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The effect of herbage mass and allowance on herbage intake, diet composition and ingestive behaviour of dairy cows

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An experiment was conducted to examine the effects of herbage mass [HM, based on regrowth intervals of 35 (T) and 21 (S) days] and herbage allowance [HA, 20.2 (H) and 12.7 (L) kg organic matter (OM)/cow] on herbage OM intake (OMI), dietary composition and ingestive behaviour of dairy cows. Four groups of three cows each were used in a 4 × 4 greco-latin square design along with four oesophageal-fistulated cows. The treatment periods were 7 days and the squares (SQ) were repeated three times in a balanced way. The experiment was conducted from 11 April to 3 July 1986. The HM (organic matter) above 3 cm was 3064, 3472 and 3515 kg/ha for T and 2395, 1113 and 2396 kg/ha (s.e. 94) for S, for SQ 1 to 3, respectively. Organic matter digestibility (OMD) was 842, 799 and 778 g/kg for T, and 851, 842 and 804 g/kg for S (s.e. 0.9), for SQ 1 to 3, respectively. Sward height (cm) after grazing was 8.5 and 7.6 for T and S, and 9.6 and 6.5 for H and L (s.e. 0.18), respectively. OMI was 15.2, 14.8 and 15.2 kg for TH, 12.3, 11.9 and 10.7 kg for TL, 15.8, 14.8 and 14.5 kg for SH and 11.9, 11.1 and 11.2 kg for SL (s.e. 0.24), for SQ 1 to 3, respectively. The OMD of the diet was closely related to proportion of live leaf in the diet and sward OMD. Average biting rate increased with decreasing HM (R^2 0.65). Grazing time was 8.93, 9.11 and 9.06 h for TH, 8.13, 7.96 and 7.91 h for TL, 8.96, 9.59 and 9.29 h for SH and 8.56, 9.36 and 8.52 h for SL (s.e. 0.155), for SQ 1 to 3, respectively. Multiple regression analysis showed that OMI was significantly related to HM (+0.48 kg/t), OMD of the sward (+0.18 kg per 10 g/kg) and pre-experimental milk yield (+0.37 kg/kg) (R^2 0.89). The increase in OMI with potential milk yield, as indicated by pre-experimental yield, accounted for 0.80 of the supplementary energy requirements.

Keywords: Cows; diet; herbage

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Introduction

Pre-grazing herbage mass under rotational grazing can be manipulated by changing the rotation interval. Thus, by using a long rotation a greater accumulation of herbage will occur than by using a short rotation. With very short swards, herbage intake may be depressed due to reductions in bite size as seen in sheep grazing experiments using continuous grazing systems (Hodgson, 1986). On the other hand, intake of digestible nutrients may be depressed on longer swards due to deterioration in the quality of the sward because of advanced maturity. Some reports suggest that intake may increase on taller swards under rotational grazing because animals have access to a greater proportion of more easily harvested material (Stockdale, 1985). However, herbage allowance is likely to influence the relationship between herbage mass and in take (Stakelum, 1986a,b; Peyraud and Gonzalez-Rodrigez, 2000).

Daily herbage intake is considered to be the product of three variables, namely intake per bite, biting rate per minute and total grazing time per day. Many studies have been conducted on the effects of sward structure on intake per bite (Hodgson, 1981, 1986) but there are few reports on the effect of sward structural characteristics, which are known to affect intake per bite, on the daily intake of herbage by dairy cows. Herbage mass, sward structure and density, and herbage digestibility are all interrelated. The present experiment was undertaken to study, under controlled conditions and without the confounding effect of time, the influence of pre-grazing herbage mass or sward surface height on herbage intake, dietary composition and the components of intake (grazing time, biting rate and intake per bite).

Materials and Methods

Experimental design

Four groups of three cows each plus four oesophageal fistulated cows (OF) were assigned to four grazing treatments (TRT) in a greco-latin square design with a 2×2 factorial arrangement of treatments. The four OF cows formed the greco component of the experimental design. The treatments were a tall (T) and a short (S) sward that were the result of regrowth intervals following cutting of 35 and 21 days, respectively, and high (H) and low (L) daily herbage allowance (HA) of either 22 or 14 kg of dry matter/cow. Each period (PER) was 1 week in duration. There were three squares (SQ) in the following sequence; SQ 1 from 11 April to 8 May, SQ 2 from 9 May to 5 June and SQ 3 from 6 June to 3 July.

Animals

The 12 cows, which comprised the four groups, were selected from a large spring calving herd. No first lactation animals were included. The 12 cows were divided into three blocks. Each block contained cows of similar yield and calving date. The cows were allocated at random to the four groups from each block. The mean calving date of the cows was 10 January (s.d. 11 days) and their mean parity was 2.5 (s.d. 0.80). Mean daily milk yield at the beginning of the experiment was 27.5 kg (s.d. 1.17) and mean live weight was 517 kg (s.d. 46.7).

Grazing management and sward conditioning

Strip-grazing management was used with the cows grazing over one strip of ground each period and no run back to previously grazed areas. The treatments were applied for 4 days (day 1 = start) and daily herbage intake was measured for the final 3 days. Herbage mass (HM), as organic matter, was estimated at the start and after 3 days. The daily grazing plots were fenced individually to give the desired HA levels. Plot sizes for the first 3 days grazing were based on HM measurements on day 1 with corrections for appropriate growth values while the fourth plot size was based on the HM values taken on that day. During the 3 days of intake measurement, HM was measured each morning in the areas to be grazed over the following 24 h and the areas were then fenced. Each area was surrounded by double strands of electrified wiring to prevent grazing beneath and through the wires. Water was supplied in each paddock. The cows entered the new paddocks each evening and moved to new areas the next evening. The herbage offered was regrowth after cutting with a single-chop forage harvester to 4.5 cm. Nitrogen was applied at 40 kg/ha after cutting. The experiment started on 11 April (1986) and finished on 3 July. The cows had been at pasture for 2 weeks before the treatments commenced.

Animal management and measurements

All cows were dosed with two magnesium-releasing rumen bullets as a preventative against hypomagnesaemia. Cows were milked at 16:8-h intervals. Milk yield was recorded on 5 consecutive days of each PER (days 3 to 7). The concentrations of fat, protein and lactose were determined for one successive morning and evening sample on day 3 of each PER using a FOSS-Let instrument (AS/M Foss, Electric, Denmark). Biting rate was measured on all cows as described by Stakelum and Dillon (2003) at three times (TIME) during the grazing down of the plots, namely, immediately the cows entered the plots, 4 h later and again after milking the following morning. Grazing times were also recorded for all cows as described by Stakelum and Dillon (2003).

Herbage intake and sward measurement

Daily herbage intake was measured by a two-stage sward difference technique (Meijs, 1981) with some modifications as described by Stakelum and Dillon (2003). Four strips (5 and 8 m long and 0.9 m wide) were cut in each grazing plot with a twin-disc rotary Agria mower to 3 cm on days 5 to 7 of each PER. The HM in the stubble between 3 and 2 cm of the cut strips was then estimated by cutting with a lawnmower to 2 cm. Post-grazing HM above 3 cm (Agria mower) and between 3 and 2 cm (lawnmower) were taken immediately after the cows moved out of the plots on days 6 to 8 of each PER. Ash determinations were carried out on subsamples of all HM determinations. Daily herbage intake was calculated as the difference between the sum of HM above 3 and 2 cm pre-grazing and the sum of HM above 3 and 2 cm post-grazing. HM and intake (OMI) are expressed as organic matter (OM). Sward surface heights were taken, before and after grazing, on the 3 days of intake measurement as described by Stakelum and Dillon (2003) with the HFRO sward stick (Hutchings, 1991). Additionally, on 14 random days (DAY) stubble heights on the 3-cm cuts pre- and post-grazing (CUTTIME) were taken. One strip per TRT and 20 heights per strip were taken on each sampling day. The procedure was repeated for the 2-cm cuts on 10 random days.

The OF animals grazed with their respective TRT for days 1 to 3 each PER to accustom them to the swards. Before sampling the swards they were removed to a bare paddock for day 4 and then returned to the paddock for sampling. This was to ensure that vigorous grazing occurred while they sampled the swards. The OF animals sampled the swards on 2 of the 3 days of intake measurement at two times (TIME) during the grazing of the plots, namely on the evenings immediately the grazing groups entered the new plots and again the following morning after milking. The sample collection and preparation was as described by Stakelum and Dillon (2003).

Intake per bite was measured using the OF cows over the period during which extrusa samples were collected. A foam plug was inserted in the lower oesophagus of each OF cow and the animal was allowed to graze over the grazing area and the number of bites (prehension bites, range 119 to 367) was carefully recorded during the collection of each sample.

Sample analyses

The herbage samples cut from the pre- and post-grazing strips were analysed in duplicate for ash by incineration in a furnace at 650 °C for 4 h. The freeze-dried OF and the pre-grazing herbage mass samples cut to 3 cm were analysed in duplicate for ash, organic matter digestibility (OMD) (Morgan and Stakelum, 1987; Morgan, Stakelum and Dwyer, 1989) and crude protein based on Kjeldhal N. A point analysis technique was used to measure the morphological composition of the OF extrusa samples as described by Stakelum and Dillon (2003). Intake of digestible organic matter (DOMI) was calculated from OMI and the mean OMD of the OF samples for both grazings.

Statistical analyses

Herbage mass, allowance, intake, sward characteristics, milk yield and composition and grazing time were analysed by partitioning the variation with respect to the factorial nature of the treatments (factors = TRT, PER, SQ, group, block, OF). A split-plot factor for TIME was added to the model for biting rate and diet composition. Student's t-tests were used to compare pairs of treatment means for effects of sward type and herbage allowance.

Differences in cutting height between pre- and post-grazing for the two machines were analysed by the following model: $Y_{ijk} = \mu + TRT_i + CUTTIME_j + (TRT \times CUTTIME_{ij}) + e_{ijk}$, where i =1 to 4, and j = 1 to 2.

Results

Cutting height and sward characteristics

The cutting height was 3.1 cm and 3.2 cm (s.e. 0.028) for the pre- and post-grazing strips, respectively. The cutting height for the lawnmower was similar for pre- and post-grazing. There was no effect of TRT on cutting height.

Table 1 outlines the characteristics of the two swards for each SQ. The range in pre-grazing HM was 1113 to 3515 kg/ha. This was associated with changes in pre-grazing sward height (range 18 to 38 cm). In SQ 1, HM and sward height were *ca*. 600 kg and 6 cm higher for T than for S, and this was associated with little change in either OMD or crude protein concentrations between the sward types. In SQ 2, HM and sward height were *ca*. 2400 kg and 14 cm higher for T than for S. This was associated with a decrease of 43 g/kg in OMD and the crude protein concentration in OM decreased by 94 g/kg for T relative to S. The very low pre-grazing HM for the S sward in SQ 2 was due to poor growing conditions subsequent to mechanical defoliation of a high HM. In SQ 3, HM and sward height were *ca*. 1100 kg and 9 cm higher for T than for S and this was associated with a decrease of 26 g/kg in OMD while the crude protein concentration in OM decreased by 32 g/kg for T relative to S. Because there were interactions between sward type and SQ, the effects of TRT are shown separately for the SQs.

Table 1. Pre-grazing herbage characteristics (above 3 cm) for each sward type by square

Square[1]	Sward type[2]		s.e.
	Tall	Short	
	Herbage mass (organic matter kg/ha)		
1	3064[a]	2395[b]	
2	3472[a]	1113[c]	132.5
3	3515[a]	2396[b]	
	Sward height (cm)		
1	25.8[c]	21.4[e]	
2	31.6[b]	17.8[f]	0.53
3	37.9[a]	29.2[d]	
	Organic matter (OM) digestibility (g/kg)		
1	842[b]	851[a]	
2	799[d]	842[b]	1.3
3	778[e]	804[c]	
	Crude protein (g/kg OM)		
1	210[b]	213[b]	
2	178[c]	272[a]	3.6
3	172[d]	204[b]	

[1]Main effect was significant for all variables at P<0.01.
[2]Main effect was significant for all variables at P<0.001.
[abcdef]Means with a common superscript do not differ significantly.

Post-grazing HM to 3 cm was significantly higher for T than for S (P<0.001) and for H than for L (P<0.001). There were significant interactions for sward type by HA (P<0.001), sward type by SQ (P<0.001) and sward type by HA by SQ (P<0.01). The values for TRT and SQ are shown in Table 2. Post-grazing sward height was significantly higher (P<0.01) for T than for S (8.5 *v*. 7.6 cm, s.e. 0.18) and significantly higher (P<0.001) for H than for L (9.6 *v*. 6.5 cm, s.e. 0.18).

Herbage allowance and intake

The realised daily HA was 20.2 and 12.7 kg OM/cow (s.e. 0.12) for H and L, respectively, based on pre-grazing HM to 3 cm. OMI was 13.3 kg (s.e. 0.48) and 13.6 kg (s.e. 0.69) based on HM to 2 and 3 cm, respectively. The HM between 3 and 2 cm

Table 2. Residual herbage mass (organic matter above 3 cm; kg/ha) for sward type by herbage allowance by square

Square	Sward type × herbage allowance				s.e.
	Tall		Short		
	High	Low	High	Low	
1	736[b]	203[ef]	496[d]	124[ef]	
2	905[a]	289[e]	233[e]	92[f]	35.1
3	831[ab]	446[d]	610[c]	262[e]	

[abcdef]Means with a common superscript do not differ significantly. All main effects were significant (P<0.001).

Table 3. Daily herbage intake (organic matter; kg/cow) for sward type by herbage allowance by square

Square[1]	Sward type[2] × herbage allowance[3]				s.e.
	Tall		Short		
	High	Low	High	Low	
1	15.2[ab]	12.3[c]	15.8[a]	11.9[cd]	
2	14.8[ab]	11.9[cd]	14.8[ab]	11.1[de]	0.24
3	15.2[ab]	10.7[e]	14.5[b]	11.2[de]	

[1,2]Main effects not significant.
[3]Main effect significant at P<0.001.
[abcde]Means with a common superscript do not differ significantly.

pre- and post-grazing was 245 (s.e. 15.3) kg OM/ha and 282 (s.e. 30.9) kg OM/ha, respectively. This caused the overestimate of OMI when the values were based solely on HM above 3 cm. The estimates of OMI used are based on HM mass values above 2 cm. HA was the dominant effect and OMI was significantly (P<0.001) lower at the L allowance for each sward type. There was, however, a significant sward type by HA by SQ effect on OMI (P<0.05). There was no effect of sward type on OMI, except that OMI was significantly higher for T than for S in SQ 2 for the L allowance (Table 3).

Dietary composition

Of the variables of interest (live leaf lamina, live stem, dead leaf lamina and dead stem), dead stem was not present in measurable amounts and the overall mean for dead leaf lamina did not exceed a proportion of 0.01 for either the first or second grazing. Therefore, these fractions are omitted from the results. Additionally, as live stem was the complement of live leaf lamina, live leaf lamina was considered sufficient to describe the morphological composition of the diet.

There were interactions between the main effects of sward type and HA and both

Table 4. Organic matter digestibility (g/kg) of the diet selected during first and second grazing periods for sward type by herbage allowance by square[1]

Square[2]	Sward type[3] × herbage allowance[4]			
	Tall		Short	
	High	Low	High	Low
		1st Grazing		
1	867[a]	868[a]	861[ab]	863[ab]
2	837[c]	827[cd]	876[a]	874[a]
3	825[cd]	816[d]	852[ab]	844[bc]
		2nd Grazing		
1	834[cd]	822[ed]	848[bc]	837[cd]
2	820[ed]	793[f]	870[a]	859[ab]
3	794[f]	770[g]	815[ed]	804[ef]

[1]The s.e. was 5.3 for each value in the table.
[2,3]Main effects significant at P<0.001.
[4]Main effect significant at P<0.01.
[abcdefg]Means, within grazing category, with a common superscript do not differ significantly.

Table 5. Relative frequency of live leaf in the diet for sward type by herbage allowance by square for the 1st and 2nd grazing of the swards[1]

Square[2]	Sward type[3] × herbage allowance[4]			
	Tall		Short	
	High	Low	High	Low
		1st Grazing		
1	0.940[a]	0.949[a]	0.924[a]	0.930[a]
2	0.712[b]	0.681[b]	0.914[a]	0.923[a]
3	0.674[b]	0.669[b]	0.806[ab]	0.827[ab]
		2nd Grazing		
1	0.783[a]	0.464[ce]	0.780[a]	0.628[b]
2	0.590[bc]	0.416[e]	0.899[a]	0.854[a]
3	0.582[bc]	0.334[e]	0.593[bc]	0.509[bce]

[1]The s.e. was 0.031 for each value in the table.
[2,3,4]All main effects significant ($P<0.001$).
[abcde]Means with a common superscript, within each grazing category, do not differ significantly.

TIME and SQ for diet OMD and therefore the mean values are shown separately for each grazing and SQ in Table 4. There was no effect of sward type on diet OMD in SQ 1. Diet OMD was 43 and 58 g/kg lower for T than for S in SQ 2 for the first and second grazing, respectively. Diet OMD was 27 g/kg lower for T than for S in SQ 3, for both grazings. The effect of HA on diet OMD was small for the S sward, the first SQ and first grazing. It was 27 and 24 g/kg higher for H than for L for the second grazing in the second and third SQ, respectively.

There were interactions between the main effects of sward type and HA and both TIME and SQ for relative frequency of live leaf lamina in the diet and therefore the mean values are shown separately for each grazing and SQ in Table 5. The frequency of live leaf lamina in the diet was similar in SQ 1 for both swards except for the second grazing at the L allowance where it was lower for T than for S. It was lower in the second and third SQ for T than for S except at the H allowance in the third SQ. It was not affected by HA for the first grazing. It was higher for H than for L for the second grazing, particularly for the T sward.

The OMD of the OF samples was highly related to the relative frequency of live leaf lamina. The regression equation using all observations (n = 96) was: OMD = 145 (s.e. 7.5) × live leaf lamina + 731 (s.e. 5.6) (r.s.d. 14.5, R^2 0.79).

Diet OMD was closely related to the OMD of the sward above 3 cm. The regression equation relating diet OMD to sward OMD was: diet OMD = 771 (s.e. 75.0) × sward OMD + 205 (s.e. 61.4) (r.s.d. 15.3, R^2 0.70). The mean values for diet OMD and sward OMD were 837 and 819 g/kg, respectively.

There was a significant ($P<0.05$) sward type by HA by SQ effect on DOMI. The mean values for SQ and the individual treatments are shown in Table 6. HA was the dominant effect and the L allowance significantly reduced DOMI ($P<0.001$) for each sward type. There was a lower DOMI ($P<0.05$) for T than for S at the H allowance in SQ 2, and a lower DOMI ($P<0.05$) for T than for S at the L allowance in SQ 3.

Table 6. Daily intake of digestible organic matter (kg/cow) for sward type by herbage allowance by square

Square[1]	Sward type[2] × herbage allowance[3]				s.e.
	Tall		Short		
	High	Low	High	Low	
1	13.0[ab]	10.4[d]	13.5[a]	10.1[d]	
2	12.3[bc]	9.6[de]	13.0[ab]	9.6[de]	0.183
3	12.3[bc]	8.5[f]	12.1[c]	9.2[e]	

[1,3]Main effects significant at $P<0.001$.
[2]Main effect significant at $P<0.05$.
[abcde]Means with common superscripts do not differ significantly ($P<0.001$).

Grazing and ingestive behaviour
Intake per bite was significantly higher for T than for S ($P<0.001$). The values were 1.29 and 1.03 g OM for the first grazing and 1.01 and 0.79 g OM for the second grazing (s.e. 0.033) for the T and S swards, respectively. There were no other significant effects. The regression equation relating average intake per bite (g) to pre-grazing HM (kg/ha) was: 0.174 (s.e. 0.0326) × HM + 0.571 (s.e. 0.0917) (r.s.d. 0.214, R^2 0.38). The corresponding equation for pre-grazing sward height (cm) was: 0.206 (s.e. 0.0291) × sward height + 0.469 (s.e. 0.0838) (r.s.d. 0.1880, R^2 0.52).

There were interactions between the main effects of sward type and HA with SQ, TIME and SQ by TIME for biting rate. There was, however, no interaction between sward type and HA in the main-plot. The mean values for biting rate are therefore shown for sward type and HA for SQ and TIME in Table 7. The dominant effect on biting rate was sward type ($P<0.001$). Biting rates were much slower on T than S especially in SQ 2 and 3. The

Table 7. Biting rate (bites/min) for sward type by herbage allowance by square at three time points during grazing down of the swards[1]

Square[2]	Sward type[3]		Herbage allowance[4]	
	Tall	Short	Tall	Short
		Time 1		
1	51.7[bc]	54.0[c]	51.8[b]	53.9[bc]
2	50.9[b]	58.4[d]	54.5[c]	54.7[c]
3	42.9[a]	52.5[bc]	47.1[a]	48.3[a]
		Time 2		
1	50.0[b]	54.7[c]	50.6[c]	54.1[d]
2	47.9[b]	59.7[d]	52.9[d]	54.7[d]
3	41.8[a]	48.8[b]	42.4[a]	48.2[b]
		Time 3		
1	47.5[c]	50.0[d]	49.3[cd]	48.2[c]
2	44.8[b]	59.1[d]	51.3[de]	52.6[e]
3	38.0[a]	47.7[c]	43.8[b]	41.9[a]

[1]The s.e. was 0.79 for all the values in the table.
[2,3]Main effects significant at $P<0.001$.
[4]Main effects significant at $P<0.01$.
[abcde]Means, within each time category, with a common superscript do not differ significantly.

Table 8. Daily grazing time (h) for sward type by herbage allowance by square

Square[1]	Sward type[2] × herbage allowance[3]				s.e.
	Tall		Short		
	High	Low	High	Low	
1	8.93[ab]	8.13[cd]	8.96[ab]	8.56[bc]	
2	9.11[ab]	7.96[d]	9.59[a]	9.36[a]	0.155
3	9.06[ab]	7.91[d]	9.29[a]	8.52[bc]	

[1]Main effects significant at P<0.01.
[2,3]Main effects significant at P<0.001.
[abcd]Means with a common superscript do not differ significantly.

regression equation relating average biting rate (bites/min) to pre-grazing HM (kg/ha) was: –0.006 (s.e. 0.0007) × HM + 65.9 (s.e. 1.87) (r.s.d. 4.37, R^2 0.65). The corresponding equation for sward height (cm) was: –0.63 (s.e. 0.07) × sward height + 66.8 (s.e. 1.90) (r.s.d. 4.25, R^2 0.67).

There were significant interactions between sward type and HA (P<0.01) and sward type and SQ (P<0.01) for grazing time. The mean values are therefore shown in Table 8 for each treatment and SQ. Grazing time was significantly higher (P<0.001) for H than for L in all SQs for the T sward. It was only significantly higher (P<0.001) for H than for L in SQ 3 for the S sward. Grazing times were not significantly different between sward types at either allowance in SQ 1. They were shorter for T than for S at the H allowance (P<0.05) in SQ 2 and at the L allowance in SQ 2 (P<0.001) and in SQ 3 (P<0.01).

Relationship between intake and sward and cow characteristics

Four regression equations relating OMI and DOMI to various sward and diet characteristics and pre-experimental daily milk yield of the cows are shown in Table 9. OMI was well predicted from HA, pre-grazing HM and OMD, and the milk production ability of the cows. None of the quadratic components of the independent variables were significant. Pre-experimental

Table 9. Equations derived from all the data (n = 48) relating organic matter (OM) intake (kg) (equations 1 to 3) and digestible OM intake (kg) (equation 4) to animal, grazing management and sward characteristics

	Equation			
	1	2	3	4
Constant (LA[1])	–14.9 (5.96)	–12.1 (7.46)	–16.5 (7.59)	–17.2 (5.11)
Constant (HA[2])	–11.4 (5.77)	–8.5 (7.24)	–13.1 (7.36)	–14.1 (4.94)
PMY[3] (kg/day)	0.37 (0.174)	0.35 (0.196)	0.43 (0.190)	0.26 (0.149)
PHM[4] (t OM/ha)	0.48 (0.129)	–	0.51 (0.162)	0.28 (0.110)
PHA[5] (cm)	–	0.03 (0.019)	–	–
Sward OMD[6] (10 g/kg)	0.18 (0.042)	0.16 (0.062)	–	0.23 (0.036)
Diet OMD[7] (10 g/kg)	–	–	0.18 (0.058)	–
R^2	0.89	0.87	0.87	0.90
r.s.d.	0.676	0.760	0.735	0.579

[1]Low herbage allowance; [2]High herbage allowance; [3]Pre-experimental milk yield; [4]Pre-grazing herbage mass above 3 cm; [5]Pre-grazing sward height; [6]Digestibility of sward organic matter; [7]Digestibility of diet organic matter.
( ) Figures in parentheses are the standard errors of the parameters.

live weight was not significant in the models. Based on the r.s.d. values, the equations were less reliable when pre-grazing sward height (equation 2) was substituted for pre-grazing HM, or when diet OMD (Equation 3) was substituted for sward OMD.

Discussion

Herbage intake

The bias in the estimation of OMI, if HM between 2 and 3 cm is ignored, was 0.28 kg OM (proportionately 0.02). This is slightly smaller than that found by Stakelum and Dillon (2003) using the same technique (proportionately 0.04). The HM in the 2- and 3-cm horizons were 245 and 282 kg OM/ha in the present experiment compared to 386 and 461 kg OM/ha reported previously by Stakelum and Dillon (2003), for the pre- and post-grazing samples, respectively. These differences are much lower than those of Meijs (1981) and Meijs and Hoeskra (1984) who measured HM in the horizon between *ca*. 4 and 3 cm pre- and post-grazing. They reported a proportional bias of 0.10 in the estimation of OMI if this HM difference is ignored. The coefficient of variation for the estimate of OMI was 0.034 which compares well with other reported values for the same or similar techniques of 0.044 (Stakelum and Dillon, 2003), 0.056 (Meijs, 1981) and 0.062 (Walters and Evans, 1979). The statistical model explained 98% of the variation in OMI.

The small effect of pre-grazing HM on OMI (*ca*. increase of 0.5 kg per 1 t increase in HM/ha) is in agreement with the results of Meijs (1981) for his experiments in early summer. Combellas and Hodgson (1979) found intake to be lower at high rather than at low HM. Other reports show small positive effects of increased HM on intake (Stockdale, 1985; Stakelum, 1986a,b). Stockdale (1985) found that OMI increased by 1.1 kg for each extra 1 t/ha in pre-grazing HM while Stakelum (1986a) found that OMI increased by between 2.1 and 2.6 kg at high HA, and between 0.7 and 1.1 kg at low HA, for each extra 1 t/ha in pre-grazing HM. There was no evidence that the slopes in the models for pre-grazing HM or sward OMD were different between the two levels of HA in the present study. A criticism of Meijs (1981) is that HM and OMD were confounded. This was also the case, but to a lesser extent, in the present study. Sward OMD was weakly but negatively associated with pre-grazing HM (a decline of 19 g/kg for each extra 1 t/ha in pre-grazing HM; R^2 0.36).

Peyraud *et al*. (1996) suggested that intake could be reduced by 2 kg/day when HM increases from 3000 to 4200 kg or decreases from 2200 to 1400 kg. These values refer to cutting to 5 cm. All of the T swards in this study lay close to, or in, the region of this relationship where increases in HM begin to restrict OMI (if *ca*. 400 kg is subtracted for the horizon between 3 and 5 cm). On the other hand, the S swards all lay in the region where decreasing HM restricts OMI, especially for SQ 2. In the study of Peyraud *et al*. (1996), pre-grazing HM and OMD were not confounded and the inclusion of a term for sward OMD in their intake models had little effect on the coefficient for pre-grazing HM. If either pre-grazing HM or sward OMD is omitted from the models in the present study the coefficient for the remaining term is greatly altered and the accuracy of the models are reduced. The effect of sward OMD on OMI (0.16 to 0.18 kg per 10 g/kg increase in sward OMD) is similar to the value (0.2) reported by Peyraud *et al*. (1996). The range in sward OMD was narrow and at the high end of the scale which may account for the small response.

The increase in OMI with increased HA is similar to those reported by Mott (1974) but higher than those of Le Du *et al.* (1979) and Combellas and Hodgson (1979). The HA in the present study were based on 3 cm cuts and were widely spaced. The relationship between HA and OMI depends on the levels of HA that are being compared, the cutting height of the herbage and the level of production of the experimental animals. Comparisons across different experiments can be difficult. Peyraud *et al.* (1996) found that OMI increased by 0.32 kg per 1 kg increase in HA within the HA range of 11 to 16 kg above 5 cm. They also reported an increase in OMI of 0.36 per 1 kg increase in HA within the HA range 12.6 to 19 kg in a companion experiment. Meijs and Hoekstra (1984) found increases of 0.46 and 0.32 kg per 1 kg increase in HA within the range 15 to 20 kg and 20 to 25 kg of HA above 4 cm, respectively. The present results of 0.47 to 0.48 kg per 1 kg increase in HA agree closely with the first of these values.

Voluntary intake changes in proportion to potential milk yield, and according to the relationships in Table 9, increased by 0.35 to 0.43 kg per 1 kg increase in pre-experimental milk yield. These values are higher than those of Greenhalgh *et al.* (1966), Curran and Holmes (1970) and Peyraud *et al.* (1996) who reported values of between 0.25 and 0.27 kg. Values ranged from 0.17 to 0.33 kg in the various models of Caird and Holmes (1986). This increase in OMI accounts for *ca*. 0.80 of the net energy requirements for 1 kg of milk and indicates that where plentiful high-quality herbage is available dairy cows can satisfy a large proportion of their energy requirements from grazing alone. The absence of an effect of live weight in the models is probably due to the narrow range in live weight (range 480 to 520 kg) of the animal groups.

Diet composition

In general, diet OMD was 18 g/kg higher than the OMD of the sward (to 3 cm). Dillon (1993) found that there was a difference of 15 g/kg in OMD between paired samples of herbage that were passed through the oesophagus and collected at the fistula or not. This indicates that the cows selected herbage of very similar OMD to that offered for grazing above 3 cm. There is less scope for selection in a grazing system such as this, where a short grazing period is used (one day), and a relatively high proportion of the offered sward is consumed (0.74 to 0.79 for the high HA and 0.87 to 0.95 for the low HA). Additionally, all swards were regrowth after mechanical defoliation and were therefore devoid of tall and short grass areas with their consequent differences in herbage composition (Stakelum and Dillon, 1990) and animal preferences (Bao, Gillar and Stakelum, 1998).

Many experiments have failed to show an effect of HA on diet OMD (Meijs, 1981; Greenhalgh *et al*., 1966; Greenhalgh, 1970; Le Du *et al*., 1979, experiment 2). Others have shown small effects (Combellas and Hodgson, 1979; Le Du *et al*., 1979, experiment 1), which agrees with the results found here. Diet OMD was highly correlated to the relative frequency of live leaf lamina in the diet. The relative frequency of leaf lamina, however, showed much larger treatment differences than the OMD of the diet. Although the live stem component was not separated into pseudostem and true stem, it was obvious that it was mainly composed of pseudostem. The OMD of pseudostem is lower than that of leaf lamina but higher than that of true stem (Terry and Tilley, 1964).

Grazing behaviour

The grazing behaviour data generally conformed to the standard theories of behavioural constraints on herbage intake at pasture (Hodgson, 1986). The small effect of HA on biting rate agrees with previous work (Jamieson and Hodgson, 1979a; Le Du *et al*., 1979). The reduction in grazing time with lower HA is also in agreement with other work (Meijs, 1981; Le Du *et al*., 1979; Combellas and Hodgson, 1979; Peyraud *et al*., 1996). It has been suggested that this curtailment of grazing time may be due to the ability of the animals to anticipate a move to fresh pasture (Jamieson and Hodgson, 1979a).

Prehension bites were measured in this experiment. The total jaw movements (biting plus manipulative) remain relatively constant across a range of sward conditions with sheep (Black and Kenny, 1984). In this experiment, a large increase in manipulative jaw movements on the T swards was noticed but not recorded while observing prehension bites. Peyraud *et al.* (1996) has suggested that this may account for the decline in OMI at very high HM.

The absolute values determined for intake per bite were about twice those calculated using OMI, grazing time and biting rate (1.03 *v*. 0.52 g OM). Hodgson (1982) says 'there is a risk that calculation of the product of rate of biting and grazing time will overestimate total daily bites'. This would result in an underestimate of intake per bite as shown by Jamieson and Hodgson (1979a). It is also likely that biting rate, as representative of the 24-h cycle, was an overestimate. Jamieson and Hodgson (1979a) suggested that short-term estimates of biting rate may overestimate the long-term average rate by as much as 16%.

The use of OF animals may also overestimate the true intake per bite as the animals become conditioned to grazing when being used to sample and tend to have a high biting rate and rate of intake. The average daily total bites calculated as the product of grazing time and average daily biting rate was 26237. This agrees with the figure of 26751 from a previous experiment (Stakelum, Lievense and Gleeson, 1987). In that experiment, average biting rate was measured at the start, in the middle and at the end of each bout of grazing, for 24 h over successive days in the grazing down of 1-day plots. The average daily intake per bite for that experiment was 0.61 g OM (calculated from OMI and total bites), and agrees well with the present figure of 0.52 g OM.

Intake per bite decreased as the swards were grazed down (1.16 *v*. 0.90 g for the first and second grazing, respectively). This is consistent with other findings (Forbes and Hodgson, 1985; Jamieson and Hodgson, 1979a,b) and is related to the decline in HM (Jamieson and Hodgson, 1979b; Hodgson, 1981; Hodgson and Jamieson, 1981). However, the decline was small and biting rate did not decline greatly as the swards were grazed down.

Grazing time for the second grazing ranged from 0.7 to 1.6 h. Therefore, 0.85 of the total time spent grazing was completed during the first grazing. It can be argued that the second measurement of intake per bite was a good representation of intake per bite near the end of the grazing down process.

It is concluded that herbage allowance has a dominant effect on intake of organic matter and digestible organic matter. Herbage mass and sward digestibility also affect intake which increases by 0.5 kg for each increase of 1 t/ha in herbage mass and by 0.18 kg per 10 g/kg increase in sward organic matter digestibility. Intake also increases with increasing milk production potential of the cows.

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