately 100 g fresh herbage were obtained by cutting the upper third of the vegetation. The herbage was dried at 70°C, ground to pass a mesh of 1-mm pore size and stored for analysis. Concentrations of N, P, K, Na and Mg, neutral-detergent fibre (NDF; Van Soest and Wine, 1967) and pepsin cellulase solubility of the organic matter (CDOM) as a measure of the digestibility of the herbage. Pepsin cellulose solubility of the organic matter was determined by employing the procedure of De Boever *et al.* (1988) (D, I), of Jones and Hayward (1975) (UK) and of Aufrere and Michalet-Doreau (1988) (F). As a second sampling method, to obtain an estimate of the quality of the ingested herbage, the faecal-N index technique was employed (Penning, 2004). Faeces was sampled immediately after excretion, at monthly intervals, dried at 70°C, ground and the nitrogen and ash concentrations were determined. The digestibility of the ingested herbage (digestibility of the organic matter, OMD) was estimated using a linear regression equation developed by Schmidt *et al.* (1999) with the faecal N and ash concentrations as variables. A regression equation proposed by Peyraud (1998), which is also based on the N and ash concentration of the faeces, was also used. As the different equations produced similar results in the range of digestibility found in the experiment, only results of the calculation according to Schmidt *et al.* (1999) are shown.

Livestock production

The liveweight changes of the cattle and sheep were obtained from weighing three 'core' cattle or sheep on each paddock at the start of the experiment and at monthly intervals during the grazing season. For each animal, quadratic regression equations were developed relating live weight to time. These equations were used to calculate daily liveweight change. Pasture performance per animal and per ha were determined for each day according to Baker (2004) and summed over the grazing season. Energy requirements for maintenance and growth were deduced from feeding standards (Baker, 2004). Body condition scores were measured at the start and the end of the grazing season [cattle, according to Lowman *et al.* (1973); sheep, according to Thompson and Meyer (1994)]. The change in body condition score from the start to the end of the season was calculated as a proportion of the body condition core at the start.

Statistical analyses

Data were analysed using the following model:

$$y = \mu + r(c) + t + c + a + tc + ta + ca + tca + e,$$

where y is the target variable, $r(c)$ the block (replication 1, 2, 3) nested within countries, t the grazing treatment (1, 2, 3), c the country (1, 2, 3, 4), a the year (1, 2, 3), tc, ta, ca and tca the interactions of factors and e the residual term. The factor 'year' was treated as a repeated measurement. The linear mixed model procedure was employed with the block as random factor and the treatment and country as fixed factors. The paddock was the experimental unit. Data of measurements within paddocks were averaged before the statistical analysis. The emphasis of the analysis was laid on the

Table 3 Means of compressed pasture heights and herbage mass on offer over years and dates within years for treatments MC, LC and LT (see Table 1 for description of treatments) with standard errors of mean (s.e.m.).

	Treatments				Level of significance	
Country	**MC**	**LC**	**LT**	**s.e.m.**	**Treatment**	**Treatment × country**
Mean compressed pasture height (cm)						
UK	7·0^{b†}	9·8^{a}	9·6^{a}	0·18	***	***
D	7·6^{b}	11·0^{a}	11·0^{a}	0·38		
F	not determined					
I‡	3·8^{b}	4·6^{ab}	4·9^{a}	1·12		
Average herbage mass of dry matter (kg ha^{-1})						
UK	3260^{b}	4260^{a}	4190^{a}	76·0	***	**
D	2100^{b}	2910^{a}	2910^{a}	49·0		
F	1880	2390	2540	182·0		
I^{1}	1270^{b}	1620^{a}	1700^{a}	88·0		

The study was conducted on sites in the UK and Germany (D) with steers, in France (F) with heifers and in Italy (I) with ewes.

[†] Data within the same line followed by a different letter are significantly different at $P < 0.05$, using Bonferroni test.

[‡] Pasture height measurements were made at the end of a grazing period of each grazing cycle, see Table 1.

$^{**}P < 0.01$; $^{***}P < 0.001$.

treatment effect and the treatment × country interaction.

In order to test for treatment effects within country the following model was applied:

$$y = \mu + r + t + a + ta + e.$$

From this analysis standard error of mean values (s.e.m.) were obtained. If significant treatment effects were found, a Bonferroni test was followed to compare means of treatments within countries. Data analysis was performed with the SPSS statistical package (SPSS for Windows 11·5.1, 2002; SPSS Inc., Chicago, IL, USA).

Results

Herbage production and nutritive value of herbage

Compressed pasture heights and herbage mass (above ground vegetation) of DM were both significantly lower in the moderate-grazing treatment (MC) compared with the lenient-grazing treatments (LC, LT; Table 3). No differences occurred between treatments LC and LT. These effects were found in all years and in all countries, indicating a consistent treatment effect. The main effects of year and country were also significant which reflected differences in herbage growth and productivity between sites as well as between years within sites. The values for the I site were lower than on the other sites as these data were taken at the end of a grazing period within each grazing cycle.

The composition of the herbage mass of DM was determined by separating it into dead and live material and the live material into leaves and stems (Table 4). The mean proportion of dead material of the above ground biomass was significantly different between the countries ($P < 0.001$) and between the years ($P < 0.001$). However, there were no significant treatment, or treatment × country, interaction effects. The contribution of the functional groups, grasses, legumes and other forbs, differed significantly between sites but there was no significant overall treatment effect for these functional groups. On the UK site, grasses strongly predominant in the pasture, whereas on the F and I sites grassland forbs played a considerable role and grasses were less predominant. The proportion of live grass leaves in the total live biomass was similar in all countries. There were significant treatment and treatment × country interaction effects. The contribution of leaves was higher in treatment MC compared with treatments LC and LT with the treatment effect being significant in D. Grass stems were a higher proportion in the UK compared with the other countries which is in part due to the higher overall contribution of grasses on this site. The contribution of grass was significantly higher in the LC and LT treatments, particularly in the UK.

Main characteristics of the nutritive value of the herbage are shown in Table 5. Data refer to hand-plucked samples which were taken to simulate grazing. The overall treatment effect on the nutritive value was small; there was a higher concentration of CP in the MC treatment compared with LC and LT treatments but no

Table 4 Means over years and dates within years of the proportion of dead material in the herbage mass of dry matter (DM) of the pasture, of live grass leaves and stems, and of live legumes and forbs in the total live herbage mass of DM, with standard errors of mean (s.e.m) for treatments MC, LC and LT (see Table 1 for description of treatments).

	Treatment				Level of significance	
Country	**MC**	**LC**	**LT**	**s.e.m.**	**Treatment**	**Treatment × country**
Dead material as proportion of total herbage mass of						
UK	0·391	0·398	0·409	0·019	NS	NS
D	0·290	0·295	0·280	0·019		
F	0·315^{b†}	0·345^{ab}	0·363^{a}	0·019		
I	0·202	0·209	0·228	0·019		
Live grass leaves as proportion of total live herbage mass						
UK	0·494^{a}	0·452^{b}	0·458^{ab}	0·017	**	***
D	0·667^{a}	0·579^{b}	0·563^{b}	0·021		
F	0·504	0·523	0·539	0·021		
I	0·573	0·520	0·572	0·030		
Live grass stems as proportion of total live sward biomass						
UK	0·386^{b}	0·494^{a}	0·467^{a}	0·019	***	***
D	0·163	0·184	0·193	0·017		
F	0·098	0·089	0·098	0·012		
I	0·135	0·170	0·132	0·019		
Live legumes as proportion of total live sward biomass						
UK	0·062^{a}	0·030^{b}	0·034^{b}	0·009	NS	***
D	0·064^{b}	0·117^{a}	0·124^{a}	0·011		
F	0·082^{a}	0·049^{b}	0·046^{b}	0·009		
I	0·011	0·016	0·015	0·012		
Live forbs as proportion of total live sward biomass						
UK	0·059^{a}	0·024^{b}	0·041^{ab}	0·008	NS	NS
D	0·105	0·120	0·120	0·014		
F	0·317	0·340	0·318	0·022		
I	0·282	0·295	0·282	0·029		

The study was conducted on sites in the UK and Germany (D) with steers, in France (F) with heifers and in Italy (I) with ewes.

[†] Data within the same line followed by a different letter are significantly different at $P < 0{\cdot}05$, using Bonferroni test.

NS, not significant; $^{**}P < 0{\cdot}01$; $^{***}P < 0{\cdot}001$.

effect on NDF concentration or CDOM values. Hand-plucked herbage from the MC swards appeared to be at a younger developmental stage as reflected in the higher CP and mineral concentrations, mainly at the UK, D and F sites. No significant treatment and treatment × country interactions occurred for the Mg and Na concentration of the herbage. Despite the generally small treatment effects, there were strong main effects of country and year for all variables ($P < 0{\cdot}001$) with the exception of Mg where the effect of year was not significant.

The OMD value of the ingested herbage was assessed by employing the faecal-N index technique. As with the nutritive value of the hand-plucked samples, there was a strong and significant country effect ($P < 0{\cdot}001$), whereas the year had no significant effect. The treatment effect was small, albeit significant, with a higher OMD on the MC treatment compared with the LC and LT treatments. The variation in OMD values was generally lower than the CDOM values of the hand-plucked samples. No significant relationship was found between the CDOM and the DOM values.

Livestock production

Livestock production and pasture performance were assessed on a per-head and a per-area basis. The average daily liveweight gains (LWG) per head were significantly affected by the grazing treatment but this effect was not consistent across countries (Table 6). On the D site, LWG on the MC treatment was significantly lower than on the LC treatment, whereas no such effect occurred on the sites in the other countries. There was a tendency for lower LWG for the traditional breeds compared with the commercial breeds in the UK and in F. The pasture performance per livestock unit and day

Table 5 Crude protein (CP), neutral-detergent fibre (NDF) and phosphorus (P) concentrations, and cellulose digestibility of organic matter (CDOM) of herbage; means over years and dates within years, with standard errors of mean (s.e.m.) for treatments MC, LC and LT (see Table 1 for description of treatments).

	Treatments				Level of significance	
Country	**MC**	**LC**	**LT**	**s.e.m.**	**Treatment**	**Treatment × country**
CP concentration (g kg^{-1} DM)						
UK	156	152	150	3·9	***	**
D	$156^{a\dagger}$	138^{b}	136^{b}	4·3		
F	160	150	151	4·0		
I	121	124	122	3·8		
NDF concentration (g kg^{-1} DM)						
UK	594	604	596	14·3	NS	NS
D	494	519	515	6·8		
F	540	543	547	5·5		
I	609	594	607	19·0		
CDOM						
UK	0·579	0·577	0·581	0·0100	NS	NS
D	0·747	0·713	0·715	0·0125		
F	0·603	0·588	0·577	0·0108		
I	0·584	0·586	0·600	0·0087		
P concentration (g kg^{-1} DM)						
UK	2·63	2·71	2·58	0·09	*	NS
D	$4·06^{a}$	$3·80^{b}$	$3·76^{b}$	0·07		
F	1·70	1·50	1·51	0·08		
I	3·65	3·47	3·40	0·19		

The study was conducted on sites in the UK and Germany (D) with steers, in France (F) with heifers and in Italy (I) with ewes.

[†] Data within the same line followed by a different letter are significantly different at $P < 0·05$, using Bonferroni test.

NS, not significant; *$P < 0·05$; ***$P < 0·001$.

was also significantly affected by the grazing treatment with, again, differences between countries being found. On the D site, the pasture performance was lower on the MC treatment than on the LC and LT treatments. On the I site, the LC treatment performed significantly less well than the MC and LT treatments. There was no effect of country ($P = 0·573$) on the pasture performance per livestock unit, irrespective of the different site conditions or whether sheep or cattle were grazing.

The body condition score of the grazers hardly changed from the start to the end of the grazing season in the MC treatment in the UK, D and F. Compared with the MC treatment, grazers increased their body condition score during the grazing season on treatments LC and LT and this effect was significant in D. In I, the sheep increased their body condition score considerably during the grazing season. This effect was due the particularly low body condition score after the winter feeding period.

The pasture performance per ha was obtained from the number of livestock unit grazing days and the accumulated energy requirements of the grazers over the grazing season (Table 6). The treatment effect was highly significant for both these latter variables and no treatment × country interaction occurred, i.e. the treatment effect was consistent over countries. The treatment effect was due to a significant difference between the MC treatment on the one hand and the LC and LT treatments on the other hand. The LC and LT treatments were not significantly different. LU grazing days for the lenient grazing treatments were proportionately 0·25–0·55 lower than that of the moderate-grazing treatment; the pasture performance expressed in energy requirements was 0·20–0·55 lower.

Discussion

The aim of the present investigation was to assist in the development and analysis of grazing systems that have a potential to support the biodiversity and nature conservation value of grassland while maintaining a reasonable level of agricultural output. Grasslands for those systems are increasingly found throughout Europe, examples are unimproved mesotrophic grasslands or grasslands with a history of agricultural improvement which are no longer utilized by livestock with high nutritional requirements (Isselstein *et al.*, 2005). The effect of extensive grassland management and

Table 6 Mean daily liveweight gains, change in body condition score and Livestock Unit (LU) grazing days per season, daily pasture performance per head and pasture performance per area per season averaged over years, with standard errors of mean (s.e.m) with standard errors of mean (s.e.m.) for treatments MC, LC and LT (see Table 1 for description of treatments).

	Treatment				Level of significance	
Country	MC	LC	LT	s.e.m.	Treatment	Treatment × country
Daily liveweight gain (kg animal^{-1})						
UK	0·983	0·974	0·827	0·094	*	***
D	0·577^{b†}	0·870^{a}	0·874^{a}	0·040		
F	0·884	0·917	0·769	0·054		
I	0·067	0·058	0·073	0·006		
Daily pasture performance per LU (MJ ME)						
UK	119·1	129·2	119·7	5·12	**	**
D	110·2^{b}	127·1^{a}	125·3^{a}	2·94		
F	121·4	127·7	114·3	4·25		
I	120·1^{b}	111·0^{c}	133·7^{a}	2·78		
Proportional change in body condition score from start to end of grazing season						
UK	6·9	8·1	9·0	2·9	*	NS
D	−1·4^{a}	26·6^{c}	11·6^{bc}	7·0		
F	1·5	12·4	6·7	5·5		
I	53·4	56·5	71·9	12·5		
LU grazing days per grazing season (ha^{-1})						
UK	346^{a}	235^{b}	211^{b}	29·0	***	NS
D	381^{a}	209^{b}	232^{b}	42·1		
F	213^{a}	151^{b}	148^{b}	2·5		
I	217^{a}	131^{b}	134^{b}	19·3		
Pasture performance over a grazing season (GJ ME ha^{-1})						
UK	40·2^{a}	29·8^{b}	25·3^{b}	2·27	***	NS
D	42·0^{a}	26·8^{b}	29·0^{b}	2·64		
F	26·1^{a}	18·9^{b}	17·0^{b}	0·92		
I	25·7^{a}	14·5^{b}	17·4^{b}	2·64		

The study was conducted on sites in the UK and Germany (D) with steers, in France (F) with heifers and in Italy (I) with ewes.

†Data within the same line followed by a different letter are significantly different at $P < 0·05$, using Bonferroni test.

NS, not significant; *$P < 0·05$; **$P < 0·01$; ***$P < 0·001$.

extensive grazing on grass and livestock production has been investigated in some situations and some countries (Dyckmans *et al.*, 1999; Fothergill *et al.*, 2001; Hofmann *et al.*, 2001; Marriott *et al.*, 2004). However, the present study is the first in which consequences of extensive management have been investigated in different European countries using the same experimental approach. Grazing treatments were chosen to reflect principal options of either production- or biodiversity-targeted grassland management which are relevant throughout Europe. The livestock breed and the grazing management varied between countries, due to the relevance of breeds and systems in the farming practice of the particular regions. Grazing management was based on long-term experience with the particular sites. The confounding of experimental treatments with grazing management and livestock breed was considered acceptable as the basic characteristics of the experimental treatments were the same on all sites. The moderate grazing treatment was aimed at maximizing the use of herbage growth for livestock production. The extensive grazing treatment was expected to have a proportionately 0·30–0·40 lower livestock production leaving a higher proportion of herbage growth unutilized. The livestock breed was either a commercial and widely used one or a traditional and unimproved one. The analysis of results is focussed on the overall treatment effects and on treatment × country interactions. The interaction in particular should be seen in relation to the different conditions in the different countries.

Pasture conditions

The management systems chosen were generally low-input ones as pastures were not fertilized and no pasture maintenance measures were applied. At the start of the experiment, numbers of plant species in the pastures were relatively high (Scimone *et al.*, 2007) compared with intensively managed and heavily fertilized swards commonly used in farming practice. Although there was no treatment effect on number of plant species over the 3 years, there was a tendency towards a higher percentage of valuable forage species such as *Lolium perenne* and *Poa pratensis* developing at the moderate grazing intensity compared to the lenient grazing intensity (Scimone *et al.*, 2007). Other investigations have shown that, starting from sown or improved grassland, extensive grazing led to a decrease in the proportion of valuable grasses in the swards (Hofmann *et al.*, 2001; Barthram *et al.*, 2002; Marriott *et al.*, 2002). It can be concluded that the short-term effects on agronomic output after the onset of extensive grazing in this study will mainly be due to changes in species composition rather than species number. These changes are obviously related to the condition of the pasture and the defoliation frequency. The grazing treatments resulted in clearly different mean sward height and mean herbage mass of DM on offer. The stocking rate for the lenient grazing treatments (treatments LC and LT) was about 0·40 lower than for moderate grazing treatment (treatment MC) and the herbage mass of DM on offer was on average 0·30–50·0 higher. Taller growing species, such as *Dactylis glomerata*, *Festuca arundinacea* and *Holcus lanatus*, could increase their cover in the extensive grazing treatments (Scimone *et al.*, 2007).

The proportion of stems, leaves and dead material was generally little affected by the grazing treatment or the treatment × country interaction. It is well established that on improved and intensively managed grassland, the switch from an intensive-grazing to a lenient-grazing regime will result in a reduced sward density, an increased proportion of grass stems and a higher proportion of dead material (Orr *et al.*, 1990; Gibb, 1991). With regard to grass stems, a similar effect of treatment was found at the UK and the D sites but a clear response in the proportion of dead material to the grazing intensity was found on none of the sites. This is obviously due to the different management history of the grasslands. No site in the present investigation was a recently sown or a strongly agriculturally improved one, rather all of them were mesotrophic or semi-natural grassland.

Nutritive value of herbage

Extensification of grassland management is usually accompanied by a reduction in the nutritive value of the herbage. This effect is less well investigated for grazed grasslands than for cut grassland. Under extensive grazing, the herbage growth exceeds the herbage demand of the grazing livestock and herbage will accumulate and mature (Strodthoff and Isselstein, 2001; Isselstein *et al.*, 2003). This process of herbage accumulation and maturation shows a high spatial and temporal variability (Correll *et al.*, 2003) which is closely related to the grazing behaviour and the dietary choices of the livestock (Wallis de Vries and Daleboudt, 1994).

In this study, there was only a small effect of the grazing treatment on the quality of the herbage. This is obviously related to the high variability of the data. The pasture structure showed a high spatial variation on all sites with patches of short leafy grass and patches of tall reproductive herbage (Scimone *et al.*, 2007). This was markedly expressed in the LC and LT treatments but was also found in the MC treatment. Thus, the variability in the herbage sampled is likely to be higher compared with intensively managed grass swards consisting of only a few grass species. When results of different studies are compared, the manner in which the herbage is sampled has to be considered. Differences between grazing intensities are more likely to be expressed where the total above-ground herbage mass is sampled, i.e. where herbage is cut at a low height. Herbage from tall grass patches which are avoided by grazers has a much lower feeding value than herbage from short grass patches which are frequently defoliated (Strodthoff, 2002). If the upper third of the grass sward is cut to simulate grazing as was the case, in this study, differences between different patches are obviously less clear. The nutritive value of the herbage is dependent on the layer of the pasture (Clark *et al.*, 1974). The top layer has a higher nutritive value than lower layers and this horizontal gradient is likely to be stronger in patches of tall grass than of short grass. In a situation where more herbage is offered than can be utilized by grazers, the grazers will seek a diet with a higher mean digestibility than that of the above-ground herbage mass. Thus, sampling of herbage by simulating grazing with the intention to determine the feeding value will give more relevant information for the understanding of herbage intake and animal performance than sampling of the total above-ground herbage mass in particular in extensive grazing systems.

In order to estimate the OMD of the ingested herbage, the faecal-N index technique was employed (Penning, 2004). It has been recommended that the technique is at its best when local regressions are developed (Penning, 2004). However, Peyraud (1998) and Schmidt *et al.* (1999) generated equations of a more general validity, of which the equation by Schmidt *et al.* was employed in this study. When comparing the CDOM values of the hand-plucked samples with the quality of the OMD ingested herbage, it was found that, despite high variability in the offered herbage, the variation in the OMD values of the ingested herbage was rather small. This indicates that the grazers could maintain a moderate level of digestibility of the ingested herbage throughout the experiment with little effect of grazing treatment, site and year. It is obvious that this was achieved by selective grazing. As a measure of the extent to which herbage selection took place, the ratio of the digestibility of the ingested herbage and the cellulase digestibility of the offered herbage (DOM:C-DOM) was calculated. The opportunity to select gives the grazer the potential to support greater performance as is demonstrated in Figure 1 which shows that the daily liveweight gain of cattle was positively related to the DOM:CDOM ratio. From studies with simply composed grass swards, it is known that grazing cattle and sheep seek to maintain a diet of similar digestibility against a decline in the quality of offered herbage (Phillips, 2002). Dietary preferences may even be maintained at the expense of total intake (Rook *et al.*, 2002). On semi-natural grasslands with a higher initial patchiness of the pasture, selectivity of grazing is probably similar or even higher compared with species-poor swards. This is consistent with direct measurements of selectivity in this experiment (Dumont *et al.*, 2007).

In extensive grazing systems where grazing livestock are fully reliant on the offered herbage and receive no supplementation, there is potential for mineral requirements not to be met leading to nutritional disorders and health problems. In this study, the grazing treatments had no significant effect on the mineral composition of the herbage. Over the comparatively short duration of the present experiment, no need for treatment-specific supplementation of minerals arose. The time at which treatment effects might be seen will depend on the status and release of minerals from the soil. As nutrient losses in grazing systems are generally lower compared with cut systems due to the recycling of nutrients via animal excreta, depletion is likely to take a longer time (Marriott *et al.*, 2005). Apart from the nutritional requirements of livestock, the supplementation of minerals should also be seen in relation to the aim of restoration of biodiversity. In particular, the phosphorus content in soil is a key factor with regard to the potential success of restoration of grassland biodiversity (Janssens *et al.*, 1998), and phosphorus supplementation should be avoided unless there is an urgent nutritional need.

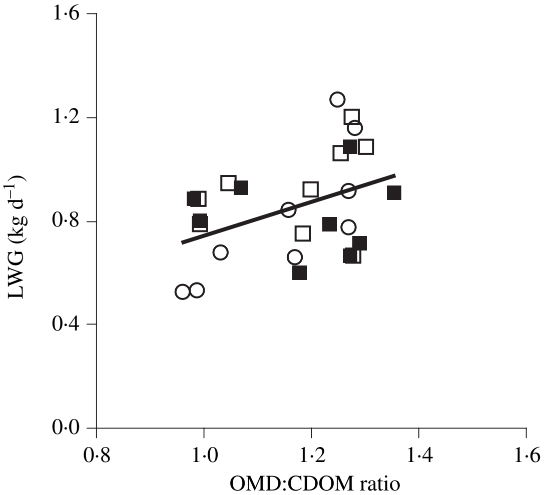

Figure 1 Relationship between the average liveweight gain (LWG; y, kg day^{-1}) of grazing cattle and organic matter digestibility (OMD): cellulose digestibility of organic matter (CDOM) ratio of herbage (x), $y = 0·649x + 0·095$, $r = 0·41$ ($P = 0·017$), s.e. = 0·18, $n = 27$. Data from Italy (sheep) not included. Treatment MC, circles; treatment LC, open quadrats; treatment LT, closed quadrats.

Pasture performance

Livestock production and pasture performance was measured on a per-head and a per-area basis. It is generally known that a grazing strategy aimed at maximizing per-area performance will compromise the individual performance of grazing livestock (Mayne *et al.*, 2000). In this study, there was only a small effect of grazing intensity and breed on the pasture performance per head. In D, the commercial breed grazing at the moderate-grazing intensity performed significantly worse than at the lenient-grazing intensity but no such effect was found on the other sites. Except in D, the grazing intensity on the MC treatment was obviously not so high that the herbage intake limited performance. In D, the average stocking rate of the MC treatment was the highest of all sites which may have reduced herbage intake per head. Experiments with growing cattle in the UK (Tallowin *et al.*, 2005) on unimproved moderately species-rich swards have shown that as target sward heights increase from 5–8 to 10–12 cm the individual liveweight gain of the grazers may decrease. The reduction in performance with lower sward heights has been shown to be caused by a reduction in the herbage intake (Wright and Russel, 1987).

Livestock breed had no clear effect on individual performance. The commercial breeds, albeit not significantly, had a slightly higher performance than the traditional breeds on the UK and the F sites. On the I site, the Karst sheep was superior to the commercial breed. It seems that this was due to the generally higher production potential of the Karst sheep on this particular grassland site as the commercial breed also performed less well at the moderate grazing treatment. This is also confirmed by the observation of a slightly greater change in body condition score from the start to the end of the grazing season for the Karst sheep compared with the Finnish sheep. Thus, the general conclusion is that there is no indication of a better adaptation of traditional breeds to extensive grazing. No difference in pasture performance per head between the Simmental and the German Angus steers was found at the D site.

In contrast to the small treatment effects on per-head performance of the grazers, there was a strong and consistent effect on the per-area performance. Irrespective of the site and the year, the lenient-grazing intensity had a significantly lower per-area performance compared to moderate-grazing intensity. There was no significant effect of breed at any site. The difference between the MC treatment, and the LC and LT treatments, was due to differences in stocking rates as well as number of grazing days which have to be seen in relation to the designed differences in the sward heights and the herbage on offer. These results are consistent with several other investigations that studied the effect of extensive management on pasture performance. When comparing the performance of sheep grazing on eutrophic de-intensified grassland either at a low or a high stocking rate, individual performance was not different whereas the per-area performance was much higher at the high stocking rate (Hofmann *et al.*, 2001). Similar results were obtained from experiments on improved upland grasslands in Scotland and Wales where fertilizer inputs and stocking rates were reduced. Grazing ewes and lambs showed similar individual LWG of lambs on plots with a low fertilizer input compared with a higher fertilizer treatment but performance was lower on a per-area basis (Fothergill *et al.*, 2001; Barthram *et al.*, 2002). An experiment with growing heifers on an unfertilized upland pasture in the Czech Republic (Pavlu *et al.*, 2005) did show that grazing at a high stocking rate to maintain a sward height of 5 cm had somewhat lower individual LWG and a markedly higher live weight gain per ha than a lower stocking rate with a target sward height of 10 cm.

Conclusions

The main expectation of the biodiversity-targeted grazing system was a reduction in pasture productivity, nutritive value of herbage and livestock production. This was generally confirmed on all sites; reductions in livestock production per area due to extensive grazing when compared with moderate grazing were at a similar level. However, the response in individual livestock performance was different as there was little or no effect of grazing treatment. The exploitation of grazing preferences by selective grazing might not only be beneficial for biodiversity targets (Rook *et al.*, 2004a) but is also a means of maintaining individual livestock performance. The breed of livestock did not show a consistent effect on the productivity of the biodiversity-orientated grazing system. Traditional breeds do not seem to have a general production advantage or disadvantage over commercial breeds in extensive grazing systems and on species-rich swards. Therefore, other considerations for the choice of an appropriate breed are more important.

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