The effect of grazing pressure on rotationally grazed pastures in spring/early summer on the performance of dairy cows in the summer/autumn period

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Two experiments (E1 and E2) were carried out to examine the effects of sward type (ST) on dairy cow performance. Applying grazing pressures (GP) in spring/early summer of 6.35, 4.24 and 3.53 cows/ha in E1, and 6.06, 5.05 and 4.03 cows/ha in E2, created the different ST. From summer to autumn, two stocking rates (SR) were applied to each sward, i.e., high (HR) and low (LR). As GP was reduced, the swards were characterised by progressively higher herbage mass of lower organic matter digestibility (OMD) and live leaf (LL) proportion, termed high (HQ), medium (MQ) and low (LQ) quality. There was no interaction between ST and SR for any animal performance variables except for grazing time. Mean diet OMD was 0.816, 0.803 and 0.794 (s.e. 0.0029) in E1, and 0.793, 0.780 and 0.772 (s.e. 0.0021) in E2, for HQ, MQ and LQ, respectively. The corresponding values for LL were 0.785, 0.740 and 0.709 (s.e. 0.0121) in E1, and 0.825, 0.790 and 0.759 (s.e. 0.0095) in E2. Milk yield per cow was 13.2, 12.2 and 10.6 (s.e. 0.55) kg in E1, and 18.4, 17.5 and 16.2 (s.e. 0.32) kg in E2, for HQ, MQ and LQ, respectively. Milk yields were 11.1 and 12.9 (s.e. 0.46) kg in E1, and 16.4 and 18.3 (s.e. 0.26) kg in E2, for HR and LR, respectively. There was no effect of ST or SR on milk composition or body weight gain. Herbage organic matter intake was 12.8, 12.5 and 11.1 (s.e. 0.28) kg in E2, for HQ, MQ and LQ, respectively. The corresponding values were 11.4 and 12.9 (s.e. 0.23) kg for HR and LR, respectively. The results show that milk yield of spring-calving dairy cows is higher in summer when high rather than low stocking rates are applied in spring/early summer. The increased milk production is attributed to higher intake of herbage of higher nutritive value.

Keywords: dairy cows; grazing; intake; milk production; stocking rate

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Introduction

Stocking rate or grazing intensity is a major determinant of production per cow and per ha from grassland (McMeekan and Walshe, 1963; Le Du *et al.,* 1979; Journet and Demarquilly, 1979). The objective in most systems of milk production in Ireland is to ensure that grazed grass makes a large contribution to the total diet of the cow during lactation (Dillon *et al.,* 1995). Grass growth rate in Ireland is highly seasonal with little or no growth in the winter and very high growth in May and June. Late spring/early summer pasture growth rate is about twice the daily cow requirement at recommended stocking rates (Dillon *et al.,* 1995). The surplus pasture can be harvested as silage or hay, or can be retained *in situ* for summer grazing. Low utilisation rates of pasture will result in wastage and may also reduce animal performance in summer. Thomson (1985) has shown that grazing at a low intensity at one time may reduce animal performance at a later stage, through a decline in feed quality. Low grazing intensity in spring has resulted in reduced growth rate of beef cattle (Dawson *et al*., 1981), reduced wool growth of sheep (Birrell and Bishop, 1980) and reduced milk production of dairy cows (Holmes and Hoogendoorn, 1983; Hoogendoorn, Holmes and Bookes, 1985) later in the year.

In a related paper (Stakelum and Dillon, 2007) the effect of grazing pressure in spring/early summer on subsequent sward characteristics was described. Pastures with high grazing pressure in spring/early summer produced swards of lower herbage mass, lower post-grazing height (PGH), higher proportion of grass leaf and lower proportion of grass stem and dead material than swards which had low grazing pressure in spring/early summer. This paper describes the effects of these swards on animal performance.

Materials and Methods

A detailed description of the experimental treatments and sward measurements has been reported previously in a companion paper on the effects of grazing pressure on sward characteristics (Stakelum and Dillon, 2007), therefore only a brief description is outlined in this paper. Two experiments (E1 and E2) were carried out at Moorepark Research Centre in 1986 (E1) and 1987 (E2). The same experimental site was used in both years consisting of swards with 80 to 90% perennial ryegrass (*Lolium perenne* L.) and some *Agrostis* and *Poa* species. The experimental site consisted of 21 equal-sized (0.472 ha) paddocks. In both years preliminary grazing took place with the aim of harvesting the grass that had accumulated over the winter/spring months. This occurred from 9 April to 23 April in E1 and from 2 April to 18 April in E2. Afterwards, the grazing season was divided into two periods. In Period 1 (P1) the swards were conditioned, by imposing three different rotational grazing pressures (GP) using dairy cows. This took place between 28 April and 20 July in E1, and between 18 April and 21 June in E2. In Period 2 (P2) the resulting swards were grazed at two stocking rates (SR) by dairy cows from 22 July to 10 October in E1, and from 26 June to 5 October in E2. Sixty-three spring-calving Friesian dairy cows balanced for calving date, parity and milk yield were randomly assigned to three groups in E1. In E2, sixty similar cows were similarly assigned.

The sward types (ST) produced as a result of the low, medium and high GP in P1 are termed low (LQ), medium (MQ) and high (HQ) quality. At the beginning of P2 each paddock was sub-divided in the ratio 0.57:0.43. This allowed two SR, with equal numbers of cows, to be applied to each sward type. The two SR were high (HR) and low (LR). In both E1 and E2 cows were blocked into groups of 6 on the basis of parity, calving date and milk yield, and within block were randomly assigned to 6 treatment groups. No first parity animals were used. Average daily pre-experimental milk yield and composition were 19.0 (s.d. 2.25) kg and 24.5 (s.d. 2.33) kg containing 3.51 (s.d. 0.400) g and 3.41 (s.d. 0.361) g fat per 100 g milk and 3.22 (s.d. 0.225) g and 3.20 (s.d. 0.182) g protein per 100 g milk, for E1 and E2, respectively. Average parity and calving date (days from January 1) were 5.3 (s.d. 2.28) and 48 (s.d. 39.3) for E1, and 4.4 (s.d. 2.43) and 68 (s.d. 33.4) for E2, respectively. Average pre-experimental body weight was 533 (s.d. 48.1) kg and 512 (s.d. 43.6) kg for E1 and E2, respectively.

Sward measurements

Sward measurements in P2 were recorded during rotations 1, 2 and 3 in E1, and during rotations 1, 2, 3 and 4 in E2. The details of these measurements were described by Stakelum and Dillon (2007). Pre-grazing herbage samples were analysed for organic matter digestibility (OMD) as described in Stakelum and Dillon (2007).

Herbage selected

In P2, 4 and 6 oesophageal fistulated (OF) cows were grazed with the experimental cows in each of grazing rotations 1 to 3 and 1 to 4 of E1 and E2, respectively. The OF cows were allocated to each of the grazing treatments in a balanced design, remaining in each paddock for the 3 days of sampling. An OF sample was obtained after evening milking on the three successive days. Approximately 2 to 3 kg of extrusa was collected from each animal at each sampling. After discarding excess saliva, a sub-sample of approximately 1 kg was retained. This was immediately stored in a freezer at –20 °C.

The extrusa samples were subsequently thawed and two sub-samples were taken. The first sub-sample (*ca.* 100 g) was placed in an aluminium tray, stored again in a freezer at –20 °C and later freeze-dried and analysed for OMD by the procedure of Morgan and Stakelum (1987) as modified by Morgan, Stakelum and O'Dwyer (1989). The second sub-sample (*ca.* 200 g) was separated into different sward components using a point analysis technique similar to that described by Heady and Torell (1959). Portions (*ca.* 20 to 30 g) of this sub-sample were placed in a 30 cm × 20 cm grided water tray. Plant components which coincided with an intersection of the grid were identified. The components enumerated were live leaf (LL), live stem (LS), dead leaf (DL) and dead stem (DS). The procedure continued until 100 contacts were identified. Samples were analysed in duplicate by each of two experienced recorders. The unit of measurement was the frequency of occurrence per 100 occurrences and expressed as a decimal.

Animal measurements

Milk production: Cows were milked at 16:8 hour intervals. Milk yield was recorded on 3 consecutive days per week. The concentrations of fat, protein and lactose were determined for one successive morning and evening sample per week using a FOSS-Let instrument (AS/M Foss, Electric, Denmark). Lactation ended when daily milk yield decreased to 4 kg per cow per day or when cows were within 6 to 7 weeks of calving. Live weight was recorded once weekly.

Grazing behaviour: Duration of grazing time (GT) was measured by fitting cows with Kienzle vibracorders (Stobbs, 1970). Estimates were obtained from each cow in each grazing rotation over 3 days in both E1 and E2. The rate of biting (BR) was recorded after evening and morning milking on 3 consecutive days in one grazing block per grazing rotation. A stop watch was used to measure the time taken for each animal to make 20 prehension bites (Hodgson, 1982). Each animal was recorded in duplicate at each measurement period. A record was discarded if the animal raised its head from the sward before it had completed 20 bites.

Herabge intake: The intake of herbage dry matter (DMI) and organic matter (OMI) was estimated on 4 occasions corresponding to the first four grazing rotations in Period 2 of E2, using the n-alkane technique of Mayes, Lamb and Colgrove (1986), as modified by Dillon and Stakelum (1989). The technique was based on the ratio of herbage C_{33} (n-tritriacontane) to dosed C_{32} (n-dotriacontane). Digestibility coefficients ($OMDC_{35}$) were calculated from marker concentrations of C_{35} (n-pentatriacontane) in both feed and faeces for each cow. Cows were dosed twice daily (after AM and PM milking) over a 12-day period with paper pellets containing approximately 500 mg of C_{32}. Faecal grab samples were collected twice daily (after milking) from each cow for the last 6 days of the 12-day period. Faecal samples from each cow were dried for 48 h at 40 °C, ground through a 1 mm screen and bulked prior to analysis. The n-alkane concentration in the herbage for the last 6 days was obtained from the same OF extrusa samples as used to estimate OMD of the OF extrusa samples. The C_{32} content of the pellets and the C_{32}, C_{33} and C_{35} concentration in faeces and herbage were analysed according to a modification of the technique of Mayes *et al.* (1986) with direct saponification (Dillon, 1993). Intake was calculated using the equation of Mayes *et al.* (1986).

Digestibility was calculated using the equation: $(M_f–M_d)/M_f$
where M_f and M_d are the marker concentrations in faeces and diet of C_{35} n-alkane.

Values for M_f were corrected for incomplete recovery of marker by multiplying by 0.95 (Dillon, 1993).

Statistical analyses
The diet composition data for the OF cows were analysed as a split-split-plot design with a factorial arrangement of treatments in the main-plot.

The model was: $Y_{ijklm} = mean + ST_i + SR_j + OF_k + (ST \times SR)_{ij} + (ST \times SR \times OF)_{ijk} + R_l + (ST \times R)_{il} + (SR \times R)_{jl} + (ST \times SR \times R)_{ijl} + (ST \times SR \times OF \times R)_{ijkl} + Day_m + (R \times Day)_{lm} + (ST \times Day)_{im} + (SR \times Day)_{jm} + (ST \times SR \times Day)_{ijm} + (ST \times R \times Day)_{ilm} + (SR \times R \times Day)_{jlm} + (ST \times SR \times R \times Day)_{ijlm} + e_{ijklm}$
where STi = sward type effect (i = 1 to 3);
SR_j = stocking rate effect (j = 1 to 2);
OF_k = OF cow effect (k = 1 to 4 for E1 and 1 to 6 for E2);
R_l = grazing rotation effect (l = 1 to 3 for E1 and 1 to 4 for E2);
Day_m = day effect (m = 1 to 3);
e_{ijklm} = residual error term with 108 and 240 degrees of freedom in E1 and E2, respectively.

ST and SR and their interaction were tested using $(ST \times SR \times OF)_{ijk}$ as the error term, while R and its interactions with ST and SR were tested using $(ST \times SR \times OF \times R)_{ijkl}$ as the error term. Terms in the sub-sub-plot were tested using $e_{ijklm.}$ The GT and BR data were analysed in a similar way with cow within block used instead of OF cow. Time was used in the sub-sub-plot for BR with m = 1 to 6.

Daily milk yield, milk composition, body weight and body weight gain data were analysed using the following mixed model: $Y_{ijkl} = mean + ST_i + SR_j + (ST \times SR)_{ij} + R_k + (ST \times R)_{ik} + (SR \times R)_{jk} + (ST \times SR \times R)_{ijk} + b_1X_1 + b_2X_2 + b_3X_3 + Cow\ (ST \times SR)_{ijl} + e_{ijkl}$
where Cow $(ST \times SR)_{ijl}$ was a random effect, and b_1X_1 to b_3X_3 were the values of the appropriate pre-experimental milk production or body weight variables, parity and calving date, respectively.

DMI, OMI, and $OMDC_{35}$ were analysed as a split-plot design with factors completely randomised in the main plot using the model;

$Y_{ijkl} = mean + ST_i + SR_j + (ST \times SR)_{ij} + Cow\,(ST \times SR)_{ijl} + R_k + (ST \times R)_{ik} + (SR \times R)_{jk} + (ST \times SR \times R)_{ijk} + e_{ijkl.}$

The terms ST, SR and their interaction were tested using Cow $(ST \times SR)_{ijl}$ as the error term.

The expected or likely milk yield (LMY) was compared to the observed milk yield. The LMY was calculated from the average milk yield (PMY) during P1 and the duration (in weeks, t) between the midpoints of P1 and P2 assuming a theoretical persistence of 0.98 per week: ($LMY = PMY \times 0.98^t$; Delaby, Peyraud and Delagarde, 2001). All analyses were carried out using the statistical procedures of SAS (SAS, 1991).

Results

Total and live-leaf daily herbage allowance

Daily allowance of herbage DM and LL per cow for the two experiments are shown in Table 1. The total DM and LL allowance for each rotation are shown in Figure 1. There was a significant increase in total DM allowance in both experiments as sward quality declined from HQ to LQ ($P < 0.001$). Also, daily DM allowance increased significantly ($P < 0.001$) in both experiments as SR decreased from high to low. The LL allowance was similar for the three sward types in both experiments. There was a significant increase ($P < 0.001$) in LL allowance in both experiments as SR decreased from high to low.

Total and LL allowances were significantly lower ($P < 0.05$) for rotation 2 than for rotations 1 or 3 in E1. Also, total DM allowance was significantly lower ($P < 0.05$) for rotations 3 and 4 than for rotations 1 and 2 in E2. There was no difference in LL allowance between rotations in E2.

Diet composition

The OMD and the proportions of LL and LS in the herbage selected by the OF cows are shown in Table 2. The dead material was ignored because it formed only a minor component (range 0.016 to 0.047) of the diet. There were no interactions between the main factors and rotation for any of the variables. In general, OMD ($P < 0.001$) and LL ($P < 0.01$) decreased,

Table 1. Daily dry matter allowance of total herbage and of live leaf (kg/cow) for cows grazing three swards at two stocking rates in Experiments 1 and 2

Experiment	Herbage component	Sward type × Stocking rate						s.e.	Significance		
		HQ		MQ		LQ			ST	SR	ST × SR
		HR	LR	HR	LR	HR	LR				
1	Total	16.5[a]	31.8[bc]	23.6[ab]	39.5[c]	33.1[bc]	52.2[d]	2.47	***	***	
2	Total	25.0[a]	38.4[c]	32.0[b]	56.6[d]	42.3[c]	68.5[e]	2.38	***	***	*
1	Live leaf	10.2[a]	17.0[b]	9.8[a]	17.2[b]	10.4[a]	16.6[b]	0.97		***	
2	Live leaf	15.5[a]	21.8[b]	15.7[a]	24.8[c]	15.2[a]	23.6[bc]	0.72		***	

[1] HR = high stocking rate; LR = low stocking rate; HQ = high quality sward; MQ = medium quality sward; LQ = low quality sward.
ST = Sward Type; SR = Stocking Rate.
[abcde] Values, within rows, with a common superscript do not differ significantly.

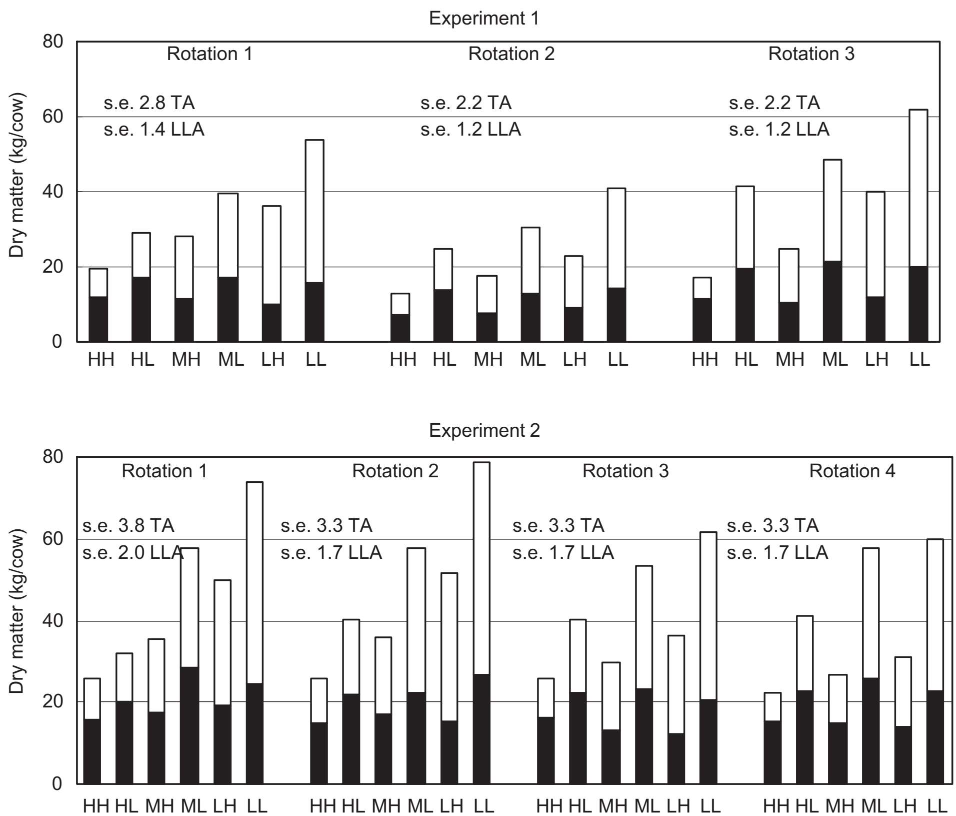

Figure 1. The average daily total (TA) and live leaf (LL) (■) dry matter allowances for herds grazing high quality swards at high (HH) or low (HL) stocking rates, medium quality swards at high (MH) or low (ML) stocking rates and low quality swards at high (LH) or low (LL) stocking rates for each rotation in Experiments 1 and 2.

Table 2. Organic matter digestibility (g/g organic matter) and live leaf and live stem as proportions of total plant fragments for the extrusa samples from oesophageal fistulated cows sampling three swards at two stocking rates for Experiments 1 and 2

Experiment	Sward type × Stocking rate[1]						s.e.	Significance		
	HQ		MQ		LQ			ST	SR	ST × SR
	HR	LR	HR	LR	HR	LR				
	Organic matter digestibility									
1	0.811^{ab}	0.820^{a}	0.796^{bc}	0.809^{abc}	0.793^{c}	0.795^{bc}	0.0041	***	*	
2	0.790^{ab}	0.797^{a}	0.777^{c}	0.783^{bc}	0.764^{c}	0.780^{bc}	0.0030	***	***	
	Live leaf									
1	0.751^{a}	0.818^{b}	0.705^{c}	0.775^{b}	0.696^{c}	0.723^{c}	0.0171	**	**	
2	0.823^{a}	0.828^{a}	0.763^{b}	0.816^{a}	0.723^{c}	0.795^{ab}	0.0134	***	***	*
	Live stem									
1	0.217^{ab}	0.155^{c}	0.271^{a}	0.200^{bc}	0.279^{a}	0.247^{ab}	0.0161	***	***	
2	0.150^{a}	0.144^{a}	0.207^{bc}	0.157^{a}	0.245^{c}	0.182^{ab}	0.0131	***	**	

[1] See footnotes to Table 1.

and LS ($P < 0.001$) increased as sward quality deteriorated from high to low in E1. Similarly, OMD ($P < 0.001$) and LL ($P < 0.001$) decreased, and LS ($P < 0.001$) increased, as sward quality deteriorated in E2. The effects of sward quality were greater for LL and LS than for OMD. The OMD ($P < 0.05$) and LL ($P < 0.01$) increased and LS ($P < 0.001$) decreased as SR fell from high to low in E1. Also, OMD ($P < 0.001$) and LL ($P < 0.001$) increased and LS ($P < 0.01$) decreased with decreasing SR in E2. However, the effect of SR on OMD was small. There was a significant interaction ($P < 0.05$) between ST and SR for LL in E2. This was due to the lack of a SR effect on LL in the HQ sward but not in the MQ and LQ swards.

There were significant interactions between ST and day for OMD, LL and LS in both E1 and E2. Also, there were significant interactions between SR and day for OMD, LL and LS in both E1 and E2. There were no third order interactions between the main factors and day. The pattern of change for OMD, LL and LS in the diet for ST in both experiments as the swards were grazed down over the 3 days is shown in Figure 2. The corresponding data for SR are shown in Figure 3. For both ST and SR, OMD and LL decreased ($P < 0.001$) and LS increased ($P < 0.001$), as the swards were grazed down. These effects increased with increasing severity of grazing.

The predicted diet OMD coefficient, based on linear regression analysis, for E1 were 0.80, 0.81 and 0.82 g/g OM for sward OMD values of 0.70, 0.75 and 0.80 g/g OM, respectively. The corresponding values for E2 were 0.77, 0.79 and 0.81 g/g OM for the same values of sward OMD. The predicted diet LL proportions for E1 were 0.71, 0.76 and 0.80 for sward LL values of 0.30, 0.50 and 0.70 g/g DM, respectively. The corresponding values for E2 were 0.76, 0.80 and 0.84 for the same values of sward LL content.

The OMD of the OF samples was related to the LL proportion according to the expression:

OMD = 0.636 (s.e. 0.0058) + 0.226 (s.e. 0.0076) × LL ($P < 0.001$, n = 216, r.s.d. = 0.020, $R^2 = 0.81$) for E1, and OMD = 0.585 (s.e. 0.0068) + 0.249 (s.e. 0.0084) × LL ($P < 0.001$, n = 432, r.s.d. = 0.025, $R^2 = 0.67$) for E2. Adding terms for either LS or DL did not significantly reduce the r.s.d.

Grazing behaviour

Average biting rate and grazing time for both experiments are summarised in Table 3. Biting rate decreased as sward quality deteriorated in both E1 ($P < 0.001$) and E2 ($P < 0.05$). Stocking rate had no effect on biting rate in either experiment. There was a significant interaction between time in the plot and ST in both experiments ($P < 0.001$). The effect of ST and number of grazing on biting rate is shown in Figure 4 for both experiments. In general, there was a more rapid decline in biting rate for the MQ and LQ swards than for the HQ sward.

There was a significant interaction between ST and SR for grazing time in E1 ($P < 0.01$). There was an increase in grazing time (*ca.* 60 min) as SR decreased from high to low for the MQ and LQ swards whereas the opposite was so for the HQ sward. There was no effect of ST on grazing time in E2. There was a decrease in grazing time (*ca.* 25 min) as SR decreased from high to low and the effect was consistent for the three sward types.

Intake and dietary digestibility using n-alkane

The DMI, OMI and diet $OMDC_{35}$ for the four grazing rotations in E2 are shown in Table 4. In general, DMI and OMI were lower for the LQ sward than for the HQ and MQ swards ($P < 0.05$). Both DMI and OMI decreased as SR increased from low to high. Significant interactions between the main effects and rotation indicated that

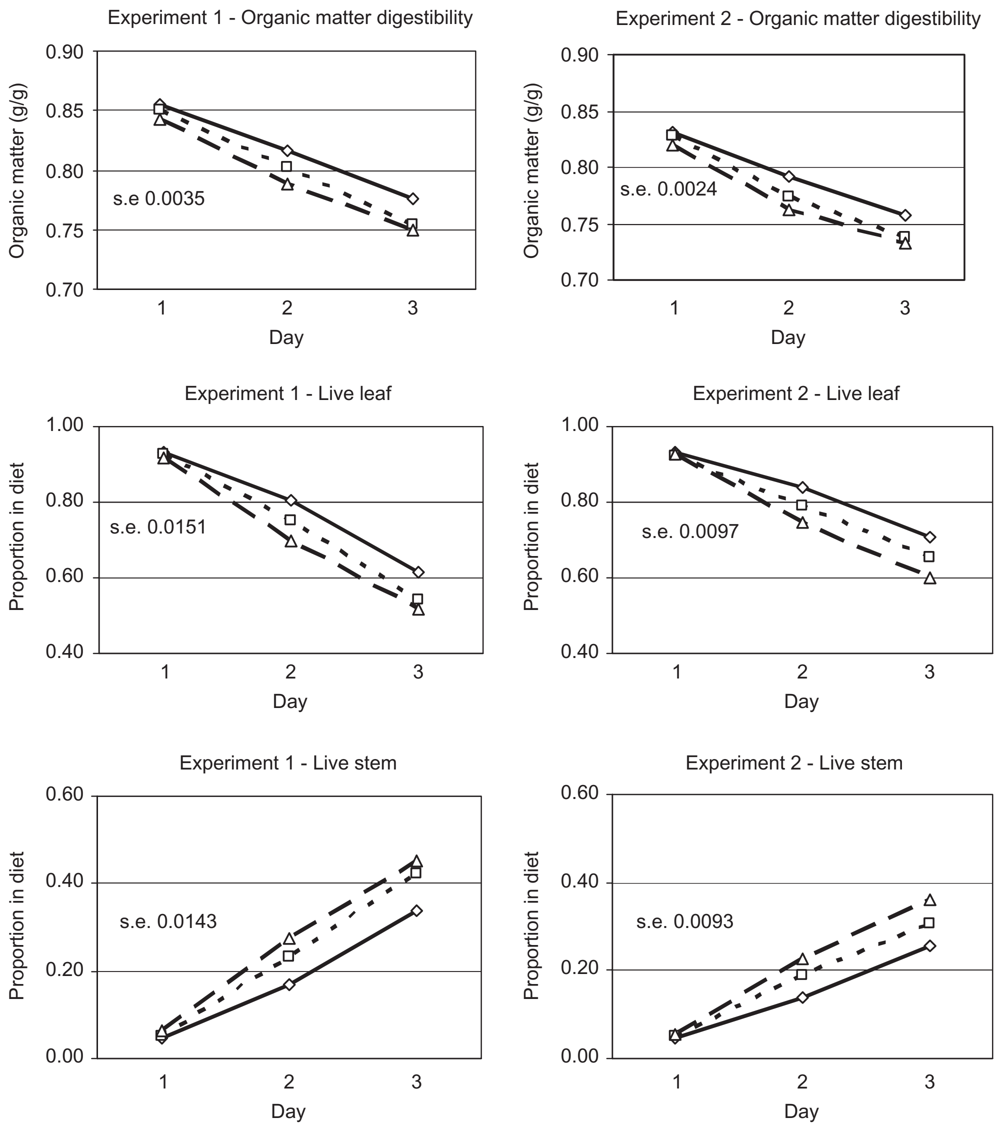

Figure 2. The organic matter digestibility (OMD), live leaf (LL) and live stem (LS) content of the herbage selected during the grazing down of the high (◊), medium (□) and low (△) quality swards over three days in Experiments 1 and 2.

these effects differed between rotations. The diet $OMDC_{35}$ decreased ($P < 0.05$) as sward quality declined. There was no effect of SR on diet $OMDC_{35}$. The DMI, OMI and diet $OMDC_{35}$ were higher ($P < 0.05$) for rotations 1 and 2 than for rotations 3 and 4. The $OMDC_{35}$ was similar to the sward OMD. The relationship between $OMDC_{35}$ and OMD of the sward was:

$OMDC_{35}$ = 0.031 (s.e. 0.1482) + 0.964 (s.e. 0.2016) × sward OMD (r.s.d. = 0.027, R^2 = 0.51).

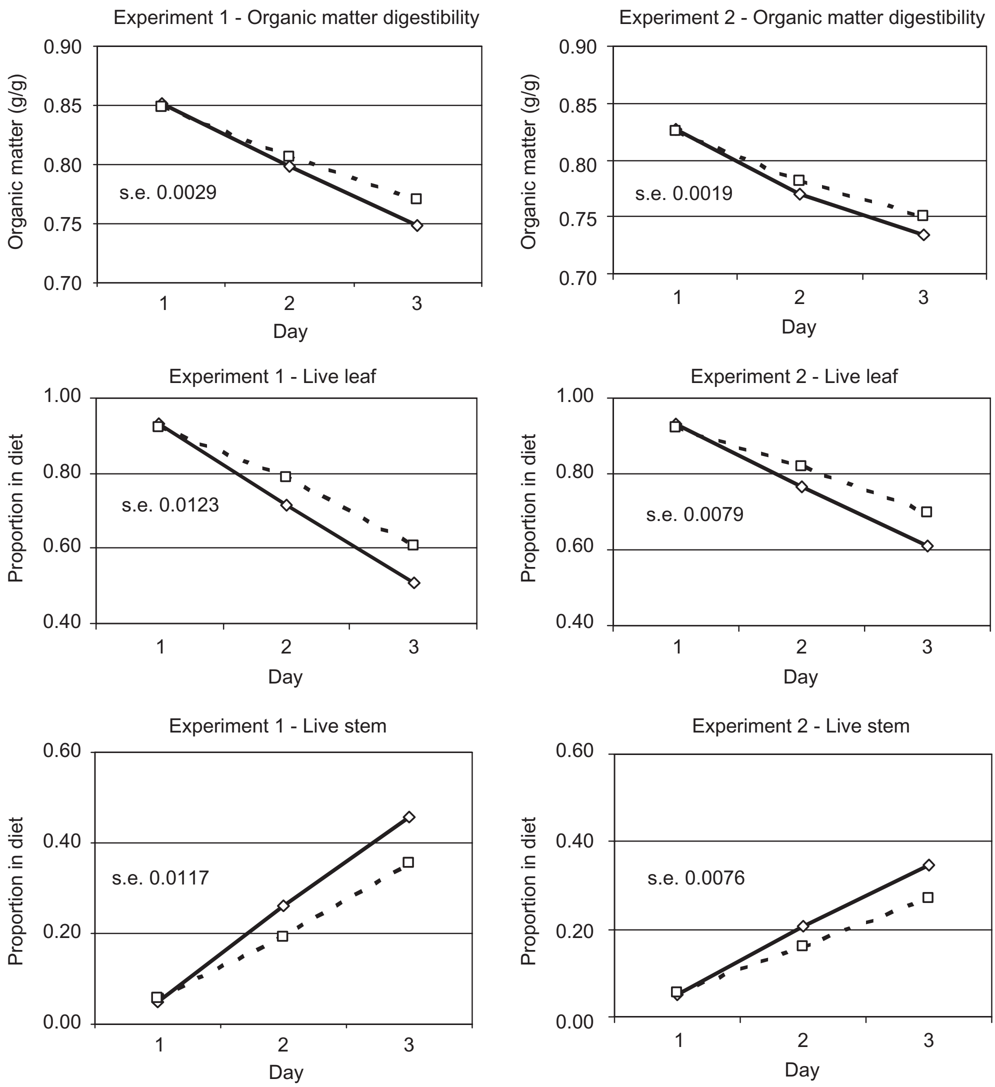

Figure 3. The organic matter digestibility (OMD), live leaf (LL) and live stem (LS) content of the herbage selected during the grazing down of the swards at high (◇) and low (□) stocking rate over three days in Experiments 1 and 2.

The mean DMI for the four rotations could be predicted using the following expression:

-14.4 (s.e. 4.29) $+ 0.187$ (s.e. 0.0787) $\times$ pre-experimental milk yield $+ 0.299$ (s.e. 0.0515) $\times$ diet LL (r.s.d. = 1.05, $R^2 = 0.63$).

Milk production and body weight

The GP applied during P1 had no significant effect on milk production, milk composition or body weight. The average daily milk production, fat concentration and protein concentration in E1 was 22.0, 21.1 and 21.7 (s.e. 0.55) kg, 3.40, 3.32 and

Table 3. The biting rate (bites/min) and grazing time (h/day) of cows grazing three swards at two stocking rates in Experiments 1 and 2

Experiment	Sward type × Stocking rate[1]						s.e.	Significance		
	HQ		MQ		LQ			ST	SR	ST × SR
	HR	LR	HR	LR	HR	LR				
				Biting rate						
1	61.7^{ab}	65.9^{a}	58.9^{b}	57.7^{b}	49.5^{c}	51.2^{c}	1.84	***		
2	56.7^{a}	57.8^{a}	58.5^{a}	54.8^{a}	53.5^{a}	51.2^{a}	2.11	*		
				Grazing time						
1	9.29^{ab}	10.14^{a}	10.24^{a}	9.27^{ab}	9.60^{ab}	8.61^{b}	0.263	*		**
2	9.80^{a}	9.58^{a}	10.01^{a}	9.54^{a}	10.08^{a}	9.50^{a}	0.259		*	

[1] See footnotes to Table 1.

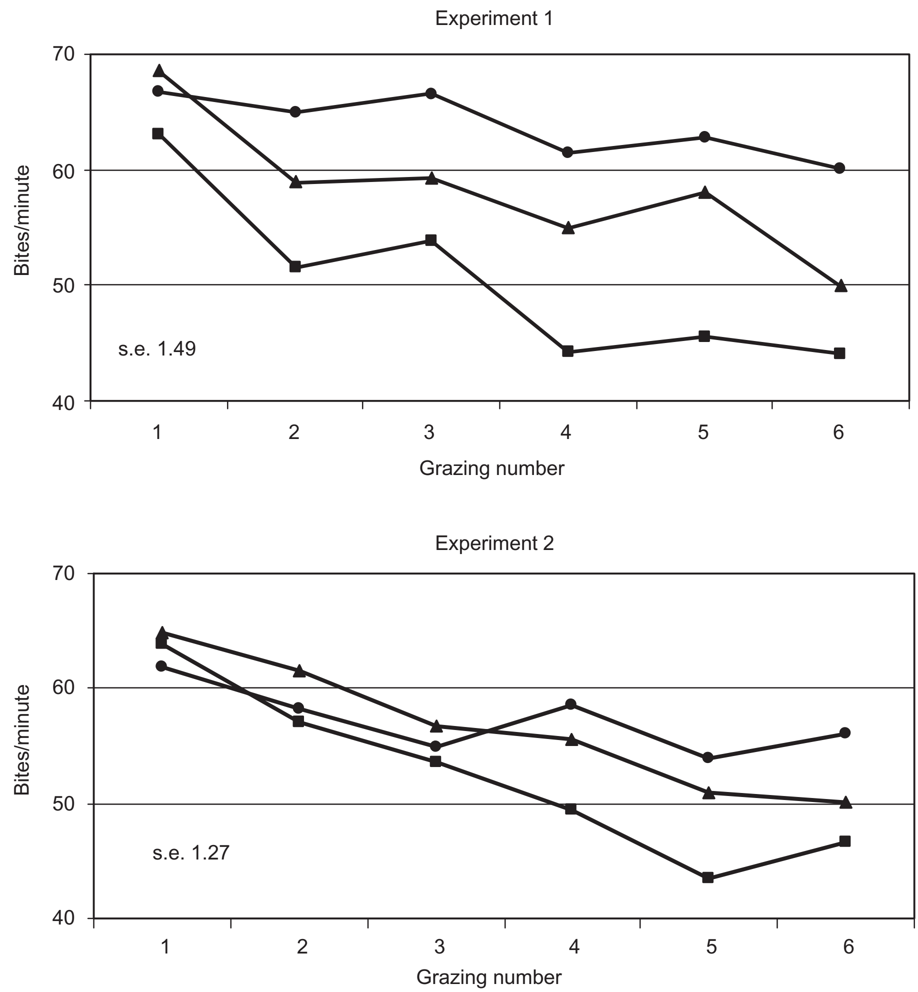

Figure 4. The average biting rate of the cows (am and pm) on 3 successive days on the high (●), medium (▲) and low (■) quality swards for six consecutive grazings in Experiments 1 and 2.

Table 4. Average daily dry matter and organic matter intakes (kg/cow) and diet organic matter digestibility (g/g) for cows grazing three swards at two stocking rates over four grazing rotations in Experiment 2 using C_{33}/C_{32} alkanes for intake, and the feed:feacal C_{35} alkane ratio for digestibility

Rotation	Sward type × Stocking rate[1]						s.e.	Significance[2]			
	HQ		MQ		LQ			*ST*	*SR*	*ST × ROT*	*SR × ROT*
	HR	*LR*	*HR*	*LR*	*HR*	*LR*					
	Dry matter intake										
1	14.6[a]	15.3[a]	14.8[a]	14.8[a]	11.5[b]	13.8[a]	0.35				
2	14.3[a]	16.3[b]	13.8[a]	15.7[b]	11.4[c]	13.9[a]	0.35				
3	14.2[a]	15.0[a]	13.1[b]	14.4[a]	11.1[c]	13.0[b]	0.35				
4	13.5[a]	15.1[c]	12.6[a]	14.6[bc]	11.6[d]	14.6[bc]	0.39				
Mean	14.1[ab]	15.4[b]	13.5[a]	14.9[ab]	11.4[c]	13.8[ab]	0.46	***	***	*	*
	Organic matter intake										
1	12.9[ab]	13.6[a]	13.2[ab]	13.1[ab]	10.2[b]	12.3[b]	0.32				
2	12.4[a]	14.1[b]	12.0[a]	13.7[b]	9.9[c]	12.1[a]	0.32				
3	12.3[a]	12.6[a]	11.5[a]	12.5[a]	9.7[b]	11.5[a]	0.32				
4	11.6[a]	13.2[b]	10.9[ac]	13.2[b]	10.1[c]	12.7[b]	0.35				
Mean	12.3[a]	13.4[a]	11.9[a]	13.1[a]	10.0[b]	12.1[a]	0.39	***	***		**
	Diet organic matter digestibility										
1	0.770[a]	0.796[a]	0.781[a]	0.773[a]	0.720[b]	0.773[b]	0.0089				
2	0.780[a]	0.782[a]	0.759[a]	0.769[a]	0.676[b]	0.717[b]	0.0089				
3	0.757[a]	0.755[a]	0.725[b]	0.722[b]	0.653[c]	0.681[d]	0.0089				
4	0.758[a]	0.758[a]	0.728[ab]	0.742[ab]	0.695[c]	0.719[bc]	0.0100				
Mean	0.766[a]	0.773[a]	0.748[a]	0.751[a]	0.686[b]	0.713[b]	0.0095	***		*	

[1] See footnotes to Table 1.
[2] There was no interaction between stocking rate and sward type.
ROT = grazing rotation.

Table 5. Average daily milk yield, milk fat and protein concentrations, body weight and body weight gain of cows grazing three sward types at two stocking rates in Experiments 1 and 2

Trait	Experiment	Sward type × Stocking rate						s.e.	Significance[2]	
		HQ		MQ		LQ			ST	SR
		HR	LR	HR	LR	HR	LR			
Milk yield (kg/cow)	1	12.5[ab]	13.8[a]	11.1[ab]	13.4[a]	9.6[b]	11.6[ab]	0.80	**	**
	2	17.4[a]	19.3[b]	16.6[ac]	18.5[ab]	15.3[c]	17.2[a]	0.46	***	***
Milk fat concentration (g/kg)	1	40.4	38.6	42.5	39.3	39.3	39.9	1.27		
	2	37.0	35.9	38.6	37.4	38.7	37.4	0.93		
Milk protein	1	34.9	36.2	35.9	34.2	37.4	35.6	0.99		
concentration (g/kg)	2	32.4	32.7	32.1	32.2	33.1	32.4	0.49		
Body weight (kg)	1	543	559	548	553	551	549	4.3		
	2	528	527	531	531	531	524	3.2		
Body weight gain (kg/day)	1	0.17	0.49	0.29	0.37	0.29	0.23	0.090		
	2	0.14	0.22	0.10	0.24	0.20	0.12	0.067		

[1] See footnotes to Table 1.
[2] There was no interaction between stocking rate and sward type.

3.41 (s.e. 0.081) g per 100 g milk, and 3.35, 3.27 and 3.23 (s.e. 0.037) g per 100 g milk, for high, medium and low GP, respectively. The corresponding values in E2 were 23.1, 23.5 and 23.2 (s.e. 0.49) kg milk, 3.45, 3.44 and 3.48 (s.e. 0.088) g fat per 100 g milk and 3.22, 3.21 and 3.29 (s.e. 0.042) g protein per 100 g milk. Average body weight in E1 was 509, 504 and 512 (s.e. 9.2) kg, and the corresponding values in E2 were 498, 515 and 516 (s.e. 7.5) kg for high, medium and low GP, respectively.

Average milk production, milk composition, body weight and body weight gain of the cows in E1 and E2 for P2 are shown in Table 5. Daily milk yield declined as sward quality deteriorated and as SR increased in both experiments. The average weekly milk yields for both experiments are shown in Figure 5. There was a significant interaction between SR and rotation for milk yield in both E1 ($P < 0.05$) and E2 ($P < 0.001$), indicating that the effect of SR increased during the course of the experiments. There was a significant interaction between ST and rotation ($P < 0.05$) for milk yield in E2 but there was no indication that the effect of ST increased after the first rotation in either experiment. There was no effect of ST or SR on fat or protein concentration of the milk in either experiment. There was no effect of ST or SR on body weight or body weight gain in either experiment.

Over the four rotations of E1, the LMY exceeded observed milk yield by 3.1, 5.0 and 6.1 kg at high SR and by 2.0, 2.3 and 4.1 kg at low SR, for HQ, MQ and LQ swards, respectively. The corresponding values for the five rotations of E2 were 2.7, 3.1 and 4.4 kg for high SR, and 0.6, 1.4 and 2.9 kg for low SR.

Average milk production for the first four rotations of E2 could be predicted using the following expression:

−10.9 (s.e. 4.70) + 0.515 (s.e. 0.0797) × pre-experimental milk yield + 0.553 (s.e. 0.1773) × DMI + 0.112 (s.e. 0.0711) × diet LL (r.s.d. 0.965, R^2 0.84).

Discussion

Three different swards were created by imposing different GP in the spring to early summer period with dairy cows. Many sward characteristics are interrelated. In this study, high sward digestibility was associated with lower pre-grazing herbage mass

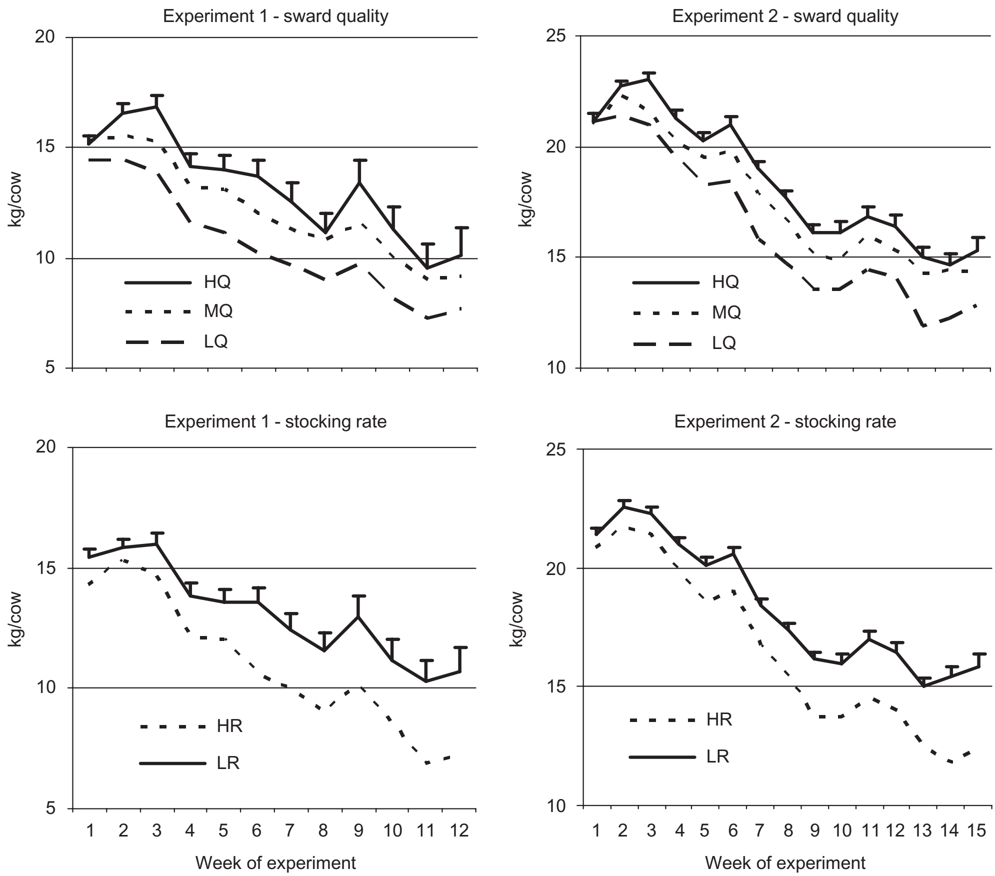

Figure 5. The average milk yield per cow for each week of Experiments 1 and 2 for the three swards and the two stocking rates (the s.e. of the main effect at each week indicated).

and daily herbage allowance. The identical SR imposed across the different swards resulted in different levels of daily herbage allowance per cow across the treatments. However, because of the sward composition differences, the allowance of live leaf was similar between ST at the same SR. The post-grazing sward height (PGH) increased progressively with decreasing sward quality. The SR used in the experiments were set at levels that represented the low and high ends of the range used in commercial farming. If however, they had been set to match the availability of grass, then a larger effect of sward quality would likely have been found.

Herbage selected

Two measures of diet digestibility were used. The estimates of diet composition from the OF samples gave information on how the diet changed as swards were grazed down. This subject was reviewed by Le Du and Penning (1982). Three problems arise when estimating average diet composition from samples taken as the sward is grazed down. Firstly, a simple mean of the three samples taken presumes that each makes an equal contribution to diet composition. Secondly, the pattern of change in diet composition as the sward is grazed has an effect. In the present study, the change was linear in both experiments, but became steeper with deteriorating sward quality. Thirdly, the last sample (the beginning of day 3 or the 5^{th} grazing) is not representative of the base of the sward when grazing has ceased. A significant quantity of the total 3-day intake still occurred after the last sampling. Based on these considerations, the OF 3-day diet composition values would over-estimate the true values. In addition, previous work at this centre found that the OMD of the OF extrusa samples was 1.5 g/g OM higher than of split fresh unswallowed samples (Dillon, 1993).

The other measure of diet OMD was based on the use of C_{35} alkane as an indigestible marker. The marker concentration in samples of herbage was 17 mg/kg DM. That is just above the level needed for acceptable accuracy of measurement (Mayes, personal communication). The estimated digestibility is sensitive to C_{35} concentration in the herbage samples. A 1 mg increase in herbage concentration of C_{35} leads to a decrease in calculated digestibility of 0.013 g/g organic matter. The C_{35} concentration in faeces was about 4.5 times that in herbage. The advantage of the marker technique is that is gives a measure of diet digestibility averaged over the 6 days of faecal sampling for each individual cow, but the estimates are not entirely free from the problems associated with the OF approach. The faecal samples from the cows represent the faeces that was excreted during the grazing down of the swards over the 3 days, but the herbage C_{35} alkane concentration is based on the same samples used to calculate the OMD of the OF samples over the 3 days. Consequently, they do not include the values for the base of sward when grazing ceases. However, the herbage C_{35} alkane changed little with grazing down of the swards (18.2, 17.8 and 16.7 mg/kg DM, s.e.d. 0.24, for days 1, 2 and 3, respectively) so the estimates of OMD can be regarded as reliable.

The herbage eaten by grazing animals is usually of a higher nutrient value than the sward as a whole (Meijs and Hoekstra, 1984; Hodgson, 1986). Poor sward quality and higher defoliation intensity reduced diet quality in both experiments. The C_{35} technique indicated that the effect was much larger than indicated by the OF samples. The $OMDC_{35}$ was similar to the sward OMD in E2. This is surprising given that the PGH for all treatments was greater than the cutting height of 4.5 cm used to characterise the different swards. Mayne and Wright (1988) suggested that differences in the diet selected by animals grazing temperate swards in a vegetative stage might simply reflect the composition of the grazed horizon rather than any active selection by the animals. The average LL content of the diet in both experiments was considerably higher than that of the sward. L'Huillier, Poppi and Fraser *et al.* (1986) also found that the nutrient content of the selected herbage was closely related to the degree of defoliation.

Poppi, Minson and Termouth (1981) showed that there was a shorter retention time in the rumen for leaf compared to stem. In the present study, LS in the diet increased as the swards were grazed down (Figures 2 and 3) and comprised between 0.244 to 0.411 of the diet on the third and final day of grazing down. This suggests that passage rate would change on a daily basis. However, the C_{35} marker is associated with the solid phase of digesta (Mayes *et al*., 1988; Dillon, 1993) and as an internal marker would be expected to behave in a similar way to the solid phase of digesta. An underestimation of C_{35} of 3 mg/kg of faecal organic matter would lead to an under-estimation of digestibility of *ca* 0.01 g/g organic matter. The faecal sampling encompassed two 3-day cycles of grazing down and this may have been too short to dilute end point errors associated with the last day of grazing of the swards.

Milk production and intake

The reduction in daily milk production between the extremes of sward quality (2.6 and 2.2 kg/day for E1 and E2, respectively) is similar to that reported from New Zealand (L'Huillier, 1988; Hoogendoorn, Holmes and Chu, 1992) and other countries (Michel and Fulkerson 1985; Baker and Leaver, 1986; Fisher *et al.*, 1995). It is of little value to attempt to make generalisations about the effect of herbage allowance on milk yield because different parts of the herbage allowance-milk yield response curve were studied for each ST and only two levels of SR were used. Also, herbage allowance was higher for E2 than E1 because the pre-grazing herbage mass was higher and the stocking rates were lower. The strong response to SR for each ST was mediated through increases in total allowance, LL allowance and PGH. However, the reduced milk yield with poorer quality swards in spite of higher total allowance and PGH and similar LL allowance clearly emphasises the importance of sward structure and OMD. The absence of an effect of treatments on milk fat and protein concentration agrees with the findings of Fisher *et al.* (1995).

The similarities of allowance of LL for ST indicate the ineffectiveness of this measure on its own to describe the sward. On the other hand, the importance of allowance of LL is indicated by the effect of SR on milk production. Clearly, the matrix within which the LL is contained exerts its own effect on production and intake. The swards contained varying proportions of short and tall grass (0.53 to 0.63 for HQ, 0.70 to 0.74 for MQ and 0.78 to 0.82 for LQ for the proportion of total sward composed of tall grass). Sward type differences in this study represented not only differences in vertical distribution of plant material but also differences in spacial distribution of short and tall grass. With short grass, stem and dead material is closer to ground level compared to taller swards. Also, while the upper horizons of tall grass contain a mixture of leaf, stem and dead material, the lower horizons of tall grass contain almost exclusively stem and dead material. Although the proportion of dead material increased and live stem decreased with rotation, with little change in live leaf proportion in both experiments, there was no increase in these components in the diet. The absence of dead material from the diet in spite of increasing amounts in the sward, suggest an important role in influencing intake and production.

The overall effect of increased SR on daily milk yield was 1.8 and 1.9 kg/cow in E1 and E2, respectively. These reductions in milk yield correspond to a proportionate decrease of 0.14 and 0.10 for an increase of 1.15 and 1.11 cows/ha in E1 and E2, respectively. Journet and Demarquilly (1979) in a review of 13 experiments showed that an increase of one cow/ha resulted in an average reduction in milk production per cow of 0.10.

Pre-experimental milk yield, intake and a measure of diet quality explained a high proportion of the variation in milk yield during the experiment (0.84). Peyraud, Delagarde and Delaby (2001) have shown from a summary of 6 experiments that for each 1 kg increase in intake, the milk yield response was 1 kg. The corresponding figure in this experiment was 0.55, but the value increased to 0.76 when diet quality was omitted from the analysis. The partial regression co-efficient for pre-experimental milk yield is particular to this study in that it is based on the average yield of the cows receiving no supplement during P1 when the herds alternated between the different grazing pressures. Pre-experimental yield is a method of classifying the cows on the basis of their relative production potential because they were all managed similarly during P1.

The discrepancy between LMY and experimental milk yield emphasises the failure of each treatment group to maintain the physiological optimum milk yield during the normal decline in lactation (Delaby, Peyraud and Delagarde, 2001). While the discrepancies were large for the lower quality swards and the high SR, it was only the low SR and HQ sward in E2 that had a discrepancy (0.64 kg of milk) that indicated close to sufficient nutrients were being consumed from the pasture. The corresponding value for this treatment in E1 was 1.97 kg. Total DM and LL allowances as well as PGH were all higher for this treatment in E2 than E1. Because the cows used in the experiment were relatively low yielding, the difference between LMY and actual milk yield emphasises the large restriction the swards and SR exerted on milk production.

In some early reports (Corbett, Langlands and Reid, 1963; Curran and Holmes, 1970) a positive linear relationship was proposed between digestibility of the diet and its intake by cattle and sheep up to a level of digestibility of 0.75 to 0.77 g/g OM. In contrast, Hodgson (1977) indicated a linear relationship for intake and digestibility for grazing calves and dairy cows for diet OMD levels in excess of 0.80. The results of E2 are in agreement with this. A simple expression incorporating pre-experimental milk yield and LL in the diet explained 0.62 of the variation in average DMI. This corresponded to the range 0.76 to 0.80 diet OMD as measured with the OF cows.

The reduction in milk yield as sward quality deteriorated and as SR increased was due to reduced intake and a lower quality diet. However, as is shown in Figure 5, the effect of sward quality remained similar across rotations in both experiments, but the effect of stocking rate increased with time. It is not immediately clear why this occurred. A possible explanation is that while the total DM and LL allowances remained similar for each sward type across rotations in experiments, the total DM and LL allowance declined for the HR compared to the LR. Mayne, Newberry and Woodcock (1988) found that lax grazing in early season (*ca*. 10 cm) resulted in an increasing effect on milk yield later in the season. The low quality sward in that study was roughly equivalent to the MQ sward in the present study and there was not a systematic investigation of possible interactions between ST and SR as was the case in this study.

Grazing behaviour

An increase in grazing time generally appears to be a compensating response on the part of the animal for a decline in short-term rate of intake (Chacon and Stobbs, 1976). In the current study, grazing time was not very sensitive to either ST or SR in E2. However, in E1 there was a significant interaction between ST and SR. Grazing time was greater for HR compared to LR for both the MQ and LQ swards. It was however, lower for HR compared to LR for the HQ sward. Hodgson (1985) showed that grazing time may be reduced on particularly short swards (low pre-grazing herbage mass) similar to the HQ sward in the present study.

Biting rate usually tends to decline as pre-grazing sward height or herbage mass increases, and as intake per bite increases (Hodgson, 1985). The principle reason for this is that the ratio of manipulation to biting jaw movement increases as intake per bite and the size of individual plant components prehended increase (Chalmers *et al.*, 1981). In the present study, the variation in biting rate was most likely a direct response to variations in sward conditions. The reduction in biting rate for grazings 1 to 6, and as sward quality declined, was due to the high degree of selection of LL by the cows. Live leaf is in highest concentration in the upper part of the sward, while stem and dead material are in highest concentration in the lower parts (Bentholm and Jacobsen, 1961). Therefore, with swards containing a high proportion of LL, the effort in selection of live leaf is less, resulting in a high biting rate. However, with a sward containing a low proportion of LL, biting rate is lower because of the increase in the manipulative jaw movements associated with prehension of longer material.

In conclusion, the results of these two experiments indicate that milk yields of spring-calving dairy cows on rotationally grazed pastures are higher in summer when high rather than low stocking rates are applied in spring/early summer. The increased milk production was attributed to the higher intake of herbage of higher nutritive value. There was no interaction between grazing pressure in the spring/early summer and the subsequent stocking rate in summer/autumn period.

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