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Original article

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Summary — The effects of daily herbage allowance (DHA = herbage mass [HM] x daily offered area [DOA]) and cow characteristics upon herbage intake at grazing were assessed in two experiments. In experiment 1, two DHA (low and medium, 19 and 26 kg organic matter [OM]/cow/day) were compared in a continuous design using two groups of five cows. In experiment 2, three DHA (low, medium and high, 19, 29 and 46 kg OM/cow/day) were compared in a 3 x 3 latin square design using three groups of five cows. Mid-lactating cows (six first lactation per trial) were used. Fat-corrected milk at turnout (FCMt) ranged between 17 to 35 kg and live weight (LW) from 510 to 680 kg. Cows strip-grazed plots of vegetative *Lolium perenne* and did not receive concentrates. Herbage mass cut to ground level (HM) ranged from 3.5 to 7.1 t OM/ha. In experiment 1, herbage organic matter intake (HOMI) (13.5 vs 14.9 kg/day) and FCM yield (20.6 vs 22.0 kg/day) tended to increase from low to medium DHA but differences were not significant. In experiment 2, HOMI increased in a quadratic manner (13.8, 16.2 and 16.7 kg/day) and FCM increased linearly ($P < 0.01$) with DHA (20.4, 21.7 and 23.0 kg/day for low, medium and high DHA, respectively). In both experiments, HOMI was consistently lower in first lactation compared to adult cows and large between-cow variations within lactation were noted. From the pooled data, HOMI was related to DHA and cow characteristics: HOMI = 7.9 – 98 DHA^{-1} + 0.264 FCMt + 0.0073 LW ($n = 95$, $R^2 = 0.60$, rsd = 1.77 kg). However, splitting DHA into its two components accounted for more of the variance in HOMI: HOMI = –20.4 – 115 DOA^{-1} + 9.63 HM – 0.873 HM^2 + 0.266 FCMt + 0.0095 LW ($R^2 = 0.70$, rsd = 1.56 kg). These relationships showed that HOMI was affected by DHA but the original sward herbage mass/structure does have an independant effect in regulating intake. Moreover, voluntary intake increases with the potential of milk yield and this increase could account for the two-thirds of the supplementary energy requirements.

dairy cows / grazing / intake / herbage allowance / animal requirements

Résumé — Effet des quantités d'herbe offertes, de la biomasse et des caractéristiques animales sur l'ingestion des vaches laitières au pâturage. *L'effet de la quantité d'herbe allouée (DHA = biomasse (HM) x surface offerte journellement (DOA)) et des caractéristiques des animaux sur les quantités de MO d'herbe ingérées au pâturage (HOMI) ont été analysées au cours de deux essais. Dans l'essai 1, deux niveaux de DHA (Bas et Moyen, 19 et 26 kg MO/vache/jour) ont été comparés dans un schéma en continu en utilisant deux groupes de cinq vaches appariées. Dans le second essai, trois niveaux d'herbe allouée (Bas, Moyen et Haut ; 19, 29 et 46 kg/jour) ont été comparés dans un schéma en carré latin 3 x 3 en utilisant trois lots de cinq vaches. Tous les animaux étaient en milieu de lactation et six primipares ont été utilisées par essai. À la mise à l'herbe, la production de lait à 4 % (FCMt) et le poids vif (LW) variaient de 17 à 35 kg/jour et de 510 à 680 kg. Les vaches n'ont pas reçu de concentré et ont été conduites en pâturage rationné sur prairies de ray-grass anglais pendant toute la durée des essais. La biomasse coupée au niveau du sol a varié de 3,5 à 7,1 t MO/ha entre les périodes. Dans l'essai 1, HOMI (13,5 versus 14,9 kg/j) et la production de lait 4 % (20,6 versus 22,0 kg/jour) ont eu tendance à augmenter entre le traitement Bas et Moyen mais les différences n'ont pas été significatives. Dans l'essai 2, HOMI a augmenté de manière curvilinéaire (13,8 ; 16,2 ; 16,7 kg/jour) et la production de lait 4 % a augmenté linéairement avec le niveau d'herbe allouée (20,4 ; 21,7 et 23,0 kg/jour). HOMI a toujours été beaucoup plus faible pour les vaches primipares que les vaches adultes et des différences interindividuelles importantes sont apparues pour un même rang de lactation. À partir de l'ensemble des données individuelles nous avons montré que HOMI peut être prédite à partir de DHA et des caractéristiques des animaux : HOMI = 7,9 – 98 DHA^{-1} + 0,264 FCMt + 0,0073 LW (n = 95, R^2 = 0,60, etr = 1,77 kg). Cependant, la précision de ce modèle est sensiblement améliorée lorsque l'on considère séparément les deux composantes de DHA : HOMI = –20,4 – 115 DOA^{-1} + 9,63 HM – 0,873 HM^2 + 0,266 FCMt + 0,0095 LW (R^2 = 0,70, etr = 1,56 kg). Ces relations montrent que HOMI est affectée par DHA mais aussi que la biomasse et/ou la structure initiale de la prairie affecte également les quantités ingérées. De plus les quantités ingérées augmentent avec le potentiel de production des animaux et cet accroissement couvre environ les deux tiers des besoins supplémentaires de production pour des pâturages de bonne qualité.*

vache laitière / pâturage / quantités ingérées / herbe offerte / besoin nutritif

INTRODUCTION

Using pasture as a primary source of energy in the diet of dairy cows has potential economic advantages. However, one of the challenges in optimizing the nutrition of dairy cows at grazing is knowing to what extent fresh grass can meet the high energy requirements of the dairy cows. The regulation of herbage organic matter intake (HOMI) is a crucial point but the effects of source of variation in HOMI are not well quantified. These include mainly the milk yield of the cows, grazing management and provision of concentrate supplements to the cows.

Among factors of grazing management affecting HOMI, daily herbage allowance (DHA), defined as the quantity of herbage cut above a sampling height (generally ground level) offered daily per cow, is of major importance (Greenhalgh et al, 1966; Combellas and Hodgson, 1979; Le Du et al, 1979). The relation between HOMI and DHA is basically curvilinear and HOMI was near the maximum when DHA was about 25 to 30 kg organic matter (OM)/day (Le Du et al, 1979). However, these aforementioned trials deal only with cows producing less than 15 kg of milk and the response curve of HOMI to DHA must be described in high producing cows which may be more sensitive due to their high energy requirements. Moreover, the interaction between DHA and potential intake of the cows has not yet been studied.

Many studies have focused on the details of the effects of sward factors upon the rate of herbage intake (Hodgson 1982, 1986). These studies were essentially developed on continuously stocked swards with grazing managements which minimize changes in sward conditions. They have generally not gone further than analysis of sward height. Under rotational grazing systems, where the changes in sward conditions are rapid, the rate of intake appears to be more closely related to the green leaf mass than to the sward height (Hendricksen and Minson, 1980). Moreover, there are still few indications about the effects of sward parameters at the level of daily intake, although such quantitative information is required to improve the predictability of HOMI.

The two experiments reported in this paper aimed at studying the effect of herbage allowance and cow characteristics upon HOMI in the case of rotationally grazed perennial ryegrass swards differing by the growth number of age of regrowth. Some sward characteristics were recorded to examine more precisely their effects prior to grazing upon HOMI. These experiments were part of a larger work designed to quantify the effect of controllable factors affecting intake and to analyse the precise sward characteristics which determine the availability of herbage for grazing dairy cows.

MATERIALS AND METHODS

Treatments and experimental design

Two experiments were carried out in spring 1988 (experiment 1) and spring 1989 (experiment 2) with grazing dairy cows. In experiment 1, two levels of daily herbage allowances (DHA) of 20 (low) and 30 kg (medium) OM/cow measured to ground level were compared in a continuous design using two groups of five cows during five successive periods. Cows were allocated to one herbage allowance throughout the experiment. In experiment 2, three levels of herbage allowances of 20 (low), 30 (medium) and 40 kg (high) were compared in a 3 x 3 latin square design using three groups of five cows. Cows were rotationally grazed on a 1 day paddock on swards of perennial ryegrass *(Lolium perenne)*. In the two experiments, the contrasting herbage allowances were achieved by varying the size of the grazing area. Each experimental period lasted 7 (experiment 1) and 8 days (experiment 2).

Animals

In both years, autumn calving Holstein cows of different levels of energy requirements were selected from a larger group of cows which were rotationally grazed. In experiment 1, ten cows were paired into two groups of five animals each on the basis of lactation number, fat-corrected milk yield at turnout (FCMt), live weight (LW) and calving date. There were six first lactation cows. FCMt ranged from 18 to 32 kg and LW from 550 to 650 kg. In experiment 2, 15 Holstein cows were divided into three groups of five according to the same criteria. There were six first lactation animals. FCMt ranged from 23 to 35 kg and LW from 530 to 690 kg at turnout. State of lactation was 140 ± 30 days postpartum at the beginning of the experiments.

Between the date of calving and the beginning of the grazing season the cows were fed on a maize silage based diet to appetite and received concentrates according to their level of milk production. The quantities of maize silage consumed were recorded individually in February and March for all cows in experiment 1. The cows were turned out to pasture during the first week in April each year. Maize silage and production concentrate were reduced during 2 weeks and finally cows received grass alone the week before the beginning of the experiments. No production concentrates were given during the experiments. The cows were milked between 0630 and 0730 hours and between 1600 and 1700 hours each day.

Grazing and pasture managements

The experiments were carried out on swards of perennial ryegrass *(Lolium perenne)* cv Vigor (1.5 ha) sown in 1985 in experiment 1 and cv Belfort (2.5 ha) sown in 1986 in experiment 2. The swards had received liberal amounts of fertilizer N. Each year, at the end of March, the swards were grazed by heifers, the refusals were cut with a forage harvester and residues removed. At this stage the swards received 50 (experiment 1) or 75 kg N/ha (experiment 2). The fields were then longitudinally divided into two unequal areas with permanent fences to provide for the two herbage allowances in experiment 1 and into three equal areas in experiment 2. The groups of cows were assigned to one area throughout the experiments.

The cows went to a new paddock every day after the morning milking. The areas necessary to provide the prescribed allowances were based on estimates of the herbage mass present prior to grazing made on 2 days, once the day before the experimental period and once on day 3. Because of the delay between cutting grass and dry matter determination, a previous estimate of area was calculated from the herbage height and its relation to herbage mass obtained on similar swards. Front and back electric fences were moved daily at 0700 hours. Back fences were moved 1 day after front fences to increase the area allowed to the cows and thus avoiding poaching. Water and minerals were freely supplied in every 1 day paddock.

In experiment 1, three periods were on first growth during the 1st, 2nd and 3rd weeks of May (24, 31 and 38 days since the sward was topped for periods 1, 2 and 3, respectively) and two on regrowths during the last week of May and the first week of June (21 and 35 days regrowths for periods 4 and 5, respectively). During these last two periods, cows grazed area previously used in period 2 and period 1, respectively. In experiment 2, measurements were realized on first growth in May (respectively, 32, 40 and 48 days after topping).

Animal measurements

The HOMI was calculated from estimates of faecal output and the digestibility of herbage consumed. Faecal output was calculated by reference to chromic oxide (Cr_2O_3) with the assumption that Cr_2O_3 was totally recovered in faeces (Mélix et al, 1987). Small amounts of concentrate pellets containing chromic oxide were fed in two meals of 400 g each immediately after the morning and afternoon milking in order to administer 16 g of Cr_2O_3 per cow/day. The concentrate included (g/kg DM) Cr_2O_3 20, barley 700, soya-bean meal 240 and molasses 40. A preliminary dosing period of 10 days was carried out before the measurements. Any uneaten fraction of the concentrate was oven-dried and weighed daily to determine the actual intake of chromic oxide. Refusals were scarce except from one cow during the first two periods of experiment 2 (about 200 g/day). Faecal sampling took place during the last 5 (experiment 1) or the last 4 (experiment 2) days of each period. All fresh dung was sampled (about 50 g of fresh material) each morning on the plot grazed the day before and a bulk sample for each cow was realized daily. Compared to grab sampling, this sampling technique limits the risk of bias in the estimation of daily mean concentration of Cr_2O_3 (Mélix and Peyraud, 1987). The faeces were marked by individual feeding of 60 g/day of different coloured plastic particles (Schulman SA) with the chromic oxide concentrate. These daily bulked samples were oven-dried at 80 °C for 72 h and mixed in a composite sample for the period and the cow in question. The cow spent less that 2 h daily out of the plot and it could be assumed that more than 80% of the defaecations were sampled. The plastic particles were then discarded and the samples were ground through a 0.8 mm screen for the analysis.

The digestibility of organic matter of grazed herbage was estimated from the concentration of nitrogen (N) and acid detergent fibre (ADF) in faecal organic matter and from the pepsin-cellulase digestibility (PCD) of herbage (cut at 8 cm of extended tiller height) according to the relation: DOM = 0.624 + 0.284 PCD + 0.0165 N – 0.00354 ADF (n = 23, r = 0.93, rsd = 0.011). This equation was derived from 23 indoor trials in which three to four cows were fed on an ad libitum basis with fresh ryegrass (10), cocksfoot (4), pure white clover (7) and mixture of cocksfoot and white clover (2 trials).

Estimates of the time spent grazing were carried out in experiment 2 on 1 day in each period. Observations were made at intervals of 10 min from morning milking time to nightfall. Grazing was recorded when a cow was seen to prehend grass with its head close to the sward. Milk yields were recorded at each milking. Milk composition was determined three times per period from aliquot sample of two consecutive milkings. These samples were analysed for fat and protein using an infrared milk analyser (Milkoscan, Foss Electric DK 3400 Hillerod, Denmark). The cows were weighed once a week at the end of each experimental period, immediately after the morning milking.

Sward measurements

Herbage mass present prior to grazing was measured by cutting two strips of 5 m long and 0.5 m wide at random on the area ahead of the grazing cow. Herbage was cut with a motorscythe (Agria) with a reciprocating blade leaving a stubble of about 5 cm. In addition, a single quadrat of 0.30 x 0.30 m was cut to ground level with kitchen scissors to estimate the stubble mass in each strip. Herbage samples were weighed fresh and subsampled for drying at 80 °C for 48 h. Because of the risk of soil contamination, all subsamples were ashed to express results as organic matter. The stubble herbage mass was added to the motorscythe estimate to give the total quantity offered. Chemical analyses were only performed on the herbage cut with the motorscythe. The extended tiller height of the longest leaftip (ETH) and leaf sheath (LSH) from ground level were measured before and after grazing. Twenty readings were taken at random per treatment during the days of intake measurements.

Sample analyses

Organic matter (OM) was determined by ashing for 5 h at 550 °C. Nitrogen content was obtained by the Kjeldahl method. The NDF and ADF contents were measured according to the method of Van Soest and Wine (1967) on a Fibertec M extraction unit (Tecator, Denmark) as described by Giger and Pochet (1987). Cellulase digestibility (PCB) was determined according to Aufrère and Demarquilly (1989). Chromic oxide was analysed using the method outlined by Poncet and Rayssiguier (1980). One g of faeces or 0.1 g of concentrate were digested in hot nitric and perchloric acids prior to an automated colorimetric determination of the hexavalent chromium with diphenyl-carbazide. The method was adapted to an auto-analyser (Technicon).

Statistical analysis

In experiment 1, animal data were analysed according to a split-plot design using the following model: Y_{ijkl} = Mean + T_i + L_j + $C_k(T_i{*}L_j)$ + P_l + T_iP_l + L_jP_l + $T_iL_jP_l$ + e_{ijkl}, where T_i = treatment effect (i = 1 to 2); L_j = effect of the lactation (j = 1 to 2); $C_k(T_i{*}L_j)$ = cow effect (within lactation and treatment); P_l = period effect (l = 1 to 5); T_iP_l = interaction treatment x period; L_jP_l = interaction lactation x period; $T_iL_jP_l$ = interaction treatment x lactation x period; e_{ijkl} = error term with 24 degrees of freedom. Treatment, lactation and treatme[nt x] lactation were tested with $C_k(T_i{*}L_j)$ as an e[rror] term.

In experiment 2, animal data were analysed as a 3 x 3 latin square design according to the following model: Y_{ijkl} = Mean + T_i + L_j + $C_k(L_j)$ + P_l + T_iP_l + L_jP_l + e_{ijkl}, where T_i = treatment effect (i = 1 to 3); L_j = effect of the lactation (j = 1 to 2); $C_k(L_j)$ = cow effect (within lactation); P_l = period effect (l = 1 to 3); L_jT_i = interaction lactation x treatment; L_jP_l = interaction lactation x period; e_{ijkl} = residual term. The residual term had 22 degrees of freedom. L_j was tested with $C_k(L_j)$ as an error term. For herbage data, similar procedures were used but only treatment and period were taken into account. All data were analysed using the GLM procedure of SAS (1987).

To examine the relationships between HOMI, animal factors which can influence voluntary intake, grazing management and sward characteristics before grazing, data from the two experiments were combined by multiple regression analysis. Predictions of HOMI were performed using individual estimates of HOMI (n = 95) and taking into account cow characteristics at turnout (25 cows), herbage allowance and sward characteristics during the experiments (19 herbage allowances x periods).

RESULTS

In both years, all the cows completed the experiment satisfactorily and results from all animals were included in the statistical analysis. In experiment 1, temperatures were normal (mean value of 13.3 °C with maximum value reaching 21 °C). Experiment 2 was characterized by warmer and dryer weather conditions (mean 16.3 °C with maximum value reaching 28 °C, total rainfall less than 14 mm), which dramatically reduced herbage accumulation after grazing and prevented a repetition of the complete latin square. Estimates of herbage mass cut by motorscythe (HMm, t OM/ha) and to ground level (HM, t OM/ha) were highly correlated (HMm = 0.78 HM – 0.90, n = 22, R^2 = 0.94) and only HM was presented thereafter.

Experiment 1

The actual levels of DHA were near to those intended although there was some between period variation. Herbage mass and sward height were slightly higher ($P < 0.10$; table I) in medium than in low DHA. This mainly arose from a much lower herbage accumulation after grazing the first growth in low DHA, herbage mass being 5.16 and 4.38 t OM/ha, respectively, for medium and low DHA in periods 4 and 5. The proportion of green leaf lamina in the pregrazing biomass averaged 43% and did not differ according to the DHA. Chemical composition of the offered herbage and PCD were similar between the two treatments. There were significant differences in sward structure and chemical composition of offered herbage between periods (table I). The highest herbage mass, ETH and NDF content of the grass and the lowest crude protein content of the grass were recorded during periods 3 and 5 (ie, with the oldest growths). The leaf sheath height expressed in proportion of ETH was also slightly higher in periods 3 and 5 than during the three other periods (0.37 vs 0.33, $P < 0.05$). Dry matter content of the grass averaged 171 g/kg fresh material and was not greatly modified according to period. PCD was high and was only slightly reduced during period 5.

Milk yield was higher and fat content of milk was lower in medium than in low allowance (table II). Fat-corrected milk, milk protein content and body live weight were not affected by the level of DHA. Nitrogen and ADF contents of faeces did not vary and thus the digestibility of the selected herbage was similar for the two levels of DHA. Cows consumed nearly 1.5 kg more on medium than on low allowance but the

Table I. Structure and chemical composition of the sward prior to grazing and grazing management of cows in experiment 1.

	Herbage allowance		*Periods*					
	Low	*Medium*	*1*	*2*	*3*	*4*	*5*	*rsd* [1]
Sward structure								
Herbage mass (t OM/ha)[2]	4.29^{a}	4.79^{b}	3.69^{a}	4.35^{b}	5.13^{c}	4.20^{ab}	5.34^{c}	0.221
Extended tiller height (cm)	30.9^{a}	34.1^{a}	26.5^{a}	30.4^{a}	39.4^{b}	26.0^{a}	40.1^{b}	2.43
Leaf sheath height (cm)	10.5^{a}	12.2^{a}	8.8^{a}	10.2^{a}	14.3^{b}	8.4^{a}	15.1^{b}	1.57
Chemical composition (g/kg DM)[3]								
Dry matter content (g/kg)	172^{a}	170^{a}	167^{ab}	168^{ab}	183^{a}	177^{ab}	161^{b}	6.8
Organic matter	898^{a}	901^{a}	900^{a}	904^{ab}	908^{b}	895^{ac}	890^{c}	2.4
Crude protein	196^{a}	196^{a}	225^{a}	190^{b}	163^{c}	224^{a}	180^{bc}	7.0
NDF	507^{a}	505^{a}	480^{a}	510^{b}	518^{bc}	493^{a}	529^{c}	5.7
Pepsine-cellulase digestibility	0.781^{a}	0.783^{a}	0.789^{a}	0.791^{a}	0.780^{a}	0.798^{a}	0.752^{b}	0.0099
Grazing management								
Offered area (m^2/day)	44.7^{a}	56.0^{b}	57.2^{a}	50.6^{b}	45.7^{c}	57.2^{a}	41.3^{d}	1.08
Herbage allowance (kg OM/day)	18.9^{a}	26.4^{b}	21.2^{a}	22.1^{ab}	23.6^{b}	24.2^{b}	22.3^{ab}	0.84

[1] Residual standard deviation, means in the same line with different superscripts are statistically different ($P < 0.05$); [2] determined at ground level; [3] herbage cut by motorscythe. OM: organic matter; DM: dry matter; NDF: neutral detergent fibre.

Table II. Effect of herbage allowance and lactation number of the cows on milk production and herbage intake in experiment 1.

Herbage allowance	*Low*		*Medium*		*Statistical effect*			
Lactation number	*Prim* [a]	*Adult* [b]	*Prim* [a]	*Adult* [b]	*HA* [c]	*LN* [d]	*HA x LN* [e]	SD cow [f]
Milk yield (kg/day)	18.0	23.3	20.3	27.5	0.05	< 0.01	NS	4.54
Fat content (g/kg)	40.4	40.2	37.2	34.0	0.02	NS	NS	4.83
Protein content (g/kg)	29.7	28.2	30.1	25.8	NS	0.03	NS	3.52
Fat-corrected milk (kg/day)	18.0	23.2	19.3	24.7	NS	0.02	NS	5.69
Live weight (kg)	536	555	563	550	NS	NS	NS	104.4
Faecal output (kg OM/day)	2.15	2.85	2.53	2.84	NS	0.09	NS	0.880
Faecal N content (% OM)	3.93	4.06	4.02	4.13	NS	NS	NS	0.227
Faecal ADF content (% OM)	27.7	27.6	27.5	26.4	NS	NS	NS	1.53
Herbage OM digestibility	0.814	0.817	0.816	0.822	NS	NS	NS	0.010
Herbage intake (kg OM/day)	11.5	15.6	13.8	16.0	NS	0.06	NS	4.61

[a] First lactation dairy cows; [b] adult cows; [c] effect of herbage allowance (HA); [d] effect of lactation number (LN); [e] effect of herbage allowance x lactation number interaction; [f] standard deviation of the cow effect: used as an error term for the analysis of HA, LN and HA x LN. NS: not significant, $P > 0.10$. ADF: acid detergent fibre.

difference failed to be significant. Extended tiller height after grazing was higher in medium than in low DHA (81 vs 104 mm, $P < 0.01$).

Milk yield and herbage intake were substantially higher in adult than in first lactation cows (+6.3 and +3.2 kg/day, respectively, for milk yield and HOMI). There were no interactions between lactation and allowance for any aspects of milk production and herbage intake. Within a lactation number, there was large between-cow variation for HOMI (standard error for the cow effect was 4.6 kg/day). These variations were correlated to the quantity of maize silage and concentrate eaten during the winter feeding period ($r = 0.74$). Only one cow grazing in the medium DHA showed a much lower HOMI than expected according to this relationship (–2.0 kg OM/day). When this cow was taken out, the correlation was 0.89.

Herbage intake was low in period 1, intermediate in period 5 and highest values were recorded during the three other periods ($P < 0.05$; table III). There were no allowance x period interactions for HOMI and milk production.

Experiment 2

The actual levels of DHA were near to those intended for the low and medium allowances and similar to those in experiment 1. The actual level of DHA was slightly higher than intended for the high allowance treatment. Herbage mass, sward height and chemical composition of the offered herbage were similar for the three levels of DHA. Only crude protein content of the grass tended to be lower for the low DHA ($P < 0.12$). Herbage mass and sward height increased during the experiment ($P < 0.01$; table IV) with highest values observed in period 3 when the sward was also characterized by a higher LSH/ETH ratio (0.37 vs 0.32, $P < 0.05$), a lower crude protein content and a lower PCD than in periods 1 and 2.

Table III. Variation of milk production and herbage intake during experiment 1.

	Periods					*Statistical effects*		
	1	*2*	*3*	*4*	*5*	*Per* [a]	*HA x Per* [b]	*rsd* [c]
Milk yield (kg/day)	22.5	22.6	23.0	21.5	21.9	0.09	NS	1.20
Fat content (g/kg)	40.8	36.9	35.7	40.9	35.4	< 0.01	NS	1.92
Protein content (g/kg)	28.5	28.3	27.9	29.0	28.5	< 0.01	NS	0.59
Faecal output (kg OM/day)	2.24	2.64	2.91	2.65	2.53	< 0.01	0.06	0.151
Herbage OM digestibility	0.821	0.819	0.807	0.824	0.816	< 0.01	0.02	0.0056
Herbage intake (kg OM/day)	12.6	14.6	15.1	15.1	13.8	< 0.01	NS	0.95

[a] Effect of the periods (Per); [b] effect of the interaction period x herbage allowance (HA); [c] residual standard deviation; NS: not significant, $P > 0.10$.

Milk yield, fat-corrected milk yield, protein content of milk and body live weight increased linearly with increasing DHA (table V). Faecal output increased from low to medium DHA, but did not differ between medium and high DHA. Nitrogen content of faeces increased, ADF content of faeces decreased and thus digestibility of selected

Table IV. Structure and chemical composition of the sward prior to grazing and grazing management of cows in experiment 2.

	Herbage allowance			*Periods*			
	Low	*Medium*	*High*	*1*	*2*	*3*	*rsd* [1]
Sward structure							
Herbage mass (t OM/ha) [2]	6.05[a]	6.02[a]	6.21[a]	4.93[a]	6.33[b]	7.02[b]	0.409
Extended tiller height (cm)	40.2[a]	42.5[a]	41.1[a]	34.1[a]	42.1[b]	47.5[c]	2.64
Leaf sheath height (cm)	13.6[a]	15.0[a]	13.9[a]	10.7[a]	13.8[b]	18.0[c]	1.17
Chemical composition (g/kg DM) [3]							
Dry matter content (g/kg)	163[a]	160[a]	170[a]	155[a]	156[a]	182[b]	5.4
Organic matter	898[a]	897[a]	897[a]	892[a]	896[a]	904[b]	3.2
Crude protein	146[a]	170[a]	171[a]	178[a]	187[a]	122[b]	15.6
NDF	536[a]	545[a]	544[a]	531[a]	537[a]	557[a]	22.5
Pepsin-cellulase digestibility	0.777[a]	0.775[a]	0.770[a]	0.789[a]	0.787[a]	0.747[b]	0.0095
Grazing management							
Offered area (m^2/day)	32.9[a]	50.0[b]	75.3[c]	68.9[a]	46.3[b]	43.0[c]	4.30
Herbage allowance (kg OM/day)	18.8[a]	29.2[b]	45.9[c]	34.7[a]	29.2[b]	30.0[b]	1.98

[1] Residual standard deviation, means in the same line with different superscripts are significantly different ($P < 0.05$); [2] determined at ground level; [3] herbage cut by motorscythe.

Table V. Effect of herbage allowance and lactation number of the cows on milk production and herbage intake in experiment 2.

Herbage allowance	*Low*		*Medium*		*High*		*Statistical effects*					
Lactation number	*Prim* [a]	*Adults* [b]	*Prim* [a]	*Adults* [b]	*Prim* [a]	*Adults* [b]	*Lin* [c]	*Quad* [c]	*LN* [d]	*HA x LN* [e]	*rsd* [f]	*SD cow* [g]
Milk yield (kg/day)	18.3	24.2	19.2	26.2	20.1	27.8	< 0.01	NS	< 0.01	0.06	0.99	3.16
Fat content (g/kg)	38.7	36.9	39.4	36.2	38.4	36.6	NS	NS	NS	NS	1.77	8.19
Protein content (g/kg)	30.6	28.5	31.4	29.3	32.5	30.1	< 0.01	NS	0.06	NS	0.56	3.42
Fat-corrected milk (kg/day)	18.1	22.8	18.9	24.4	19.7	26.3	< 0.01	NS	< 0.01	0.04	0.89	3.26
Live weight (kg)	535	589	541	603	542	607	0.02	NS	0.01	NS	10.1	64.1
Faecal output (kg OM/day)	2.40	2.96	2.66	3.20	2.72	3.16	< 0.01	NS	< 0.01	NS	0.196	0.383
Faecal N content (% OM)	3.80	3.80	4.24	4.13	4.38	4.25	< 0.01	0.04	NS	NS	0.104	0.249
Faecal ADF content (% OM)	28.6	28.6	27.1	26.3	25.1	26.2	< 0.01	NS	NS	0.09	1.072	1.621
Herbage OM digestibility	0.805	0.805	0.817	0.818	0.826	0.820	< 0.01	NS	NS	0.06	0.0041	0.0089
Herbage intake (kg OM/day)	12.4	15.2	14.7	17.6	15.8	17.7	< 0.01	0.10	< 0.01	NS	1.14	2.35
Grazing time (min/day)	360	370	400	400	400	400	0.07	NS	NS	NS	4.5	7.8

[a] First lactation dairy cows; [b] adult cows; [c] linear (Lin) and quadratic (Quad) effect of herbage allowance; [d] effect of the lactation number (LN); [e] effect of the interaction herbage allowance (HA) x lactation number; [f] residual standard deviation; [g] standard deviation of the cow effect: used as an error term for the analysis of lactation number effect. NS: not significant, $P > 0.10$.

herbage increased linearly with increasing DHA. Herbage intake increased in a quadratic manner with herbage allowance (13.8, 16.2 and 16.7 kg/day, respectively, for low, medium and high DHA). Grazing time was depressed in low DHA and did not differ significantly between medium and high DHA. The difference occurred during the second half of the day (ie, between afternoon milking and nighfall); the cows grazed only 130 min in the low DHA compared to 180 min for the medium and high DHA. Extended tiller height after grazing increased linearly ($P < 0.01$) with the level of DHA (93, 146, 173 mm, respectively, for low, medium and high allowance).

Fat-corrected milk yield, body live weight, faecal output and HOMI were consistently higher in adult than in first lactation cows (table V). Although the interaction between lactation and allowance was not significant, HOMI was fairly constant between medium and high allowance for adults cows but tended to increase ($P < 0.11$) for first lactation animals (+0.1 and +0.9 kg/day, respectively, for adult and first lactation cows between high and medium DHA). Grazing time was not affected by lactation ($P > 0.10$) and consequently the mean rate of intake, calculated by the ratio HOMI/grazing time tended to be higher in adult than in first lactation cows (45 vs 38 g OM/min, $P < 0.10$).

Digestibility of the selected herbage and HOMI were similar during the first two periods but were significantly reduced ($P < 0.01$) during the third period (table VI) despite a higher grazing time ($P < 0.01$). Thus, the mean rate of intake was consistently lower in period 3 (33 g OM/min) than in the two other periods (45 g OM/min, $P < 0.01$).

DISCUSSION

Estimates of energy allowances and requirements

Without a reference method, validation of HOMI is difficult. One approach could be to compare net energy (NE) intake and NE requirements for actual cow's performances. Calculations were based on the mean data for the whole time of the experiments because reliable estimates of live weight change are difficult to obtain in short periods. Thus, the two experimental DHA were considered in experiment 1 and a mean theoretical DHA was considered in experiment 2. Body live weight changes were calculated by

Table VI. Variation of milk production and herbage intake during experiment 2.

	Periods			*Statistical effects*	
	1	*2*	*3*	*Per* [a]	*rsd* [b]
Milk yield (kg/day)	23.8	22.8	21.3	< 0.01	0.99
Fat content (g/kg)	38.2	37.0	37.8	NS	1.77
Protein content (g/kg)	30.9	30.3	30.0	< 0.01	0.56
Faecal output (kg OM/day)	2.71	2.89	2.94	0.02	0.196
Herbage OM digestibility	0.834	0.822	0.788	< 0.01	0.0041
Herbage intake (kg OM/day)	16.5	16.3	13.9	< 0.01	1.14

[a] Effect of the periods; [b] residual standard deviation; NS: not significant, $P > 0.10$.

the difference between LW in the last and first period in each experiment, data being previously adjusted for treatment effect in experiment 2. NE requirements for maintenance, milk yield and body reserve deposition were calculated according to Inra (table VII). NE content of grazed herbage was derived from a mean digestibility of 0.815. NE intake exceeded NE requirements by about 1.0 UFL/day in all cases. Although some slight biases in the method used to estimate HOMI should not be excluded, this may be because maintenance requirement at grazing was underestimated in our calculation. According to Langlands et al (1963), energy requirement is increased by about 20% in good grazing conditions with ample quality grass. This is equivalent to 1.0 UFL/day for a dairy cow weighing 600 kg and is in good agreement with the previously mentioned difference. Such an increase in maintenance requirement is not taken into account in the Inra net energy system.

On the other hand, the method was precise. The residual standard deviation was 1.0 and 1.1 kg OM/cow/day, respectively, in experiment 1 and 2 (ie, 7% of HOMI). Similar values (5–9%) were obtained by other workers using indirect methods to estimate HOMI in grazing dairy cows (Combellas and Hodgson, 1979; Le Du et al, 1981; Arriaga Jordan and Holmes, 1986).

Effect of herbage allowance on herbage intake, grazing behaviour and milk yield

The response of HOMI between low and medium DHA was of a similar magnitude in experiment 1 and 2 (+0.19 and 0.23 kg/kg extra allowance, respectively) although it failed to be significant in experiment 1 probably because the effect of allowance was tested with cow variation as an error term and also because one cow showed an unexpectedly low herbage intake in medium DHA treatment. In experiment 2, the relationship between intake and allowance was curvilinear. Intake increased by 2.4 kg OM between low and medium allowance and by only 0.5 kg (not significant) with a further increase of allowance. Similar curvilinear relationships have been previously reported in several trials under strip-graz-

Table VII. Comparison between energy requirements and estimates of allowances during experiments 1 and 2.

	Experiment 1 [1]		*Experiment 2* [1]
	Low	*Medium*	
Herbage intake (kg OM/day)	13.5	14.9	15.7
Net energy intake (UFL/day) [2]	15.5	17.1	18.0
Requirements of net energy (UFL/day) [3]	13.7	14.0	14.6
Energy balance (UFL/day)	1.8	3.1	3.4
Live weight gain throughout the experiments (kg)	0.15	0.40	0.60
Overall difference between intake and valorization [4]	1.1	1.3	0.7

[1] Mean values in both herbage allowance in experiment 1 and mean value for the three herbage allowances in experiment 2; [2] the net energy content of the ingested grass was estimated according to Inra 1988 with a mean digestibility of 0.815; [3] requirements for maintenance (UFL/day) = 1.4 + 0.006 live weight (LW); requirements for milk production = 0.44/kg fat-corrected milk (FCM); [4] requirements for body reserve deposition = 4.5 UFL/kg LW gain.

ing management and involving similar short experimental periods (Greenhalgh et al, 1966, 1967; Combellas and Hodgson, 1979; Le Du et al, 1979). However, these previous results referred to dairy cows weighing less than 500 kg, producing less than 16 kg FCM/day and eating less than 13 kg OM/day. Moreover, our results showed that the response to allowance might be different according to the animal characteristics. Herbage intake of first lactating cows increased between medium and high allowance and this was not the case for adult cows. This might be explained by some social competition when young cows grazed together with older and more experienced cows.

Taken together the two experiments show that individual herbage intake can be predicted when taking into account some cow characteristics and the daily herbage allowance measured to ground level (table VIII, eq 1). The quadratic function of DHA has often been proposed to predict intake (Meijs and Hoekstra, 1984; Stockdale, 1985; Caird and Holmes, 1986). However, intake should not decrease at very high herbage allowances and a hyperbolic model must be preferred, even though the precision is quite similar (table VIII, eq 2) for the two equations. Gibb and Treacher (1976) proposed an asymptotic function of DHA but they did not consider the potential intake of the animal. Extended tiller height after grazing (ETHa) and DHA were correlated ($r = 0.81$, $n = 19$) and, therefore, ETHa could also be used to predict intake. However, the model was less accurate when grazing management was characterized with ETHa than with DHA (table VIII, eq 3).

Measurement of milk yield was not the main interest in our experiments because

Table VIII. Equations derived from all data (n = 95) to explain variations in herbage intake and including variables related to animal, grazing management and sward characteristics.

Equations	*1*	*2*	*3*	*4*	*5*	*6*	*7*
FCMt (kg/day) [1]	0.265	0.264	0.264	0.266	0.263	0.265	0.261
LW (100 kg) [2]	0.74	0.73	0.88	0.95	0.95	0.95	1.00
DHA (kg OM/day) [3]	0.333	–	–	–	–	–	–
DHA^2 (kg OM/day)	–0.0033	–	–	–	–	–	–
DHA^{-1} (day/kg OM)	–	–98	–	–	–98	–	–
$ETHa^{-1}$ (cm) [4]	–	–	–30	–	–	–	–
DOA^{-1} (m^{-2}) [5]	–	–	–	–115	–	–114	–134
HM (t OM/ha) [6]	–	–	–	9.63	–	9.43	–
HM^2 (t OM/ha)	–	–	–	–0.873	–	–0.820	–
GLM (t OM/ha) [7]	–	–	–	–	–	–	13.83
GLM^2 (t OM/ha)	–	–	–	–	–	–	–2.548
ETHb (cm) [8]	–	–	–	–	0.91	–	–
$ETHb^2$ (cm)	–	–	–	–	–0.013	–	–
PCD [9]	–	–	–	–	–	25.0	36.8
Constant	–2.5	7.9	5.9	–20.4	–8.9	–40.3	–41.2
R^2	0.60	0.60	0.51	0.70	0.70	0.72	0.69
rsd (kg OM/day) [10]	1.78	1.77	1.97	1.56	1.63	1.52	1.58

[1] Fat-corrected milk at turnout; [2] live weight; [3] daily herbage allowance; [4] extended tiller height after grazing; [5] daily offered area; [6] herbage mass; [7] green leaf mass; [8] extended tiller height before grazing; [9] pepsine-cellulase digestibility; [10] residual standard deviation.

of the sudden suppression of the concentrate at turnout and the short duration of the experimental periods. However, there were substantial increases of milk yield with herbage allowance in both experiments: milk protein content increased with allowcance in experiment 2 and milk fat content decreased with DHA in experiment 1. These results would be expected where the level of energy intake was increased. They were also in general agreement with those of studies on the effect of stocking rate and involving much longer periods of experiment (Hoden et al, 1991).

The grazing efficiency, defined as intake per unit of allowance, was 0.56 in medium DHA where intake was hardly depressed but decreased up to 0.36 for high allowance and increased to 0.71 for the low allowance. A value of about 0.55 was also obtained in experiment 1 for the medium DHA. These data support the suggestions of Combellas and Hodgson (1979) and Le Du et al (1979) that under strip-grazing management, herbage intake depression occurs when about one-half of the herbage mass has been consumed. However, this practical rule does not in itself assist the understanding of sward factors which may affect herbage availability and intake.

On low DHA treatment, grazing time was slightly reduced and the difference occurred in the second part of the grazing day after the afternoon milking. This agrees with previous observations reported by Le Du et al (1979) and Combellas and Hodgson (1979) for strip-grazing dairy cows and Jamieson and Hodgson (1979) for grazing calves. No measurements of grazing time were recorded after nightfall. However, further experiments (Astigarraga, 1994; Peyraud et al, unpublished) showed that grazing time during night hours is always short (about 30 min) for similar grazing conditions. Thus, it is reasonable to assume that the difference in daylight grazing time may reflect the between treatment difference in total daily grazing time. It has been suggested that this decrease reflects the ability of cattle to anticipate the change to the next strip of fresh grass (Tayler, 1953; Jamieson and Hogdson, 1979). Alternatively, cows may also abandon grazing because sward structure may represent a physical limit to prehend the grass. Indeed, this decrease in grazing time with low DHA and hence with low residual sward height contrasted with the increase in grazing time to compensate for low herbage height generally reported in continuous stocked animals (Zoby and Holmes, 1983; O'Sullivan, 1984; Hodgson, 1986). Indeed, short continuously grazed temperate swards generally contain a dense mat of green leaf whereas in our study, the sward grazed at low DHA ended with very little green leaf mass compared to high DHA (86 vs 840 kg/ha, ie, 3 and 20% of residual herbage mass, respectively, for low and high DHA; Wade, 1991). The data presented by Penning et al (1994) also strongly suggested that content of leaf lamina was one of the most important factors determining herbage availability in a sward under rotational grazing.

Effect of pregrazing herbage mass/structure upon intake

Variations of intake between periods were noted in the two experiments. They cannot be related to the stage of lactation. In experiment 1 variation of intake appeared to be erratic on a time basis and in experiment 2 less than 1 week elapsed between the first two periods and the last period where intake was sharply decreased. Indeed, splitting herbage allowance into its two components (offered area and herbage mass) accounted for more of the variance in individual herbage intake (table VIII, eq 4), the quadratic term of HM being highly significant. Herbage mass and extended tiller height before grazing (ETHb) were closely correlated ($r = 0.94$, $n = 19$); therefore, ETHb had also a highly significant effect (table VIII, eq 5) when added to DHA. These relationships clearly show that the pregrazing sward structure does have an independent effect upon herbage intake of grazing dairy cows and that DHA or ETHa alone is not sufficient to predict herbage intake accurately. Using multiple regression analysis, Stockdale (1985) detected a small positive effect of herbage mass upon herbage intake and Stakelum (1986b) also demonstrated experimentally an increase of herbage intake with herbage mass. Meijs (1981) failed to identify such an effect in an exhaustive study but in his study herbage mass and maturity were confounded.

The quadratic component for herbage mass or height supports an optimum range of mass or height for intake. From these relations, it appears that HOMI might not be greatly affected between 4.0 and 5.5 t OM/ha but might be reduced by 2 kg/day when HM falls from 4 to 3 t/ha (ie, 2.2 and 1.4 t OM/ha for HMm) or increases from 5.0 to 6.5 t OM/ha (ie, 3.0 to 4.2 t OM/ha for HMm). A decline of HOMI for high herbage mass has been previously reported (Hodgson and Wilkinson, 1968; Jamieson, 1975) but in these studies high herbage mass and low quality of herbage were confounded. This is not the case in our study where taking into account the pepsin-cellulase digestibility improved slightly the precision of the model but had little effect upon the coefficients for HM and HM^2 (table VIII, eq 6). These data could explain the results of Combellas and Hodgson (1979), who found that intake of cows was lower at high than at low herbage mass at comparable levels of digestibility and allowance. Because of the narrow range of the proportion of green leaf lamina in HM (41 to 47%) the precision of eq [4] in table VIII was not improved when considering the green leaf mass instead of HM (table VIII, eq 7). Moreover, despite its theoritical advantage when contrasting proportion of green leaf material occurs, eq [7] (table VIII) requires tedious work to estimate green leaf mass.

It is reasonable to assume that when herbage mass is not related to herbage quality, the increased mass of the sward increases intake primarily because cows have access to a greater proportion of easily harvestable material before they had to graze the deeper horizons. The higher prehensibility of taller swards is clearly demonstrated in continuous grazing where rate of intake is linearly related to sward height (Allden and Whittaker, 1970; Hodgson, 1982). The reason why intake decreases for the highest herbage mass is not clear. One possibility is that the amount taken per bite was too large, thus resulting in many manipulations of the bites in the mouth before swallowing. This may dramatically reduce biting rate as the rate of jaw movement is remarkably constant across a large range of sward conditions (Black and Kenny, 1984). Biting rate was not recorded in our studies but it was shown to decline as sward height or herbage mass increased (Hodgson, 1985; Penning et al, 1994).

No interaction between allowance and period was noted in experiment 1 and the term DHA x HM was never significant in the equations proposed in table VIII. The results reported by Greenhalgh et al (1966) with dairy cows showed a remarkably constant relationship between intake and herbage allowance in a series of short-term studies on different swards. Combellas and Hodgson (1979) also failed to show a clear DHA by herbage mass interaction in an experiment designed to examine the interaction between these two factors. However, the data of Stakelum (1986a and b) suggest a herbage allowance by herbage mass interaction. This aspect merits further study.

Between-cow variation of intake

Because of the sudden suppression of the concentrate at the beginning of the experiments, mean individual FCM yield was consistently lower, but well correlated with FCM at turnout (FCMt: FCM = 5.1 + 0.60 FCMt, $n = 25$, $R^2 = 0.81$, rsd = 1.6 kg). This means that cows did not achieve their potential production during the trials. Moreover, because correlations between intake and milk yield may be due to intake limiting milk secretion, we have preferred to use FCM at turnout as a covariate in the equations proposed in table VIII.

Voluntary intake changes in proportion to potential milk yield and, according to the relationships found in table VIII, increased by about 270 g OM/kg FCMt. This numerical value agrees with previously published partial coefficients of multiple regression analysis. Greenhalgh et al (1966) and Curran and Holmes (1970) reported values of 250 g/kg milk. Values ranged between 170 to 330 g/kg milk in the work of Caird and Holmes (1986) according to the models used. In our situation, this additional increase in HOMI accounts for the two-thirds of the supplementary net energy requirements for 1 kg of FCM. This suggests that when plentiful amounts of high quality grass are available, high yielding cows could satisfy a large proportion of their energy requirements from grazing alone. According to eq [4], [5], [6] and [7], HOMI increases by 0.9 to 1.0 kg/100 kg LW. Increases of about 1.5 kg/100 kg LW were obtained in direct comparisons between cattle differing in size (Hodgson and Wilkinson, 1967; Zoby and Holmes, 1983). Similarly partial coefficients obtained by Greenhalgh et al (1966) and Caird and Holmes (1986) were between 0.8 and 1.1 kg/100 kg LW. No intrinsic effect of the lactation number was detected and thus milk yield and live weight accounted for the observed difference of intake between first lactating and adult cows. Stage of lactation was not significant in models probably because it varied in a narrow range (from 100 to 200 days postpartum). Caird and Holmes (1986) also showed that HOMI is hardly affected by the stage of lactation after the second month of lactation.

CONCLUSION

The results indicate that herbage intake of individual grazing cows is greatly affected by herbage allowance but the original sward structure plays a role in regulating intake. Intake of grass is likely to decline at a progressively faster rate when herbage mass is below 4.0 t OM/ha (ie, 2.2 t OM/ha with a motorscythe cut). In addition, the results show that voluntary intake increases with the potential of milk yield and this may have some practical implications for feeding concentrates.

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