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Effect of continuous grazing on forage quality, quantity and animal performance

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Abstract

The effects of different grazing intensities of heifers on sward parameters such as sward structure, plant species diversity, herbage growth and forage quality as well as individual live-weight gains and live-weight gains per pasture area were studied in an upland area in the northern part of the Czech Republic over 4 years (1998–2001). The sward was maintained at a target height of 5 and 10 cm under intensive (IG) and extensive (EG) grazing, respectively. The total biomass production was higher under the IG than the EG treatment. In the Czech upland conditions, double peak curves of biomass growth during the grazing season were more typical than curves with one high spring peak. Species that responded positively to both treatments were the predominately short growing *Trifolium repens*, *Taraxacum* spp., *Veronica arvensis* and *Agrostis capillaris*. Tall species like *Senecio ovatus*, *Alopecurus pratensis*, *Elytrigia repens* and *Aegopodium podagraria* were associated with unmanaged plots. Total crude protein contents and forage digestibility were higher under IG. The content of crude fibre showed a reverse effect. Seasonal live-weight output per hectare under IG was approximately 1.5 times higher than EG treatment. However, if state subsidies are included, EG can be more profitable under the current Czech conditions than IG and satisfies both farmers and nature conservation objectives.

Keywords: Grassland; Pasture; Extensification; Sward structure; Plant species diversity

1. Introduction

Cattle systems are of major importance in the uplands and mountainous areas of the Czech Republic. In the early 1990s economic transformation led to a decrease in livestock numbers; the number of cattle decreased from 3.36 million in 1990 to 1.127 million in 2003 (Czech Statistical Office, 2004). Despite some reforestation of grasslands of low productivity, the total area of permanent grasslands increased from 833,000 to 961,000 ha during this period, because part of the arable land was reseeded with grasses in less favoured areas. Expected conversion of arable land into grassland and low EU quotas for ruminants will probably support further extensification of grassland utilization (Kvapilík and Střeleček, 2003). Extensification is beneficial on account of the reduction or even avoidance of mineral fertilization as well as changes in the timing and frequency of sward defoliation. In practice, however, it could be dangerous due to the risk of temporary or permanent abandonment of marginal areas (Pavlů et al., 2005). Unmanaged meadows and pastures are estimated to account for 30% of the total area of grasslands in the Czech Republic (Hrabě and Müller, 2004). Extensive grazing seems to offer the most suitable solution to the problem of increasing grassland area and the reduction in livestock numbers. Several studies have shown that changes in management intensity could affect sward structure, plant species diversity, productivity as well as the nutritive value of the forage (Hofmann et al., 2001; Barthram et al., 2002; Gaisler et al., 2004; Marriott et al., 2005; White et al., 2004). In general, there is a negative relationship between plant

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species diversity, forage quality and biomass production, causing in many cases conflicts between farmers and nature conservation (Mitchley, 2001; White et al., 2004).

Extensive grazing promotes selective patch grazing, which results in an uneven distribution of grazing pressure, both within and between plant communities and plant species (Tainton et al., 1996; Rook et al., 2004). Patchiness created by extensive grazing is particularly important for nature conservation if it creates a patchwork in sward structure (Bakker, 1998; Adler et al., 2001). In practice it is, therefore, desirable to find a type of management acceptable for both agricultural and nature conservation targets (Watkinson and Ormerod, 2001).

Although the impact of extensification on grassland production is well documented in studies from western Europe (e.g. Treweek et al., 1997; Fothergill et al., 2001; Marriott et al., 2002; Garcia et al., 2003), data from continental parts of Europe are missing. The main purpose of this 4-year study in the Czech uplands was to investigate how intensive and extensive grazing affect a wide range of sward parameters such as growth rate of herbage, forage yields, sward structure, plant species diversity and forage quality. A further aim of the study was to detect individual live-weight gains of heifers and live-weight gains per grazed area under different grazing intensities.

2. Materials and methods

The experiment was carried out from 1998 to 2001 in an experimental pasture in the Jizerské Mountains in the northern Czech Republic, at an altitude of 420 m. The average annual precipitation in the area was 803 mm and the mean annual temperature was 7.2 °C. The geological substratum is granite underlying low deep brown soil (cambisol): pH/KCl = 5.1, C_{ox} = 3.9%, available P content = 64 mg kg^{-1}, available K content = 95 mg kg^{-1} and available Mg content = 92 mg kg^{-1}. The experimental area was drained, ploughed and reseeded with a highly productive grass/clover mixture in the 1980s and was intensively managed by cutting and grazing. In the early 1990s mulching was applied once a year only (in August) and then the grassland was abandoned. There was no agricultural management in the 5 years before the start of the experiment in 1998. The dominant species in 1998 were common bent (*Agrostis capillaris*), meadow foxtail (*Alopecurus pratensis*), red fescue (*Festuca rubra*), ground-elder (*Aegopodium podagraria*) and hedge bedstraw (*Galium album*). No fertilizers were used during the experiment.

The pasture was continuously stocked with growing heifers (1998–1999 Czech Pied, 2000–2001 Holstein) of 150–220 kg initial live-weights. The treatments were: intensive grazing (IG), extensive grazing (EG) and unmanaged control (U). The experiment was arranged in two completely randomized blocks. The paddock area for each IG and EG plot was approximately 0.35 ha, whereas the control area was 0.12 ha only. IG paddocks were grazed by two separate herds consisting of four to five heifers, while EG paddocks were grazed by two separate herds of two to three animals only. With the exception of the first week of the grazing season, no supplementary feed was supplied. The stocking density in the different treatments was adapted to the target sward height of 5 cm (IG) or 10 cm (EG) and was maintained by varying the grazing area available for the treatment. To maintain the target sward height, an additional non-sampled area with the required sward height for both IG and EG treatments was added in the course of the grazing season. The grazing seasons lasted from the end of April to the end of October.

2.1. Sward sampling

Sward height was measured using the first contact method (modified point quadrat method) weekly. Measurements were derived from the first perpendicular contact of a long needle at 0.20 m intervals (Pavlů and Velich, 1997). Sward height was calculated as a mean of 100 records on 20 m linear transect across each paddock. Herbage under four exclosure cages (1 m × 1 m) was harvested every 3–5 weeks in each paddock. Stable height was 5 and 10 cm in IG and EG treatment, respectively. The exclosure cages were relocated after sampling. The sward height under the exclosure cages was adjusted to the target sward height for different treatments after moving. The 3-week period for sampling was used at the beginning of the grazing season, a 4- and 5-week period in late summer and autumn, respectively.

Relevés were made in permanent 1 m × 1 m plots using a continuous grid of nine 0.33 m × 0.33 m subplots in four replications in each paddock. The proportional cover of all vascular species was recorded. Plots were visually estimated before the start of grazing in May each year from 1998 to 2001. An initial estimation was conducted before the first experimental manipulation in order to provide baseline data for each plot. Nomenclature of plant species follows Kubát et al. (2002).

Four samples of herbage in each treatment were taken by hand plucking every week to simulate grazing and were subsequently dried for 48 h at 70 °C. After drying, the herbage samples for 2 weeks were mixed and analyzed for crude protein (CP), crude fibre (CF) and in vitro digestibility organic matter (IVDOM). CP and CF were determined by Wenden's method (AOAC, 1984). IVDOM was estimated as the percentage of digested forage if fed to a ruminant. The analysis of digestibility was estimated by Steingass and Menke (1986) method. The digestion involved incubating forage samples inoculated with rumen fluid for 24 h in Vitrogest equipment.

The live-weight of the heifers was identified by weighing at regular monthly intervals. Performance of the heifers was recorded until the end of September, when extensive grazing in the EG treatment was finished.

2.2. Data analysis

Repeated measures ANOVA was used to evaluate biomass production, species diversity, forage quality and animal performance data.

The community response was analyzed by constrained ordinations. The redundancy analysis (RDA, Lepš and Šmilauer, 2003) in the CANOCO package followed by a Monte Carlo permutation test was used to evaluate trends in plant species composition. All default parameters in CANOCO were used. A total of 999 permutations of the performed analyses were used. The data form repeated observations with the baseline (measurements performed before the introduction of grazing), thus the interaction of treatments and year are the most important variables. The mean of nine subplots was used for statistical evaluation. A biplot ordination diagram constructed by the CanoDraw program was used to visualize the results of the analyses.

3. Results

The mean sward heights were 5.8, 4.4, 5.2 and 5.3 cm under IG and 9.7, 8.8, 10.3 and 10.8 under EG in 1998, 1999, 2000 and 2001, respectively. There was greater variability in sward height in the EG treatment than in the IG treatment, both within the different monthly measurements and across the growing season. The seasonal pattern of biomass growth was similar under both treatments, but mostly higher under IG (Fig. 1a). There were significant differences between treatments except in 2001 (Table 1). Peak of biomass production was found in May and a significant seasonal development (effect of time) was recorded in all grazing seasons. There was significant interaction of time and treatments indicating a non-parallel biomass growth within a season under the IG and EG treatments in 1999 and 2000. The summer peak of biomass production was higher than in spring under IG during these years.

Forage yields were significantly higher under IG ($P < 0.01$) and the significant effect of a year ($P = 0.006$) showed their seasonal variation. Mean forage yield was 3.65 (S.E. 0.07), 3.90 (S.E. 0.26), 3.33 (S.E. 0.18) and 3.42 (S.E. 0.28) t ha^{-1} under IG, whereas values of 2.61 (S.E. 0.09), 3.07 (S.E. 0.18), 2.20 (S.E. 0.10) and 3.35 (S.E. 0.29) were found under EG in 1998, 1999, 2000 and 2001, respectively.

There was a significant effect of treatments on plant species composition (see Table 2, analysis A1 for details). *Campanula rotundifolia*, *A. capillaris, Cerastium holosteoides*, *Veronica serpyllifolia* and *Ranunculus repens* were species which thrived under IG (see Fig. 2). *Poa pratensis* and *Plantago lanceolata* were species associated with EG. *Taraxacum* spp., *Trifolium repens* and *Cirsium palustre* were supported by both management treatments. *Elytrigia repens*, *Senecio ovatus*, *Cirsium arvense*, *G. album* and *A. podagraria* were most common in the unmanaged control.

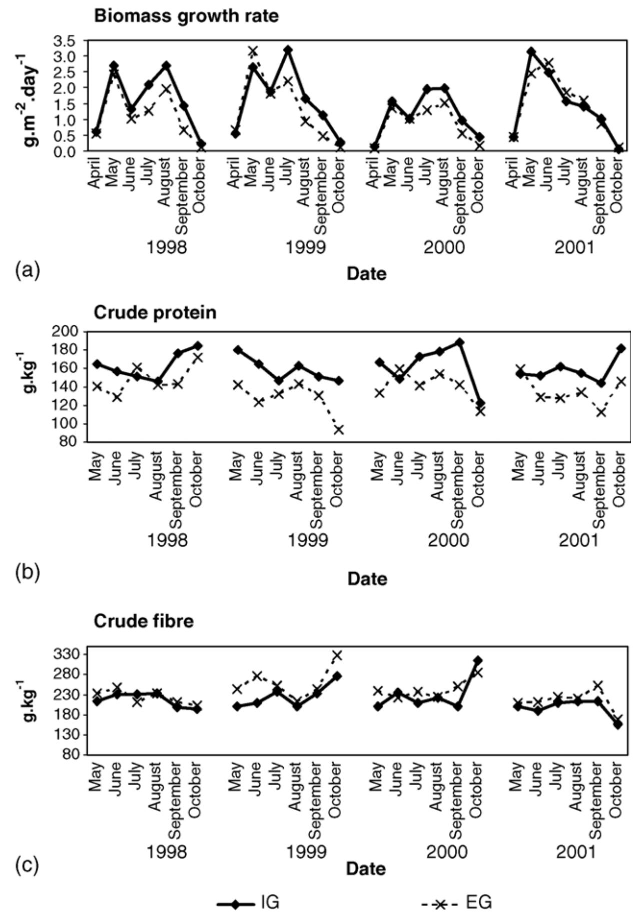

Fig. 1. Seasonal patterns of: (a) biomass growth rate (g of dry matter m^{-2} day^{-1}), (b) crude protein (g kg^{-1} of dry matter) and (c) crude fibre (g kg^{-1} of dry matter) under intensive (IG) and extensive grazing (EG) for the seasons 1998–2001.

There was also a remarkable successional development independent of the experimental treatments (see Table 2, analysis A2 for details). *T. repens*, *Taraxacum* spp., *Veronica arvensis*, *C. holosteoides* and *A. capillaris* increased their

Table 1
Results of repeated measurements—ANOVA analyses of biomass production within grazing seasons

Year	Effect	Degrees of freedom	*F*-ratio	*P*-value
1998	Treatment	1	44.93	>0.001
	Time	7	41.52	>0.001
	Treatment × time	7	1.08	0.38
1999	Treatment	1	6.86	0.02
	Time	7	35.35	>0.001
	Treatment × time	7	4.01	0.001
2000	Treatment	1	28.60	>0.001
	Time	8	17.88	>0.001
	Treatment × time	8	1.97	0.05
2001	Treatment	1	0.03	0.87
	Time	5	42.00	>0.001
	Treatment × time	5	1.96	0.095

Table 2
Results of RDA analyses of plant species composition data

Tested hypothesis	Explanatory variables	Covariables	%Explained variability	*F*-ratio	*P*-value
A1: Is there a difference in development between treatments? Yes	Year × IG, year × EG, year × U	Year, PlotID	18.1 (20.1)	15.3 (8.7)	0.001
A2: Is there a successional trend in species composition? Yes	Year	Year × IG, year × EG, year × U, PlotID	15.8	21.8	0.001

IG, intensive grazing; EG, extensive grazing; U, unmanaged; PlotID, plot identificator; %explained variability = species variability explained by axis 1 (all ordination axes) – measure of explanatory power of the explanatory variables; *F*-ratio, *F*-statistics for the test of particular analysis (all axes); *P*-value, corresponding probability value obtained by the Monte Carlo permutation test (999 permutations), i.e. type I error probability in testing the hypothesis that the effect of one (all) explanatory variables is zero.

cover during the study period, whereas *S. ovatus, A. pratensis*, *E. repens*, *A. podagraria*, *Phleum pratense* and *Poa annua* showed an opposite trend. This result indicates a replacing of tall dominants by short grasses and prostrate forbs. The total plant species diversity increased under both grazed treatments in comparison with unmanaged plots (Fig. 3).

3.1. Forage quality and animal performance

Grazing intensity significantly affected forage quality (Table 3). Average CP contents were higher in the IG treatment than in the EG treatment with the exception of July 1998, June 2000 and May 2001 only (Fig. 1b). Average crude fibre contents exhibited a reverse trend (Fig. 1c). Exceptions were July 1998 and June 2000 only. As a consequence the digestibility of organic matter was mostly higher in the IG than in the EG treatment. The effect of year

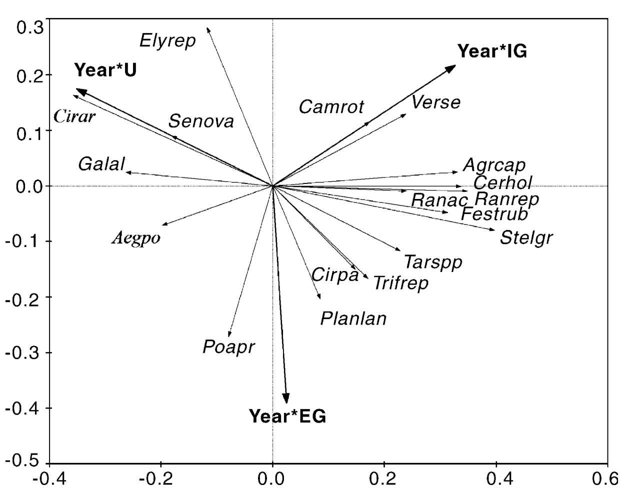

Fig. 2. Ordination diagram showing the results of RDA analysis of plant species composition data. *Abbreviations*: *Interaction of environmental variables, Aegpo—*Aegopodium podagraria*, Agrcap—*Agrostis capillaris*, Camrot—*Campanula rotundifolia*, Cerhol—*Cerastium holosteoides*, Cirar—*Cirsium arvense*, Cirpa—*Cirsium palustre*, Elyrep—*Elytrigia repens*, Festrub—*Festuca rubra*, Galal—*Galium album*, Planlan—*Plantago lanceolata*, Poapr—*Poa pratensis*, Ranac—*Ranunculus acris*, Ranrep—*Ranunculus repens*, Senova—*Senecio ovatus*, Stegr—*Stellaria graminea*, Tarspp—*Taraxacum* spp., Trifrep—*Trifolium repens*, Verse—*Veronica serpyllifolia*.

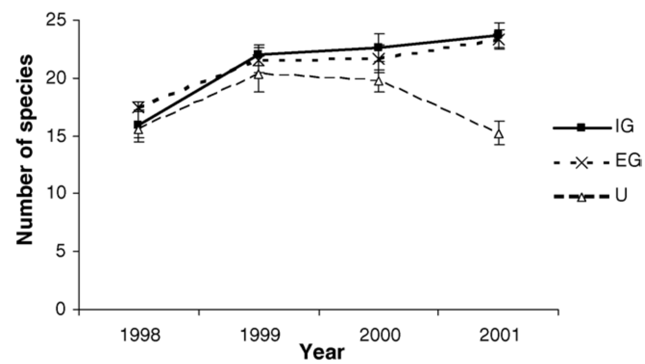

Fig. 3. Number of plant species per 1 m^2 as a function of management. IG—intensive grazing, EG—extensive grazing, U—unmanaged control. Standard errors are indicated by the vertical lines.

was significant for all investigated quality parameters, indicating high year-to-year variability of quality parameters over the investigated grazing seasons. The significant effect of month showed seasonal changes in quality parameters with exception of CP only. There was also a significant interaction between treatment and month and between year and month. The first interaction indicated a non-parallel

Table 3
Results of repeated measurements—ANOVA analyses of nutrient contents in pasture forage, IVDOM, in vitro digestibility of organic matter

Variable	Effect	Degrees of freedom	*F*-ratio	*P*-value
Crude protein	Treatment	4	30.04	<0.001
	Year	3	6.38	<0.002
	Month	5	2.13	<0.065
	Treatment × month	20	3.05	<0.001
	Year × month	15	9.24	<0.001
Crude fibre	Treatment	4	32.11	<0.001
	Year	3	82.77	<0.001
	Month	5	6.37	<0.001
	Treatment × month	20	2.47	<0.001
	Year × month	15	20.34	<0.001
IVDOM	Treatment	4	57.86	<0.001
	Year	3	34.73	<0.001
	Month	5	9.20	<0.001
	Treatment × month	20	3.28	<0.001
	Year × month	15	28.86	<0.001

development of parameters under the investigated treatments within the grazing seasons. The second interaction showed that the seasonal development of parameters differed between years.

A significant effect of grazing intensity ($P = 0.013$) on daily live-weight gains per head was revealed. Average daily live-weight gains per head were 754, 916, 842 and 794 g under IG and 979, 1080, 836 and 764 g under EG treatment in 1998, 1999, 2000 and 2001, respectively. The average seasonal live-weight output per hectare reached values of 412, 338, 351 and 351 kg ha^{-1} in the IG treatment, whereas values of 330, 194, 211 and 243 kg ha^{-1} were found in the EG treatment in 1998, 1999, 2000 and 2001, respectively. A significant effect of treatment ($P = 0.027$) and year ($P = 0.015$) but non-significant interaction between treatment and year for live-weight output per hectare was revealed.

The mean stocking rates over the grazing season were 967, 1141, 962 and 1024 kg ha^{-1} under IG and 697, 576, 610 and 532 under EG in 1998, 1999, 2000 and 2001, respectively.

4. Discussion

Actual sward heights were influenced by either avoided or infrequently grazed sward components particularly on extensively grazed plots, where a higher variability of the actual sward height was found due to selective grazing. In spite of sward height variability in the EG plots a double normal distribution of sward heights was not found as was recorded for lightly grazed pastures by Gibb and Ridout (1986, 1988).

The shape of curves for aboveground biomass production was similar under both treatments with a summer decrease probably due to unbalanced precipitation during the grazing seasons. Reduction in biomass growth rate was found in June in all years. The second peak occurred in July and/or August accompanied by higher temperature connected with higher precipitation. This second growth peak was more remarkable under IG, where it was even higher than the spring peak.

Based on the results it can be assumed that the curve with a double peak was more typical during the experiment than one peak traditionally shown by seaside (Orr et al., 1988) as well as Czech authors (Velich, 1991). Double peak curves occurred three times during the four experiment seasons in this study. Total yields of herbage were relatively low and according to Velich's (1991) classification, the experimental grassland is designated as low productivity under Czech conditions.

Tall species (*E. repens*, *A. podagraria*, *S. ovatus*, *G. album*) were dominant in the unmanaged grassland. Similarly, Kahmen and Poschlod (2004) and Pykälä (2005) observed an increase of tall species (>0.6 m) in number as well as in abundance in abandoned grassland. EG resulted in an increase in variability of sward height. A similar variability under EG was documented by Bakker (1989, 1998) in temperate grasslands. *T. repens*, *Taraxacum* spp., *F. rubra* and *R. repens* are species tolerant to heavy grazing usually dominant in short swards (Correll et al., 2003; Matějková et al., 2003; Pavlů et al., 2003). They occurred in both treatments in the experiment, predominately in the heavily grazed sward. In terms of abundance, grazing at the small scale seems to be more important than the intensity of grazing management at the scale of the whole paddock. The successive increase in time (see Fig. 3) of *A. capillaris* and prostrate herbs (*T. repens*, *Taraxacum* spp.) in grazed plots was in accordance with the findings of Belsky (1992) and Mitchley (1988) that the replacement of tall grasses by mid or short grasses occurs under frequent defoliation. An increase of plant species diversity at a scale of 1 m^2 occurred after introduction of grazers. This is in accordance with the findings in many studies performed on mesic grasslands (e.g. Krahulec et al., 2001; Bakker et al., 2003; Hellström et al., 2003).

The significant differences in the parameters of forage quality (CF, CP and IVDOM) were influenced by differences in the sward heights. Hofmann et al. (2001) as well as Audic et al. (2002) demonstrated that herbage from extensively managed swards showed considerably lower nutritional values than that from the intensively managed ones. In intensively grazed paddocks the heifers mostly grazed low, younger biomass and plants remained in the vegetative stage, whereas in the extensively grazed treatment heifers had the choice of both young and mature reproductive plants. EG resulted in the creation of a variable sward with lightly grazed taller and heavily grazed shorter tufts with different herbage quality. In the temperate European climate the decline in herbage use results in a taller and less digestible vegetation (Louault et al., 2002), in which the content of senesced/dead material seems to have a high influence on digestibility of organic matter (Søegaard, 2002). For these reasons random hand plucking of the pasture vegetation cannot reflect an actual selectively grazed sward and cannot comprise a further range of factors such as grazing selectivity of particular species, preference of leaves to stems or avoidance of areas contaminated by urine (Jones and Moseley, 1993).

The live-weight gains per head of grazed heifers revealed in this study are comparable with the data published from Czech conditions (Pavlů and Velich, 1997). There was a tendency to have higher daily live-weight gains of milk–beef breed (Czech Pied) under EG and the milk breed (Holstein) under IG, however due to the low number of animals used during the experiment it is difficult to generalize these findings. As a result of approximately two times higher stocking rate the total live output of heifers per hectare in the IG treatment was about one and a half times higher. This finding corresponds with the conclusions of Thériez et al. (1997) and Hofmann et al. (2001) that the animal production per area unit is markedly reduced under EG, but the individual animal performance is relatively similar under both extensive and intensive management. This contrasting relationship between stocking rate and individual live-weight gains has also been recorded in an experiment utilising sheep (Barthram et al., 2002). Using a common market value of heifers (€0.9 kg^{-1}, Czech Statistical Office, 2004) the value of live-weight gains would be €376 and €251 ha^{-1} in IG and EG, respectively. Including a state subsidy of €96 ha^{-1} for grassland extensification, EG has the potential to be more profitable, if a larger area is managed with the same herd size.

To avoid an increase of fallow land area, EG appears to be good landscape management tool in the grassland dominated regions in the Czech Republic. In spite of lower forage quality, EG may meet the demands of grazers though providing sufficient production per head. A balanced stocking rate and herbage production is particularly difficult due to the high variability of biomass growth during the grazing seasons. Extensive and intensive grazing resulted in an increase of small-scale plant species diversity in contrast to unmanaged plots dominated by tall species only. However, this can only be achieved with the help of economic support for extensive systems, e.g. ‘‘the extensive pasture subsidy’’ in the Czech Republic.

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References

Adler, P.B., Raff, D.A., Lauenroth, W.K., 2001. The effect of grazing on spatial heterogenity of vegetation. Oecologia 128, 465–479.

AOAC, 1984. Official Methods of Analysis, 14th ed. Association of Official Analytical Chemists, Washington, DC, US.

Audic, C., Hardy, A., Pelletier, P., 2002. Extensification of grazed pastures in French suckling cow systems. Grassland Sci. Eur. 7, 1008–1009.

Bakker, J.P., 1989. Nature Management by Grazing and Cutting. Kluwer Academic Publishers, Dordrecht.

Bakker, J.P., 1998. The impact of grazing on plant communities. In: Wallis De Vries, M.F., Bakker, J.P., Van Wieren, S.E. (Eds.), Grazing and Conservation Management. Kluwer Academic Publisher, Dordrecht, pp. 137–184.

Bakker, C., Blair, J.M., Knapp, A.K., 2003. Does resource availability, resource heterogeneity or species turnover mediate changes in plant species richness in grazed grasslands? Oecologia 137, 385–391.

Barthram, G.T., Marriott, C.A., Common, T.G., Bolton, G.R., 2002. The long-term effects on upland sheep production in the UK of a change to extensive management. Grass Forage Sci. 57, 124–136.

Belsky, A.J., 1992. Effects of grazing, competition, disturbance and fire on species composition and diversity in grassland communities. J. Veg. Sci. 3, 187–200.

Correll, O., Isselstein, J., Pavlů, V., 2003. Studying spatial and temporal dynamics of sward structure at low stocking densities: the use of an extended rising-plate-meter method. Grass Forage Sci. 58, 450–454.

Czech Statistical Office, 2004. Statistical Yearbook of the Czech Republic 2003. Prague.

Fothergill, M., Davies, D.A., Morgan, C.T., 2001. Extensification of grassland use in the uplands. 1. Sheep performance in years 1–6. Grass Forage Sci. 56, 105–117.

Gaisler, J., Hejcman, M., Pavlů, V., 2004. Effect of different mulching and cutting regimes on the vegetation of upland meadow. Plant Soil Environ. 50, 324–331.

Garcia, F., Carrère, P., Soussana, J.F., Baumont, R., 2003. The ability of sheep at different stocking rates to maintain the quality and quantity of their diet during the grazing season. J. Agric. Sci. 140, 113–124.

Gibb, M.J., Ridout, M.S., 1986. The fitting of frequency distributions to height measurements on grazed swards. Grass Forage Sci. 41, 247–249.

Gibb, M.J., Ridout, M.S., 1988. Application of double normal frequency distributions fitted to measurements of sward height. Grass Forage Sci. 43, 131–136.

Hellström, K., Huhta, A.P., Rautio, P., Tuomi, J., Oksanen, J., Laine, K., 2003. Use of sheep grazing in the restoration of semi-natural meadows in northern Finland. Appl. Veg. Sci. 6, 45–52.

Hofmann, M., Kowarsch, N., Bonn, S., Isselstein, J., 2001. Management for biodiversity and consequences for grassland productivity. Grassland Sci. Eur. 6, 113–116.

Hrabě, F., Müller, M., 2004. Aktuální problémy pastevní exploatace travních porostů. In: Sborník z mezinárodní vědecké konference—Pastvina a zvíře, MZLU, Brno, pp. 194–203.

Jones, D.I.H., Moseley, G., 1993. Laboratory methods for estimating nutritive quality. In: Davies, A., Baker, R.D., Grant, S.A., Laidlaw, A.S. (Eds.), Sward Measurement Handbook. British Grassland Society, Reading, pp. 265–284.

Kahmen, S., Poschlod, P., 2004. Plant functional traits responses to grasslands succession over 25 years. J. Veg. Sci. 15, 21–32.

Krahulec, F., Skálová, H., Herben, T., Hadincová, V., Wildová, R., Pecháčková, S., 2001. Vegetation changes following sheep grazing in abandoned mountain meadows. Appl. Veg. Sci. 4, 97–102.

Kubát, K., Hrouda, L., Chrtek, J., Kaplan, Z., Kirschner, J., Štěpánek, J. (Eds.), 2002. Klíč ke Květeně České republiky. Academia, Praha.

Kvapilík, J., Střeleček, F., 2003. Cattle and sheep quotas negotiated between the Czech Republic and the EU. Czech J. Anim. Sci. 39, 487–499.

Lepš, J., Šmilauer, P., 2003. Multivariate Analysis of Ecological Data Using CANOCO. Cambridge University Press, Cambridge.

Louault, F., Soussana, J.F., Perrodin, M., 2002. Long-term effects of a reduced herbage use in a semi-natural grassland. I. Plant functional traits and plant response groups. Grassland Sci. Eur. 7, 338–339.

Marriott, C.A., Bolton, G.R., Barthram, G.T., Fisher, J.M., Hood, K., 2002. Early changes in species composition of upland sown grassland under extensive grazing management. Appl. Veg. Sci. 5, 87–98.

Marriott, C.A., Bolton, G.R., Fisher, J.M., Hood, K., 2005. Short-term changes in soil nutrients and vegetation biomass and nutrient content following the introduction of extensive management in upland sown swards in Scotland, UK. Agric. Ecosys. Environ. 106, 331–344.

Matějková, I., van Diggelen, R., Prach, K., 2003. An attempt to restore a Czech species-rich mountain grassland through grazing. Appl. Veg. Sci. 6, 161–168.

Mitchley, J., 1988. Control of relative abundance of perennials in chalk grassland in southern England. II. Vertical canopy structure. J. Ecol. 76, 341–350.

Mitchley, J., 2001. Species diversity in grassland. In: Shiyomi, M., Koizumi, H. (Eds.), Structure and Function in Agroecosystem Design and Management. CRC Press, Boca Raton, pp. 45–59.

Orr, R.J., Parsons, A.J., Treacher, T.J., Penning, P.D., 1988. Seasonal patterns of grass production under cutting and continuous stocking mamagement. Grass Forage Sci. 43, 199–207.

Pavlů, V., Hejcman, M., Pavlů, L., Gaisler, J., 2003. Effect of rotational and continuous grazing on vegetation of an upland grassland in the Jizerske hory Mts., Czech Republic. Folia Geobot. 38, 21–34.

Pavlů, V., Hejcman, M., Pavlů, L., Gaisler, J., Nežerková, P., Guerovich Andaluz, M., 2005. Vegetation changes after cessation of grazing management in the Jizerské Mountains (Czech Republic). Ann. Bot. Fenn. 42, 343–349.

Pavlů, V., Velich, J., 1997. Sward structure under continuous and rotation grazing. In: Proceedings of the 18th International Grassland Congress, vol. II, Canada, pp. 113–114.

Pykälä, J., 2005. Plant species responses to cattle grazing in mesic seminatural grassland. Agric. Ecosys. Environ. 108, 109–117.

Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., Wallis De Vries, M.F., Parente, G., Mills, J., 2004. Matching type of livestock to desired biodiversity outcomes in pastures—a review. Biol. Conserv. 119, 137–150.

Søegaard, K., 2002. The effect of grazing management on botanical composition and herbage quality on field level. Grassland Sci. Eur. 7, 162–163.

Steingass, H., Menke, K.H., 1986. Schätzung des energetischen Futterwertes aus der in vitro mit Pansensaft bestimmten Gasbildung und der chemischen Analyse. 1. Untersuchungen zur Methode Übers Tierernährg 14, 251–270.

Tainton, N.M., Morris, C.D., Hardy, M.B., 1996. Complexity and stability in grazing systems. In: Hodgson, J., Illius, A.W. (Eds.), The Ecology and Management of Grazing System. CABI Publishing, Wallingford, pp. 3–36.

Thériez, M., Brelurut, A., Pailleux, J.Y., Benoît, M., Liénart, G., Louault, F., De Montard, F.X., 1997. Extensification en élevage ovin viande par agrandissement des surfaces fourragères. Résultats zootechniques et économiques de 5 ans d'expérience dans le Massif Central Nord. INRA Prod. Anim. 10, 141–152.

Treweek, J.R., Watt, T.A., Hambler, C., 1997. Integration of sheep production and nature conservation: experimental management. J. Environ. Manage. 50, 193–210.

Velich, J., 1991. Základy pastevní techniky. In: Velich, J., Petřík, M., Regal, V., Štráfelda, J., Turek, F. (Eds.), Pícninářství. VŠZ, Praha, pp. 180–184.

Watkinson, A.R., Ormerod, S.J., 2001. Grasslands, grazing and biodiversity: editor's introduction. J. Appl. Ecol. 38, 233–237.

White, T.A., Barker, D.J., Moore, K.J., 2004. Vegetation diversity, growth, quality and decomposition in managed grasslands. Agric. Ecosys. Environ. 80, 213–226.