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Effect of grazing method and herbage allowance on the grazing efficiency of milk production in organic farming

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Abstract

In order to improve grazing management for organic farming systems two grazing experiments were conducted. In experiment 1, two rotational grazing methods (GMs), daily strip (S)-grazing or paddock (P)-grazing were evaluated. Herbage allowances (HAs) for S-grazing were 20.0 (1996) or 22.5 kg dry matter (DM) per day (1997). Cows were on an average allocated to paddocks for 6 days according to post-grazing sward height. S-grazing decreased ($P < 0.001$) pasture area requirement per cow by 26% and increased ($P < 0.001$) average milk yield per hectare by 36%. The duration of retarded growth was longer for P-grazing. In experiment 2, two levels of HA 18 and 24 kg DM per cow were compared in daily S-grazing of legume-rich swards. During the first grazing cycle the lower allowance was more effective ($P < 0.001$) in pasture utilisation than the higher allowance, due to a 18% decrease in grazing area requirement per cow. During three subsequent grazing cycles, HA had no significant effect ($P > 0.05$) on grazing area requirement per cow. The average grazing area requirement over the entire grazing season was decreased (8.8%) for the lower allowance ($P < 0.01$), but milk yield per hectare was similar between grazing strategies. High precipitation and tramping on silt soil protracted pasture re-growth, particularly at the lower HA. After the first grazing cycle pre-grazing herbage mass (HM) was lower for the lower allowance necessitating an expansion of grazing area. This clearly indicates the importance of grazing management to the success of organic farming systems, where pasture growth is not supported by soluble mineral fertilisers but relies on biological processes. In both experiments, nutritive value of herbage was relatively high (mean crude protein (CP) content 174 g kg^{-1} DM, neutral detergent fibre (NDF) content 498 g kg^{-1} DM, in vitro organic matter digestibility (OMD) 0.752), but the average pre-grazing HM was low (<2 t DM ha^{-1}, above 3 cm). © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Organic farming; Milk production; Grazing management; Grazing method; Herbage allowance

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1. Introduction

Herbage availability and digestibility, the main factors affecting nutrient supply in grazing animals, is dependent on stocking rate, forage species, the supply of available nitrogen and other sward growth factors (Leaver, 1985; Dufrasne et al., 1998). In conventional production systems optimum stocking rate is closely linked to nitrogen fertilisation (Holmes, 1968; Delagarde et al., 1997). Within the EU there are defined standards for organic crop (2092/1991, CEC 1991) and animal (1804/1999, CEC 1999) production. For instance soluble mineral fertilisers are not permitted, such that the ability of legumes to fix atmospheric nitrogen is of particular importance in organic farming and other low input systems (Bohlool et al., 1992; Granstedt, 1992). During grazing the amount of sward available nitrogen depends on complex soil–plant–animal inter-relationships (Ledgard, 1991).

Animal performance expressed on an individual animal or per hectare basis is determined by the efficiency of grazing management. The effects of grazing system (continuous or rotational) have only minor effects on dairy cow performance (Leaver, 1985). Rotational grazing is however, easier to manage than continuous grazing, because rotational grazing allows precise identification of grass quantity and quality (Campling, 1975; Peyraud and Gonzales-Rodrigez, 2000). The benefits of rotational grazing have generally been reported for clover-based swards at high stocking rates, whereas studies showing no differences between grazing methods (GMs) have been based on swards receiving relatively high applications of N fertiliser (Leaver, 1985). Therefore, rotational grazing may also be suitable for legume–grass pastures often used in organic farming systems.

Daily strip (S)-grazing is a more controlled means of rotational grazing. In daily S-grazing the specified quantity of grass per cow, daily herbage allowance (HA), is maintained by daily adjustment of grazing area according to herbage mass (HM). Although S-grazing is an efficient management tool it is also difficult to implement. If HA is too low, milk yield per animal will decrease but excessive HA results in a lower milk yield per hectare.

The aim of the current study was to improve milk yield per hectare by manipulating grazing management of legume–grass pastures established without soluble mineral fertilisers within an organic farming system. Two rotational GMs were initially evaluated followed by a comparison of two HAs. The underlying hypothesis was that the use of daily S-grazing to control HA would improve milk production per hectare. The effects of protein and energy supplementation on the performance of animals grazing the same pastures are reported in a companion paper (Khalili et al., 2002).

2. Material and methods

Experiments were conducted at the Siikasalmi experimental farm of the University of Joensuu (62°30′N, 29°30′E) in North Karelia between 1996 and 1998. The farm was converted to an organic farming system in 1996. The North Karelia region has cold winters and an annual snow cower of 5.5 months. Mean temperature and sum of precipitation over three summer months (June–August) demonstrated that weather conditions were typical (15.0 °C, 204 mm) during 1996, hot and dry (17.0 °C, 129 mm) in 1997 and rainy (14.6 °C, 307 mm) during 1998 compared with the long term (1961–1990) regional average (14.9 °C, 220 mm).

2.1. Pastures

2.1.1. Experiment 1, 1996 and 1997

During the conversion to organic farming, three grass–clover pastures (total 3.3 ha) were established during the summers of 1992–1993. Cows were grazed pastures until experiment 1 started. These swards have not received soluble mineral fertiliser since 1991–1993. In summer of 1993 one area received rock potassium (8 t ha^{-1}) and in the summer of 1994 an average of 9 t ha^{-1} diluted urine was applied. During this study no fertilisers were applied. Soil consistence had a very find sand (0.02–0.06 mm) texture with an organic matter (OM) content of 60–120 g kg^{-1} dry matter (DM) and a pH (water) of 6.1. Swards predominated in timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis*), typical for Finnish pastures. Other species included white clover (*Trifolium repens*), alsike clover (*T. hybridum*) and smooth meadow grass (*Poa pratensis*). During the spring of 1997 one of the three pastures was seeded with oats (*Avena sativa*) and hairy vetch (*Vicia villosa*) as grazed nurse crops. Prior to the start of the current study the proportion of clovers in older pastures had decreased with a spatial variation typical of grass–legume swards. In the beginning of experiment 1, the average proportion of legumes in pastures was low during both summers (0.13 and 0.09, respectively). Directly after grazing each area was topped to a sward surface height (SH) of 10 cm. All pastures were irrigated at the end of the exceptionally dry summer of 1997.

2.1.2. Experiment 2, 1998

New swards (total 4.0 ha) were established in the spring of 1997 (3.1 ha) and 1998 (0.9 ha) using oats and vetch as grazed nurse crops. Some composted farmyard manure (19 t ha^{-1}) was applied prior to seeding to the majority of the ley established in 1997, which had previously been fallow for 9 years. Following topographical moulding of the soil surface the ley established in 1998 received also applications of composted farmyard manure (30 t ha^{-1}). Compost applied had a mean total N content of 5 kg t^{-1}. None of these areas had received applications of soluble mineral fertiliser since 1992. Soil consistence had a silt (0.02–0.002 mm) or silty very fine sand texture, with an OM content of 60–120 g kg^{-1} DM and a pH (water) of 6.2. Swards predominated in timothy, meadow fescue and white clover. Other species including alsike clover, smooth meadow grass and red clover (*T. pratense*) were also present. In the beginning of experiment the average proportion of legumes (mainly clovers and some vetch) in the recently established pastures was relatively high (0.36). Under the dense nurse vetch some seedlings were spaced out. Due to heavy precipitation, open vegetation and silty soil herbage was sensitive to tramping. Therefore, an additional area of similar botanical composition (0.3 ha) was included into the rotation cycle after the first cut of herbage for silage production was taken. After grazing strips were topped to a SH of 10 cm.

2.2. Experimental animals

Eight Finnish Ayrshire cows 176 ± 78 (1996), 152 ± 51 (1997) and 148 ± 45 (1998) days in milk were used. Cows were divided into two squares according to milk yield and treatments were randomly allocated to cows within a square.

2.3. Experimental design and treatments

During each summer experiments lasted 12 weeks which approached the duration of the entire grazing season typical for the region (beginning of June to September).

2.3.1. Experiment 1, 1996–1997

The effect of two rotational GMs on grazing area requirements and milk production expressed on an individual cow or hectare basis was studied. Paddock (P)- and S-grazing were compared. Adequate grazing pressure was achieved either through regulating HA of daily strips or regulating post-grazing paddock SH. This approach avoided additional problems due to extended paddock residence time that can arise to errors in estimates of herbage production. Three pastures (1 ha) were all divided into two equal areas. The GM was randomly applied to areas within each pasture at the beginning of both summers. At the beginning of the study mean HM of S and P grazed areas was similar (1996: 1440 kg DM ha^{-1} versus 1250 kg DM ha^{-1} and 1997: 1540 kg DM ha^{-1} versus 1690 kg DM ha^{-1}) as was the average proportion of legumes in the sward (1996: 0.13 versus 0.12 and 1997: 0.09 versus 0.09). For S-grazing, cows were allocated to fresh grazing area each day with a HA above 3 cm of 20.0 kg DM per cow (1996) or 22.5 kg DM per cow (1997). For P-grazing, cows were grazed on the same paddock until a target post-grazing SH of 10 cm was reached. The rotation cycle lasted 21 days with an average grazing period of 6 days. Grazing time on each pasture per grazing episode was equal and S- and P-grazed cows were simultaneously transferred to the next pasture.

2.3.2. Experiment 2, 1998

The effects of low (LH) and high (HH) HA of 18 and 24 kg DM per cow, on grazing area requirements and milk production were studied within a S-grazing system. Three pastures were divided into two similar areas and allocated at random to the two HA treatments. At the beginning of the first rotation cycle the average HM of LH and HH areas was similar (2240 kg DM ha^{-1} versus 2440 kg DM ha^{-1}). Cows received fresh pasture each day. The length of rotation cycle was adjusted to grazing conditions and pastures were grazed from two to four times, depending on the severity of tramping. Cows were simultaneously transferred to the next pasture.

2.4. Measurements and analytical procedures

In both experiments HM before S-grazing was estimated by cutting six randomised areas of 74.0 cm $\times$ 22.5 cm to a height of 3 cm. Herbage samples were collected during days 5–21 of each period to estimate DM yield per hectare. Herbage DM content was determined by oven drying at 105 °C for 24 h. In experiment 1, the pre-grazing HM for P-grazing was estimated counting backwards from the previously grazed area. Herbage samples for analysis were dried at 60 °C and stored at room temperature. Herbage samples from pasture pooled on a weekly basis were analysed for OM by ashing at 600 °C for 12 h, nitrogen (Kjeldahl N), neutral detergent fibre (NDF) according to Van Soest et al. (1991) and in vitro organic matter digestibility (OMD) using a cellulase based method (Friedel, 1990). Representative samples of herbage from each pasture were submitted for botanical composition determinations on at least two occasions during each summer. Post-grazing SH were measured using a sward stick (Bircham, 1981) and a total of 20 and 50 measurements per strip and paddock, respectively were recorded. In experiment 1, post-grazing SH for S-grazing was only measured during 1997. Measurements and procedures concerning milk production are reported in a companion paper (Khalili et al., 2002).

2.5. Statistical analysis

In experiment 1, the effects of GM on estimated HM, daily grazing area requirement, stocking rate, post-grazing SH, nutritive value of herbage and milk production per hectare were analysed for each grazing episode (on an average 6 days) using the paired sample *t*-test. The total number of observations (grazing episodes) was 24 and 22 for 1996 and 1997, respectively. The average daily grazing area per cow during each grazing episode was estimated by dividing the grazed paddock area by the duration (days) of grazing episodes (P-grazing) or as the mean value of strips grazed daily (S-grazing). Respective post-grazing SH at the end of grazing episode (P-grazing) were compared with the mean value of post-grazing SH of daily strips (S-grazing). Data concerning the effect of GM on milk production per cow was analysed according to the model reported by Khalili et al. (2002).

In experiment 2, the effect of two HA on HM, daily grazing area requirement, stocking rate, post-grazing SH height and milk production per hectare were analysed for each sampling day (days 5–21 per period) using the paired sample *t*-test. The total number of daily observations per rotation cycle (1–4) decreased from the first rotation cycle to the last (64, 36, 40 and 22) due to the number of rotation cycles per pasture was limited as a result of tramping. The effect of HA on herbage nutritive value was analysed using the paired sample *t*-test based on weekly samples (24 observations). The effect of HA on milk production per cow was analysed according to Khalili et al. (2002).

3. Results

3.1. Grazing area requirement, stocking rate and milk yield per hectare

Grazing area requirements and average stocking rates of both experiments are presented in Table 1. For experiment 1 (1996–1997) S-grazing had on an average a 26% lower ($P < 0.001$) daily grazing area requirement per cow than P-grazing (155 m^2 versus 209 m^2) and a 36% higher ($P < 0.001$) mean stocking rate (3.24 versus 2.39 cows per

Table 1
Temporal variation of grazing area requirement and post-grazing sward height in experiments 1 and 2

	Experiment 1										Experiment 2				
	Grazing system (1996)					Grazing system (1997)					Herbage allowance				
	n[a]	Strip	Paddock	S.E.M.[b]	Significance	*n*[a]	Strip	Paddock	S.E.M.[b]	Significance	*n*[a]	18	24	S.E.M.[b]	Significance
Grazing area requirement[c] (m^2 per cow)															
Grazing 1	3	121	186			3	126	159			32	106	130	6.11	***
Grazing 2	3	171	196			3	124	187			18	142	151	8.82	
Grazing 3	3	164	234			3	176	235			20	117	121	6.34	
Grazing 4	2	182	247			3	188	237			11	157	156	11.1	
Mean	11	160	216	8.46	***	12	150	202	7.90	***	81	124	136	3.89	**
Post-grazing sward height (cm)															
Grazing 1	3	Not measured	10.4			3	15.7	16.7			32	9.5	13.0	0.57	***
Grazing 2	3		9.8			3	11.1	10.6			18	8.6	10.7	0.49	***
Grazing 3	3		10.1			3	9.7	11.6			20	9.1	11.2	0.63	**
Grazing 4	2		10.1			3	9.1	10.0			11	7.7	9.7	0.64	*
Mean	11		10.1			12	11.6	12.0	0.66		81	9.0	11.6	0.32	***
Mean stocking rate (cow per hectare)	11	3.12	2.28		***	12	3.38	2.51		***	81	3.42	3.20	0.11	
Milk yield (kg ha^{-1})	11	5000	3680		***	12	5470	4050		***	81	5640	5570	188	

Treatments: In experiment 1, two rotational grazing methods, daily strip grazing or paddock grazing were evaluated. Daily herbage allowances (HAs) for strip grazing were 20.0 (1996) or 22.5 kg DM per cow (1997). In experiment 2, two levels of HAs, 18 kg and 24 kg DM per cow were compared in daily strip grazing.

[a] Number of observations: experiment 1, number of grazing episodes; experiment 2, number of daily observations.

[b] Standard error of the mean of pair-wise difference determined using the paired sample *t*-test.

[c] Grazing area requirements were estimated by regulating herbage allowance of daily strips or post-grazing paddock sward height.

* $P < 0.05$ (statistical significance between treatments determined using the paired sample *t*-test).

** $P < 0.01$ (statistical significance between treatments determined using the paired sample *t*-test).

*** $P < 0.001$ (statistical significance between treatments determined using the paired sample *t*-test).

hectare). Consequently milk yield per hectare and per grazing season was 36% higher for S- compared with P-grazing (5230 kg versus 3860 kg, $P < 0.001$).

For experiment 2 (1998) the length of rotation cycle was calculated as 27 days (not predetermined). LH resulted in a more effective ($P < 0.001$) pasture utilisation than HH during the first grazing cycle, because LH decreased grazing area requirements by 18% (Table 1). HA had no effects ($P > 0.05$) on grazing area requirements during subsequent grazing cycles. The lower HA decreased the average grazing area requirement ($P < 0.01$) by 8.8% over the entire grazing season. Average milk yield per hectare (5600 kg ha^{-1}) and average stocking rate (3.30 ha^{-1}) were not affected ($P > 0.05$) by differences in HA.

3.2. Pre-grazing HM and post-grazing sward height

Pre-grazing HM and post-grazing SH are presented in Tables 2 and 1, respectively. The average proportion of weeds in the sward was 0.16 for experiment 1 and 0.08 for experiment 2. In experiment 1, mean estimates of pre-grazing HM were higher ($P < 0.001$) for S-grazing compared with P-grazing (1450 kg DM ha^{-1} versus 1070 kg DM ha^{-1}). Post-grazing SH observed for both methods in 1997 was not affected ($P > 0.05$) by GM (Table 1). In experiment 2, mean pre-grazing HM during the grazing season was lower ($P < 0.001$) for LH compared with HH (1760 kg DM ha^{-1} versus 2130 kg DM ha^{-1}). The average post-grazing SH was also lower ($P < 0.001$) for LH relative to HH (9.0 cm versus 11.6 cm).

3.3. Proportion of legumes and nutritive value of herbage

Chemical composition of herbage for both experiments is presented in Table 2. Besides GM, weather conditions and the proportion of legumes also had an influence on herbage nutritive value (data not presented). For experiment 1, the average proportion of legumes in the sward was 0.15. During the summer of 1996 the proportion of legumes increased slightly, and was somewhat higher for S- compared P-grazing (0.17 versus 0.13, $P = 0.066$). As a result average herbage crude protein (CP) content was higher ($P < 0.01$) for S-grazing (corresponding values 188 g kg^{-1} DM versus 171 g kg^{-1} DM). At the end of summer 1997 the mean proportion of legumes in the sward was higher (0.24) than the previous summer, but the contribution of legumes varied with sward age. GM had no effect ($P > 0.05$) on herbage nutritive value or the proportion of legumes in the sward. For experiment 2 (1998) the average proportion of legumes in the sward increased from 0.36 to 0.58 during the grazing season. Relative to HH, LH had a lower ($P < 0.05$) NDF content (438 g kg^{-1} DM versus 467 g kg^{-1} DM) and a higher ($P < 0.01$) in vitro OMD (0.757 versus 0.739).

3.4. Milk production per cow

GM or HA had no effect ($P > 0.05$) on the daily yields of milk or milk constituents (Table 3). Milk protein content ($P < 0.05$) and milk urea ($P < 0.01$) concentrations were higher for strip compared with paddock grazed cows during 1996, but not in 1997.

Table 2
Mean pre-grazing herbage mass (HM) and herbage chemical composition in experiments 1 and 2 during 1996–1998

	Experiment 1										Experiment 2				
	Grazing system (1996, $n^a = 11$)					Grazing system (1997, $n^a = 12$)					Herbage allowance (1998, $n^a = 12$)				
	Strip		Paddock		Significance	Strip		Paddock		Significance	18		24		Significance
	Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.		Mean	S.D.	Mean	S.D.	
Pre-grazing HM[b] (kg DM ha^{-1})	1310	289	960	173	***	1600	453	1190	339	**	1760	861	2130	1046	***
DM (g kg^{-1} fresh weight)	172	12.4	179	19.2		217	55.9	219	47.2		166	32.6	161	29.3	
DM composition (g kg^{-1} DM)															
Organic matter	905	9.75	903	10.4		914	15.7	917	11.1		910	11.2	909	8.26	
CP	188	16.0	171	15.9	**	171	35.8	176	35.4		173	30.8	167	26.8	
NDF	486	24.1	489	24.8		556	60.1	551	60.8		438	29.6	467	37.8	*
In vitro OMD	0.785	0.019	0.774	0.025	*	0.728	0.040	0.726	0.038		0.757	0.026	0.739	0.033	**

Treatments: In experiment 1, two rotational grazing methods, daily strip grazing or paddock grazing were evaluated. Daily herbage allowances (HAs) for strip grazing were 20.0 (1996) or 22.5 kg DM per cow (1997). In experiment 2, two levels of HAs, 18 kg and 24 kg DM per cow were compared in daily strip grazing.

[a] Number of pooled herbage samples per treatment analysed for organic matter (OM), crude protein (CP), neutral detergent fibre (NDF) and *in vitro* organic matter digestibility (OMD).

[b] Pre-grazing herbage mass for paddock grazing estimated by grazing area demand.

* $P < 0.05$ (statistical significance between treatments determined using the paired sample *t*-test).

** $P < 0.01$ (statistical significance between treatments determined using the paired sample *t*-test).

*** $P < 0.001$ (statistical significance between treatments determined using the paired sample *t*-test).

Table 3
Milk production of individual cows in experiments 1 and 2

	Experiment 1								Experiment 2			
	Grazing system (1996)				Grazing system (1997)				Herbage allowance (1998)			
	Strip	Paddock	S.E.M.	Significance	Strip	Paddock	S.E.M.	Significance	18	24	S.E.M.	Significance
Milk (kg per day)	19.1	19.2	0.52		19.3	19.2	0.55		19.5	20.4	0.35	
Milk composition (g kg^{-1})												
Fat	41.1	39.0	0.95		41.9	42.5	0.63		41.4	39.6	0.59	
Protein	33.7	33.0	0.23	*	31.4	31.5	0.22		31.8	32.1	0.15	
Lactose	46.1	46.5	0.24		46.9	46.9	0.29		46.5	46.4	0.14	
Urea (mg kg^{-1})	324	277	12.0	**	238	265	13.0		156	137	8.0	
Yield of milk constituents (g per day)												
Fat	766	747	23.8		805	813	26.6		815	787	13.5	
Protein	639	626	16.9		601	600	16.4		620	637	7.5	
Lactose	881	890	27.1		905	903	30.5		917	931	13.6	

Treatments: In experiment 1, two rotational grazing methods, daily strip grazing or paddock grazing were evaluated. Daily herbage allowances (HAs) for strip grazing were 20.0 (1996) or 22.5 kg DM per cow (1997). In experiment 2, two levels of HAs, 18 kg and 24 kg DM per cow were compared in daily strip grazing.Number of observations per each treatment was 16 and 8 for experiments 1 and 2, respectively.

* $P < 0.05$ (statistical significance between treatments within year).

** $P < 0.01$ (statistical significance between treatments within year).

4. Discussion

4.1. Grazing management

For organic farming systems where soluble mineral fertilisers are not permitted and the amount of complementary feeding is restricted, efficient grazing of swards containing legumes is central to the viability of milk production. In the present study, the potential of two GMs to improve grazing management was assessed.

4.1.1. Grazing method

The efficiency of grazing can be defined in terms of milk production per cow or milk yield per hectare depending on the most limiting factor. Grazing systems designed to maximise individual animal performance are simultaneously inefficient with respect to herbage utilisation per hectare (Le Du et al., 1979; Leaver, 1985). In the present study, grazing area requirement per cow and milk yield per hectare were used as indicators of grazing efficiency, since grazing area requirements per cow often increase during the conversion to organic farming systems. In this respect S-grazing was more efficient than P-grazing, since S-grazing decreased (26%) pasture area requirement per cow and increased milk yield (36%) per hectare. The assumption of similar amounts of available herbage based on either HA or post-grazing SH, was confirmed by similar post-grazing SH of GM during 1997 and comparable animal performance across both years.

Few recent studies have compared paddocks with S-grazing. No differences in milk yield were observed between GMs consistent with the observations of Peyraud et al. (1989). In the previous study grazing areas of fertilised *Lolium perenne* pasture were allocated each day or over a 5-day period based on HA estimates of 26 kg OM per day. Consequently differences in grazing area requirements between S- and P-GMs (56.0 m^2 versus 59.2 m^2) could be due to variations in applications of fertilisers, pasture species and grazing management. In the present study the same area was repeatedly grazed while cows in the study of Peyraud et al. (1989) were allocated predominantly primary growths. Long exposure to a paddock can extend the duration of disturbed sward growth (Dobbelaar, 1988). Pre-grazing HM was estimated to be lower for P- compared for S-grazing, which could have contributed to the current observations.

4.1.2. Proportion of legumes in the sward

Clovers are valuable forage plants often having a higher nutritive value than grasses (Leaver, 1985; Wilkins et al., 1994; Vanhatalo et al., 1995). In organic farming systems sward N supply is dependent on biological processes; primary through biological N fixation but and also due to mineralisation of soil OM, plant residues and manure (Granstedt, 1992; Younie, 1999). However, these processes can be disturbed by unfavourable growing conditions such as inclement weather, drought and compacted soil (Hansen, 1996). When the proportion of legumes in a sward decreases, the amount of fixed N also decreases (Kristensen et al., 1995). Thus, grasses in unfertilised swards are susceptible to N deficiency, that ultimately causes a reduction in herbage production.

In the present study the average proportion of legumes in herbage was low (0.15) for experiment 1 and relatively high (0.47) for experiment 2. The optimum proportion of clover within a sward has been reported to vary between 0.20 and 0.50 (Frame and Newbould, 1986; Taylor and Quesenberry, 1996). For grazed pastures a lower proportion of clover (0.20–0.40) has been recommended to avoid problems associated with bloat (Leaver, 1985). In spite of the high proportion of legumes no cases of bloat were observed (experiment 2), but the CP content of legume-rich herbage was uncharacteristically low. It appears that heavy precipitation and tramping may have caused soil compaction a factor known to reduce N availability (Younie and Hermansen, 2000). Nitrogen supply and subsequent herbage growth were probably limited by the low proportion of legumes in the sward (experiment 1) and unfavourable growing conditions (experiment 2). Legumes are vital components of pasture based milk production in organic farming, but as the current study demonstrated growing conditions are also important.

4.2. Herbage Allowance

When GM and botanical composition have been considered on a seasonal level, management decisions concerning HA and other practical issues such as pre-grazing HM, post-grazing sward height, the length of rotation cycle and supplementary feeding have to be addressed. The influence of HA in the short term, and stocking rate in the long term have been examined in several studies, but information of effect of HA on milk production per hectare over the entire grazing season is limited.

4.2.1. Milk production

A curvilinear relationship has been shown to exist between daily HA, herbage intake and milk yield (Le Du et al., 1979; Leaver, 1985; Mayne and Peyraud, 1996). High HA are required to achieve high intakes and milk yields per cow. However, relatively large incremental increases in HA have often had only minor effects on milk production of individual animals. In the present study HA had no effect on the daily yields of milk or milk constituents. Peyraud et al. (1989) also reported that fat corrected milk yield was not affected when HA was increased from 18.9 to 26.4 kg DM per cow. In contrast, extreme differences in HA from 25–30 to 50 and from 50 to 70–75 g DM (kg live weight)$^{-1}$ (corresponding approximately HA changes from 14 to 25 kg DM per cow per day and from 25 to 36 kg DM per cow per day) have been shown to increase milk production (Le Du et al., 1979). Marginal milk production responses were 0.25 and 0.11 kg milk (kg HA)$^{-1}$, respectively. Also moderate increases in HA from 16 to 20 and 20 to 24 kg DM per day have been shown to elicit corresponding responses of 0.45 and 0.20 kg milk (kg HA)$^{-1}$ (O'Brian et al., 1997). An optimal HA for milk production within organic farming system is unable to be estimated from current data since herbage intake was not measured.

In the present study milk yield per hectare was not affected despite of 0.25% decreased in HA. In contrast, Le Du et al. (1979) reported that milk yield per hectare increased by 38 and 109% when HA was decreased by 34 and 63%, respectively. However, the conclusions drawn from this study was reported to be somewhat artificial since progressive effects of grazing treatments upon the sward were minimised. Peyraud et al. (1989) also reported a 25% incremental increase in milk yield per hectare when HA was decreased by 27%, but unlike the present study, most of areas grazed were of primary growths. Since HA of repeatedly grazed and unfertilised areas was maintained at 18 and 24 kg DM per cow, negative cumulative effects of low HA on sward growth were observed in the current study.

4.2.2. Pre-grazing herbage mass

Although HA is one of the primary factors influencing daily herbage intake and animal performance, structural characteristics of the sward are also important. Remarkable reductions in herbage intake have been observed when animals grazed swards supplying less than 2.5 t OM ha^{-1} when HA was maintained through stocking rate (Peyraud et al., 1996). Scandinavian pastures are typically rather open and tall, such that the bulk density is often lower than that of dense and leafy *L. perenne* pastures (Virkajärvi and Höglind, 1999). Estimated pre-grazing HM was generally lower than that recommendations of 2000–3000 kg DM ha^{-1}, suggesting that sward productivity in the current study was depressed when typical rotation cycle lengths were implemented. In experiment 1, the nutritive value of legume-poor swards was ensured by a constant rotation cycle of 21 days, despite a low pre-grazing HM (Valk et al., 2000). For experiment 2, a higher pre-grazing HM of legume-rich swards was attained using a flexible rotation cycle that was on an average 27 days long. However, higher grazing pressure for the lower HA during early summer coupled with current growing conditions (no fertiliser, heavy precipitation, silt soil and tramping) depressed HM supply to a greater extent for LH than HH. Pre-grazing HM and possibly sward structure appear to have been sub-optimal, consistent with relatively high marginal milk production responses to energy and protein supplements and the lack of interactions between HA and supplementation level (Khalili et al., 2002).

The major factor affecting the HM of pastures is N supply (Leaver, 1985). In conventional systems low N inputs applied to grass swards reduce HM, which is in general, associated with a low herbage CP content and decreased animal performance (Peyraud and Astigarraga, 1998). At HM above 5 cm, green leaf mass and extended tiller height are greatly reduced in unfertilised *L. perenne* swards but HM to ground level and stem height are not affected by applications of N fertiliser (Delagarde et al., 1997). Limitations in sward structure associated with low HM of unfertilised pastures (1900 kg OM ha^{-1}, above 5 cm) were also shown to decrease herbage intake (−2.0 kg OM per day) and milk yield (−2.0 kg per cow) compared with fertilised pastures. Consequently, daily grazing area requirement per cow (HA 20.0 kg OM per cow per day) in early summer was 48% higher for unfertilised compared with fertilised pastures (114 m^2 versus 77 m^2). In organic farming systems cases of legume-poor pastures resemble that of low N inputs in conventional systems. If the grazing area requirement per cow can be decreased, without having a detrimental affect on animal performance, more nutrients per area unit will be directly recycled to support herbage production, as demonstrated in the present study. The authors want to point out that results now reported may change as soil fertility could change in the long-term. However, it is possible that within organic farming systems, N deficiency can sometimes substantially reduce herbage intake through reductions in pre-grazing HM and sward structure. Extended rest periods between grazing episodes have been suggested as a means of increasing the HM of N deficient pasture at the expense of large reductions in herbage nutritive value (Delagarde et al., 1997).

4.2.3. Nutritive value

Nutritive value of herbage and access to herbage determine the intake and nutrient supply in grazing cows (Leaver, 1985; Mayne et al., 1999). For any given grazing system, pasture species, application of fertilisers, sward growing conditions, stage of maturity and stocking rate affect nutritive value of herbage (Leaver, 1985; Delagarde et al., 1997; Wales et al., 1998). Thus, herbage nutritive value also indicates the efficiency of grazing management and the necessity for supplementary feeding. Nutritive value of herbage in the current study was rather good as indicated by mean CP, NDF and in vitro OMD values of 174 g kg^{-1} DM, content 498 g kg^{-1} DM and 0.752, respectively. Variations in the proportion of legumes in the sward was in line with herbage NDF content, that was 68 g kg^{-1} DM lower in experiment 2 than experiment 1 (Buxton, 1996). There were only small differences in herbage nutritive value between treatments. For experiment 1, the marginally higher proportion of legumes during 1996 tended to increase herbage CP content during S-grazing. In experiment 2, the average NDF content and pre-grazing HM were lower and in vitro OMD was higher for LH compared with HH, suggesting that the stage of herbage maturity was advanced due to higher stocking rates (Buxton, 1996).

4.2.4. Post-grazing sward height

Post-grazing SH is the most practical indicator of grazing management. Low post-grazing SH indicative of over-grazing will decrease animal performance and protract sward re-growths. High post-grazing SH due to under-grazing will decrease the utilisation of pasture and have a negative impact on herbage nutritive value. In cases where post-grazing SH of *L. perenne* is lower than 8–10 cm in rotational grazing systems it has been suggested that intake and milk production are likely to fall (Le Du et al., 1979). Both HA and sward structure affect post-grazing SH (Parga et al., 2000). In Finland a SH of 10 cm has been recommended, due to the low bulk density and modest tiller number of prevalent grass species (Virkajärvi and Höglind, 1999). In experiment 1, the average post-grazing SH of 11 cm was close to a target of 10 cm. In experiment 2, cows compensated for the lower HA by eating closer to ground level which could partly explain similar milk production between grazing treatments and lower pre-grazing HM for LH. However, the lower post-grazing SH was associated with a reduction in sward productivity. Based on the current data a mean post-grazing SH of 10–12 cm for grass–legume based swards grown under organic farming conditions in Finland appears to be optimal.

5. Conclusions

Current GM or HA had no effect on the milk production of individual animals. Pasture utilisation was more efficient for daily S-grazing compared with P-grazing resulting in improved milk yield per hectare. Mean grazing area requirements per cow over the entire grazing season was decreased at lower HAs, but milk yield per hectare was unaffected. High precipitation and tramping on silt soil protracted pasture re-growth, particularly at lower HAs. In conclusion, pasture productivity in organic farming systems can be improved through more efficient grazing management. However, monitoring of grazing conditions is vital to the success of this approach, since pasture growth within organic farming systems is not supported by mineral fertilisers but relies on biological processes.

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