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Short term fasting as a tool to design effective grazing strategies for lactating dairy cattle: a review

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Abstract. Varying the time since the last meal (i.e. fasting) is a means of manipulating foraging behaviour. Management practices that restrict grazing time, and/or change the timing of the grazing session, may be analogous to changes introduced with different fasting regimes, suggesting that the same pattern of responses on foraging behaviour could be expected. Concepts related to eating patterns of grazing dairy cows are briefly reviewed, and impacts of short-term (i.e. within day) fasts on ingestive behaviours are discussed. Finally, several experiments that examined impacts of short-term fasts on eating patterns, ingestive behaviours and performance of lactating dairy cows are reviewed. Management practices that create shorter grazing sessions (i.e. longer fasting periods before grazing), and/or involve afternoon grazing, result in longer initial grazing bouts, higher intake rates, reductions in rumination time during the grazing session, as well as more pronounced changes in rumen pH, concentrations of rumen fermentation metabolites and rumen load. All of these changes have been associated with improvements in performance of grazing dairy cattle. These concepts and findings have implications in defining optimal grazing strategies, as well as allowing cattle performance, sward conditions and nutrient balances to be predicted and analysed in an integrated manner.

Additional keywords: bite mass, bite rate, chewing, ingestion, pasture, rumen digesta loads, volatile fatty acids.

Introduction

There are many situations where dairy cattle are fed *ad libitum*. This is especially true in the Northern Hemisphere, where dairy cattle are often housed and allocation of feed is under the direct control of the manager. However, in grazing systems under which dairy cattle are pastured for much or all of the year, such as in Australia and South America, dairy cattle are exposed to large seasonal variations in herbage growth and nutritional quality, thereby exposing them to variable herbage allowance. In the most intensive dairy grazing systems in Australia and other countries, these annual variations in herbage production are often balanced by use of conserved forage and/or concentrates. Cattle foraging behaviours and strategies to obtain nutrients in pastoral ecosystems are determined by (i) their short and long-term physiological state, (ii) pasture availability and (iii) the feeding level and type of supplements (Gill and Romney 1994; Soca *et al*. 2002). Grazing behaviour is characterised by alternation, during the day, of grazing, rumination, rest and social activities (Gibb *et al*. 1997). Factors that explain control of grazing time are less well understood than factors that control intake rate, such as bite mass, time per bite and the ratio between prehension and manipulation of jaw movements (Laca *et al*. 1994; Chilibroste 1999).

Understanding the factors that control meal length could lead to a better understanding of within day dry matter (DM) intake patterns (Forbes 1995). Whereas short-term changes in energy supply and gut fill are probably involved in control of meal size and frequency, it is long-term signals, such as changes in energy stores, that are probably involved in control of DM intake. The role of learning on long-term DM intake control was highlighted by Provenza (1995), although short-term DM intake and diet selection at grazing are mediated by different foraging strategies that result from integration by cattle of short- and long-term information (Forbes 1995), suggesting a very complex process.

Our objectives are 3-fold. The first two are to discuss eating patterns of lactating dairy cattle and how ingestive behaviours that underlie eating patterns are impacted by short-term fasting. The final objective is to examine the potential to integrate short-term fasting into practical management systems of dairy cattle, such as those used in Australia, where grazing and supplements are available. To meet this objective, we focused on studies, including many of the authors', which were published in theses and symposia, as well as in languages other than English.

Eating patterns of grazing dairy cattle

Within-day eating patterns of grazing dairy cattle are related to photoperiod, with larger and more frequent meals occurring during daytime. In temperate environments, about 80% of grazing takes place during the hours of light (Rook *et al*. 1994). Artificial extension of winter daylength (from 9–12 h of natural lighting) to 16 h, using fluorescent lighting, increased DM intake by 6% and milk yield by 1.4 kg/day (Peters *et al*. 1980) in housed dairy cows.

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However, regardless of the production system and associated feeding conditions, cattle eat discrete meals. Thus, periods of eating and fasting alternate on both the short- and long-term (Forbes 1995), suggesting that changes in DM intake for an individual animal occur through modification of the size of the meal and the interval between them. In lactating dairy cows, larger and more intensive grazing bouts occur in the afternoon than at other times (Rook *et al*. 1994; Gibb *et al*. 1997). Under daily strip-grazing, this ingestive behaviour may be even more pronounced (Barrett *et al.* 2001), due to rapid depletion of available herbage. Cattle take short pauses during a meal and these differ from the longer gaps that separate meals. In lactating cows, the critical intermeal interval is 5–7 min, with little variation among cows, within seasons or with physiological states of the cows (Forbes 1995).

The temporal pattern of grazing meals in dairy cows, unmodified by depletion of the herbage, has been demonstrated under continuous stocking management (Gibb *et al*. 1997). Although cattle may increase total grazing time, perhaps to compensate for constraints on intake rate (IR), there is an underlying pattern to grazing meals. The increase in afternoon grazing activity has been interpreted to be an optimum foraging strategy to harvest herbage of higher digestibility with higher concentrations of soluble carbohydrates and DM (Gibb *et al*. 1998; Soca 2000). It is also known that cattle adapt their grazing behaviour in anticipation of future events, including energy requirements, and so can be hyperphagic under certain conditions (Baile and McLaughlin 1987), primarily associated with their higher risk of being attacked by predators during darkness.

Modifications of the base temporal grazing pattern may be impacted by limiting the amount of herbage and/or by changing grazing management. Dulphy *et al*. (1980) established that, in indoor *ad libitum* fed cattle, the pattern of allocation of the diet within day is the major variable that impacts ingestive behaviour. Feed allocation usually initiated eating, even if the cattle still had feed remaining from a previous allocation, but restricted feed allocation often decreased the number of meals to the number of feed offerings. Associated with limitations in access to feed, an increase in IR and reduction of efficiency of rumination may occur (Dulphy *et al*. 1980). Grazing management may also modify the basic temporal pattern of grazing. For example, Orr *et al*. (2001) found that dairy cows provided with equal daily herbage allowances, following either the morning or afternoon milkings, spent the same total time grazing per day, but had different temporal meal patterns. Cows receiving a new pasture allowance in the afternoon spent a higher proportion of their total grazing time during the late afternoon and evening, when the sugar content of the grass was higher, and so their short-term IR (i.e. g DM/min) was higher. As a consequence, they had a higher milk yield than cows offered the same herbage allowance in the morning. Soca (2000) observed a longer grazing bout (219 *v*. 80 min) in dairy cows that were only allowed to graze between the afternoon and morning milkings, compared to cows without restrictions on grazing time.

It is clear that, regardless of feeding system and conditions, dairy cows eat discrete meals and each meal is preceded by a fast that varies in length according to the management system. An understanding of the impacts of the length of the premeal fast on the duration and ingestive behaviours of the next meal will lead to a better understanding of DM intake and animal performance, which will impact design of grazing strategies for Australia and other countries.

Effect of short-term fasting on ingestive behaviours that underlie eating patterns of lactating dairy cattle

Several experiments have studied the influence of fasting on ingestive behaviour and selectivity in cattle and sheep (Chilibroste *et al*. 1997; Greenwood and Demment 1988; Dougherty *et al*. 1989*a*; Newman *et al*. 1994; Patterson *et al*. 1998). These experiments mainly focused on effects of length of fasting on the mechanism of pasture ingestion and IR during the subsequent grazing session. However, few experiments have studied effects of fasting on more than one meal (Erhard *et al*. 2001) or within a day (Soca *et al*. 1999).

Effect of short-term fasting on grazing time

Varying the time since the last meal is one mechanism to manipulate feeding motivation (Forbes 1995). For example, Greenwood and Demment (1988) found that cattle fasted for 36 h grazed 45% longer than those that were not fasted, and that most of the differences could be attributed to a much longer initial grazing bout. During fasting, the metabolism of the cow changes as the contribution of consumed nutrients to animal needs decline and catabolic processes provide more substrates. In the rumen, several changes occur (Chilibroste 1999), since fermentation and passage of particles are both continuous processes. Thus, fasted cattle have a progressively emptier rumen compared with those that are not fasted (Chilibroste *et al*. 1997, 1998).

In an experiment designed to separate effects of fasting on rumen fill from effects on the metabolic status of the cattle, Chilibroste *et al*. (1998) used two fasting lengths, either with or without the presence of synthetic indigestible material in the rumen before grazing. Fasting *per se* increased grazing time, but its magnitude tended to vary depending on whether inert rumen bulk was in the rumen (i.e. inclusion of indigestible material in the rumen of cows fasted for a longer period reduced grazing time by 44 min *v.* 13 min in cows fasted for the shorter time). A tendency to an interaction between duration of fasting and amount of indigestible material in the rumen supports the hypothesis of additive effects of these factors on grazing time control (Mbanya *et al*. 1993; Gill and Romney 1994; Forbes 1995).

Total grazing time, especially first grazing bout length, is sensitive to changes in input of nutrients (e.g. fasting length) and rumen fill. In general, increases in grazing time are associated with increases in bite mass and rate.

Effect of short-term fasting on bite mass

Prior fasting increases bite mass by cattle grazing grass (Chacon and Stobbs 1976; Patterson *et al*. 1998) and legume swards (Dougherty *et al*. 1989*a*). Fasting also increased bite mass by sheep grazing grass (Allden and Whittaker 1970) and legume swards (Newman *et al*. 1994), and the duration of the effects of fasting on bite mass appeared to be bigger as the period of fasting increased (Patterson *et al*. 1998).

Chilibroste *et al*. (1997) fasted dairy cows for 16 h, after which they were allowed to graze for 1, 1.75, 2.5 and 3.25 h. Bite mass was higher during the first hour of grazing *v.* later in the grazing session (0.97 *v*. 0.74 g DM/bite). This suggests a short transient effect of fasting on bite mass and/or a rapid response of the cows to sward depletion. In a later experiment, Chilibroste *et al*. (1998) imposed two lengths of fasting before grazing (16 and 2.5 h) and found no impact on bite mass. While this is not consistent with Patterson *et al*. (1998), who found that bite mass after a 6-h fast was 25% higher than in cows fasted for 1–3 h, Chilibroste *et al*. (1998) used a grazing bout duration of 138 min after fasting while Patterson *et al*. (1998) grazed cows for 60 min. Differences in the length of these grazing sessions on bite mass may support a hypothesis that the effect of fasting on increasing bite mass is a transient event. Indeed, Dougherty *et al*. (1989*b*) showed a linear reduction in bite mass with increased time of grazing within a grazing session, and suggested that 3 h of imposed fasting was sufficient to override any satiety effect induced by the preceding grazing session.

Effect of fasting on bite rate

Cows fasted for 6 *v*. 1 h increased IR, bite mass and bite rate (Patterson *et al*. 1998). The increased bite rate was associated with a reduction in time dedicated to forage selection, but not to increased frequency of jaw movement. As the grazing session progressed, bite rate declined, although the reduction was less than in cows with the longer fasting time (Patterson *et al*. 1998). Increased bite rate was also associated with reduced rate of ingestive mastication, which caused larger particles to reach the rumen and, eventually, longer particle retention time, which may restrict DM intake (Greenwood and Demment 1988). In contrast, Dougherty *et al*. (1989*a*) did not report any impact of short-term fasting on bite rate of cattle grazing tall fescue, but they did report an impact for cattle grazing lucerne. They attributed this to longer residual effects of the previous grazing session on rumen particle retention with tall fescue, thereby suggesting a higher rumen load of cows grazing tall fescue. However, this hypothesis is not supported by Chilibroste *et al*. (1998), who found that dairy cows with different rumen loads due to different fasting lengths before grazing, did not modify bite rate during the first grazing bout. If it is assumed that overt behaviour reflects underlying motivation (Erhard *et al*. 2001), then bite rate and meal duration may be responses to the level of motivation to graze.

Effect of fasting on rumen fill and fermentation

Relationships between fasting and changes in rumen events have been little studied (Chilibroste 1999), although a hypothesis linking ingestion with rumen digestion was proposed (Greenwood and Demment 1988). Indeed it has been shown that fasted animals compromise rumination to sustain high instantaneous IR (Greenwood and Demment 1988; Soca *et al*. 1999), and chewing rate was better associated with herbage mass than with the metabolic state of the cow (Greenwood and Demment 1988; Chilibroste 1999), suggesting that the major cost of increasing instantaneous IR is an increase in particle size, which may change rumen processes (Chilibroste 1999).

Changes in total DM, organic matter (OM), neutral detergent fibre (NDF) and liquid rumen pool sizes within the day in grazing dairy cows fasted overnight before grazing (Table 1; from Chilibroste *et al*. 1998) suggest that overnight fasting decreases the size of all rumen pools, as well as the ratio between solids and liquids. Total rumen pool size declined during fasting i.e. from the start of fasting (SF) to the end of fasting/start of grazing (EF/SG). This was presumably because of continuous clearance of material from the rumen. In addition, rumen pool sizes after the second grazing session were smaller than those at the beginning of the fasting period. The DM pool of particles >1.25 mm (average is 3.01 kg) did not differ due to the allowed length of the grazing session (i.e. 1, 1.75, 2.5 or 3.25 h) after the 16-h fast, and the proportion of particles >1.25 mm in the newly ingested pool declined with an increase in allowed grazing time. The different trends for the wet and dry rumen pool sizes, relative to time after grazing, could be partly due to the slight increase in rumen DM content as the length of the allowed grazing period increased. This increase might be

Table 1. Impacts of the length of the grazing session on total, liquid, dry matter (DM), organic matter and neutral detergent fibre (NDF) rumen pools, as well as the fraction removable by hand (MAT, g/kg DM) and rumen DM content (DMC, g/kg) (from Chilibroste *et al*. 1998)

SF, start of fasting; EF/SG, end of fasting and start of the grazing session after the 16-h fasting period; G1.0, G1.75, G2.5 and G3.25 are for grazing times 1, 1.75, 2.5 and 3.25 h, respectively

	Fasting or grazing treatment						s.e.m.	Slope during G[A]	P[B]
	SF	EF/SG	G1.0	G1.75	G2.5	G3.25			
	Rumen pool (kg)								
Total	94.1	50.6	74.0	77.0	75.1	79.7	7.57	2.0	n.s.
Liquid	83.4	45.9	65.3	66.7	63.2	65	5.84	–0.6	n.s.
DM	11.6	4.8	7.9	8.2	8.3	9.2	0.80	0.5	*
Organic matter	10.3	4.2	7.0	7.3	7.4	8.1	0.65	0.5	*
NDF	5.8	2.5	3.7	4.0	4.0	4.4	0.35	0.3	n.s.
	Rumen characteristics								
MAT (g/kg DM)	970	926	927	935	946	942	18.2	0.7	n.s.
DMC (g/kg)	114	95	108	107	110	115	6.8	0.3	n.s.

[A]Slope is the change in rumen pool or rumen characteristics per hour of grazing time.
[B]*P*-value is the probability of the linear slope of G1 to G3.25 (*, $P < 0.05$; n.s., not significant).

related to the grazing patterns of the cows, which seemed to require at least one period of rumination about 90 min after the grazing session started. That period is possibly to rechew ingested material, suggesting that ingestive chewing was not efficient, as was expected based upon Ulyatt *et al*. (1986) and Waghorn (1986). Nevertheless, this finding is consistent with the hypothesis that cows must reduce the proportion of chewing during eating in order to increase IR (Parsons *et al*. 1994), particularly after a fast (Greenwood and Demment 1988).

If it is assumed that the proportion of rumen particles >1.25 mm after 16.5 h of fasting was about 15% of the total (Bosch and Bruining 1995), then wet sieve analysis by Chilibroste *et al*. (1998) showed that about 75% of newly ingested material during the grazing session was still >1.25 mm after 1 h of grazing. However, as the grazing session continued, and a period of rumination occurred, this value declined to approximately 55%. Waghorn (1986) also found that about 32 and 51% of the DM in rumen digesta after eating was retained on 4-mm and 2-mm sieves, respectively, and that 38% of the material retained on the 4-mm sieve was >10 mm in length. Unfortunately there is a lack of quantitative information on the amount and effectiveness of ingestive mastication during grazing (Laca *et al*. 1994), and so its impact on digestion and passage of particles from the rumen is not known.

The effect of 16 h of fasting on pool sizes of rumen fermentation metabolites (Table 2; Chilibroste *et al*. 1998) shows that increases in fermentation metabolite pools in the rumen with increased allowed grazing time may reflect higher DM intake with the longer grazing session (Chilibroste *et al*. 1997) and/or further availability of soluble fractions due to rumination. The much greater increases in major volatile fatty acids (VFA; i.e. C2, C3, C4) pool sizes (i.e. 0.46, 0.66, 1.10, respectively, expressed as slope/G1) *v*. DM and OM pool sizes (0.06, 0.07) suggests a delay in availability of more rapidly fermentable substrate to microorganisms, probably associated with low chewing efficiency during eating, as was discussed earlier. The fermentation product pool sizes after grazing in cows fasted for 16.5 or 2.5 h (Chilibroste *et al*. 1998) showed a similar lack of change before and after grazing. Small increases in VFA pool sizes immediately after initiation of grazing are to be expected. This is due to a low efficiency of chewing during eating, since one of the main effects of ingestive chewing is to release soluble nutrients from feeds (Ulyatt *et al*. 1986), which are then rapidly and completely fermented.

Greenwood and Demment (1988) suggested that fasted cattle might have slower rumen passage rates because the onset of rumination may be delayed by longer particle sizes in rumen ingesta caused by less ingestive mastication due to a higher IR. However, a correlation analysis among several grazing experiments (Chilibroste 1999) showed that the rumen clearance rate of OM, NDF and sulfuric acid lignin, either before or after grazing, was not correlated with any indicator of rumen load (i.e. rumen pool sizes of total, DM, NDF or lignin) or rumen chemical composition. Bosch (1991) also observed a lack of correlation between rumen clearance rate and load. The need for a better understanding and more accurate quantification of passage of particles out of the rumen has been discussed by Tamminga *et al*. (1989) and Dijkstra and France (1996), and it seems to be critical if a quantitative link between ingestion and digestion is to be described.

Practical applications of short-term fasting on performance of lactating dairy cattle

Multiple short-term meals, and the associated IR, must be integrated in order to understand and predict daily DM intake as the sum of DM intake of the individual meals within day, where periods of eating, rumination, idling (i.e. activities not associated with eating or rumination) and resting alternate (Demment *et al*. 1995). Grazing management decisions can be made on a daily (or longer) scale, but the underlying processes occur continuously (e.g. digestion) or in discrete bouts (e.g. ingestion). Integration of ingestive and digestive processes during grazing is required to accurately predict nutrient supply to grazing cattle, regardless of supplemental feed usage

Table 2. Impact of the length of the grazing session on rumen pH, pool sizes of ammonia (NH_3P), acetic acid (C_2P), propionic acid (C_3P), butyric acid (C_4P), isobutyric acid (iC_4P), valeric acid (C_5P), isovaleric acid (iC_5P) and total volatile fatty acids (TVFAP) and the ratio of non-glucogenic to glucogenic [($C_2P + C_4P$)/ C_3P: NGR] fatty acids (from Chilibroste *et al.* 1998)

SF, start of fasting; EF/SG, end of fasting and start of the grazing session after the 16-h fasting period; G1.0, G1.75, G2.5 and G3.25 are for grazing times of 1, 1.75, 2.5 and 3.25 h, respectively

	Fasting or grazing treatment						s.e.m.	Slope during G^A	P^B
	SF	EF/SG	G1.0	G1.75	G2.5	G3.25			
pH	6.14	7.05	6.57	6.43	6.31	6.04	0.17	–0.23	**
NH_3P (g)	7.78	2.79	3.85	6.20	5.61	7.18	1.36	1.30	*
C_2P (mol)	4.77	1.75	2.33	3.28	3.72	4.89	0.34	1.08	**
C_3P (mol)	1.71	0.42	0.69	1.15	1.35	1.78	0.11	0.46	**
C_4P (mol)	1.07	0.18	0.28	0.51	0.77	1.00	0.06	0.31	**
iC_4P (mol)	0.04	0.02	0.02	0.03	0.03	0.05	0.01	0.01	*
C_5P (mol)	0.08	0.01	0.03	0.02	0.04	0.07	0.02	0.02	*
iC_5P (mol)	0.10	0.04	0.04	0.06	0.06	0.07	0.02	0.01	*
TVFAP (mol)	7.69	2.42	3.37	5.04	5.84	7.81	0.50	1.88	**
NGR	3.41	4.62	3.80	3.30	3.28	3.29	0.24	–0.20	*

[A]Slope is the change in rumen pool or rumen characteristics per hour of grazing time.
[B]*P*-value is the probability of the linear slope of G1 to G3.25 (*, $P < 0.05$; **, $P < 0.01$).

(Chilibroste *et al*. 2001; Baumont *et al*. 2004). Intervention in grazing management, by restricting the allowed grazing time and/or the timing of the grazing session, causes changes in cattle behaviour. These changes may be analogous to changes introduced by imposing different fasting regimes (Soca *et al*. 2002). Unfortunately, there are very few studies that have integrated the incidence of ingestive and digestive factors with DM intake and diet selectivity, as well as considered restrictions on grazing time, IR and the capacity to digest ingested herbage.

Restricting the allowed grazing time increases herbage production and utilisation since it reduces negative effects of cattle on the sward, such as treading, trampling and fouling. However, changing the time of day of the grazing session can also impact the sward by creating grazing sessions during times of the day that the sward is wetter. For example, in the early morning the sward can be more prone to damage from treading, trampling and fouling because it is wet (i.e. dew moisture) and this can lead to soil contamination of the standing biomass. This effect is important, as increases in herbage production of over 30% during the autumn/winter period have been observed by the authors under commercial Uruguayan conditions.

In grazing dairy systems, fasting is a normal occurrence, since cows experience alternating periods of eating, rumination, idling, resting, as well as movement for milking (Rook *et al*. 1994; Gibb *et al*. 1997). On large Uruguayan dairies, for example, distances of up to 3 km from the milking parlor to the grazing plots are not uncommon, thereby causing cows to have imposed fasting periods of up to 5 h/day. On daily strip grazing systems, a high proportion of removable pasture is consumed during the first half of the grazing session, and so cows may behave as though they have been fasted and may compete for herbage to achieve a higher instantaneous IR (Chilibroste *et al*. 1999).

Short-term fasting with limited availability of pasture

It is not uncommon that available pasture allowances are insufficient to fully meet the nutrient requirements of the cows due to limited availability, low nutrient density and/or high nutrient requirements of the cows. In such circumstances, dry hays, silages, commodity feeds and/or commercial concentrates may be supplemented to maintain milk production and/or restrict losses of bodyweight. Thus, a short-term fast may be terminated with a grazing session or a meal of a supplemental feed. In addition, it is possible to create more than one grazing session, by restricting grazing times, and/or to create fasting periods during the day. The interactions between times of allowed grazing sessions, lengths of created fasting periods and allocation of supplemental feeds are important to understanding, and selecting, optimal grazing management strategies when pasture allowances are insufficient (Appendix 1).

Chilibroste *et al*. (1999) allowed cows to graze oat pasture for 8 h from 0630 to 1430 hours in one grazing session, or for 6 h in each of two sessions from either 0830 to 1230 and 1630 to 1830 hours, or from 1230 to 1430 and 1630 to 2030 hours. Cows in all groups were supplemented with about 3.6 kg DM/day of maize silage at either 1730 (8-h group) or at 1830 and 2030 hours respectively in the two 6-h groups. They were also supplemented with 6.3 kg DM/day of a concentrate in two equal meals at milking. Maize silage and concentrates were completely consumed by all groups, and average sward utilisation did not differ among groups. However, milk production tended to be higher ($P < 0.07$) in the 6-h *v*. 8-h group (19.1 *v*. 17.7 kg/day), and also tended to be higher in the 6-h group that started grazing later *v.* the one which started earlier (20.0 *v*. 18.2 kg/day), but with a somewhat lower milk fat proportion.

The trend to higher milk production for the late starting 6-h grazing group could have been due to higher intake of pasture (i.e. the DM of hand plucked samples at the beginning of the grazing sessions at 0630, 0830 and 1230 hours for 8-h, 6-h early and 6-h late groups, were 14, 15 and 18% DM, respectively) and/or a potentially higher nutrient value of the grazed sward due to time of the day (i.e. CP was 20, 15 and 14% of DM, respectively). In addition, there may have been better synchronisation between herbage intake and intake of other feeds. However, the fast before grazing by the 6-h late group may have induced a stronger motivation to eat (Chilibroste *et al*. 1997), which is consistent with the first grazing bout being longer (i.e. 120 min) than in the 8-h and 6-h early groups (82 and 94 min, respectively). This is consistent with the observation that the probability of finding a cow grazing at any time was higher in 6-h late (81%) *v*. 8-h (57%) or 6-h early (59%) cows, and it was associated with lower rumination and resting times (Soca *et al*. 1999).

To test the hypothesis of Chilibroste *et al*. (1999) that a source of dry medium quality hay fibre may prevent a reduction in milk fat proportion when cows experience a high instantaneous IR, Chilibroste *et al*. (2001) allowed cows to graze oat pasture for 8 h from 0730 to 1530 hours, or for only 4 h from 1130 to 1530 hours either without, or with, *ad libitum* access to Moha hay (*Setaria italica*) at all times that they were not in the pasture or the milking parlour. Cows in all groups were supplemented with about 4.5 kg DM/day of maize silage at 1730 hours, as well as 1.8 kg DM/day of whole cottonseed and 3.1 kg DM/day of a concentrate in two equal meals at milking. Maize silage, cottonseed and concentrates were completely consumed by cows in all groups, and average sward utilisation did not differ among groups. Even though cows with *ad libitum* access to dry hay only ate about 1 kg DM/day, their milk fat percent (4.07 *v*. 3.49) and fat production (0.93 *v*. 0.75 kg/day) were higher ($P < 0.01$), and milk yield was higher (23.0 *v*. 18.0 kg/day). These differences suggest that one of the potential digestive costs of inducing a high instantaneous IR (i.e. too rapid fermentation of non fibrous carbohydrate) can be prevented through nutritional management.

To separate effects of the length and timing of the grazing session, which were confounded in Chilibroste *et al*. (1999, 2001), Mattiauda *et al*. (2003*a*) allowed cows to graze white clover pasture for 8 h from 0700 to 1500 hours, or for 4 h from either 0700 to 1100 hours or 1100 to 1500 hours. Cows in all groups were supplemented with about 4.8 kg DM/day of maize silage after the milking at 1530 hours, and with 6.3 kg DM/day of a concentrate in equal allocations during milking at 0530 and 1530 hours, respectively. Maize silage and concentrates were completely consumed by all cows in all groups, but estimated pasture DM intake was higher for 8-h *v*. 4-h grazed cows (8.5 *v*. 6.6 kg DM). Milk production (25.2 *v*. 23.3 kg/day) and milk fat percent (3.98 *v*. 3.68) were higher for cows allowed to graze for

8 h. However, there were no differences in milk production and composition between the two 4-h grazing groups. The higher milk production of the 8-h grazing cows was almost certainly due to increased pasture DM intake, as it seems that cows on the 4-h grazing treatment were not able to compensate for the severe reduction in pasture accessibility.

In the 4-h grazing groups, cows that started grazing at 0700 hours expended more time grazing than those that started at 1100 hours (Fig. 1; Mattiauda *et al*. 2003*c*), although daily DM intake did not differ (Mattiauda *et al*. 2003*a*). However, cows that started grazing later in the morning at 1100 hours had higher intake rates (33.7 *v*. 28.8 g/min), probably because of the higher pasture DM content (189 *v.* 167 g/kg DM) and/or the extra 4 h of fasting before grazing (i.e. 8 *v*. 4 h) before the grazing session started (Mattiauda *et al*. 2003*c*).

Cows that started grazing at 1100 hours had a steeper decline in rumen pH and a steady increase in ammonia concentration after initiation of the grazing session (Mattiauda *et al*. 2003*b*). Highest ammonia values occurred either 12 or 8 h after the start of the grazing session for treatments 0700 hours (191 mg/L) and 1100 hours (233 mg/L), respectively. This apparent delay in availability of nutrients, although seemingly without consequences on DM intake or utilisation of ingested nutrients to support milk production, is reflective of the changes in ingestive behaviour.

Experiments of Chilibroste *et al*. (1999, 2001) and Mattiauda *et al*. (2003*a*, 2003*b*, 2003*c*) were designed to limit the amount of total feed offered and the allowed grazing times, which might have reduced the extent of differences in DM intake and/or milk production among groups (Appendix 1). Nevertheless, it is clear that small changes in the length of the grazing session and/or on fasting before grazing, and consequently on hunger and/or the motivation to eat, were quickly reflected in ingestion and digestion patterns. Further research is needed to determine the potential to manage these changes, as well as their impacts on DM intake, milk production and milk composition.

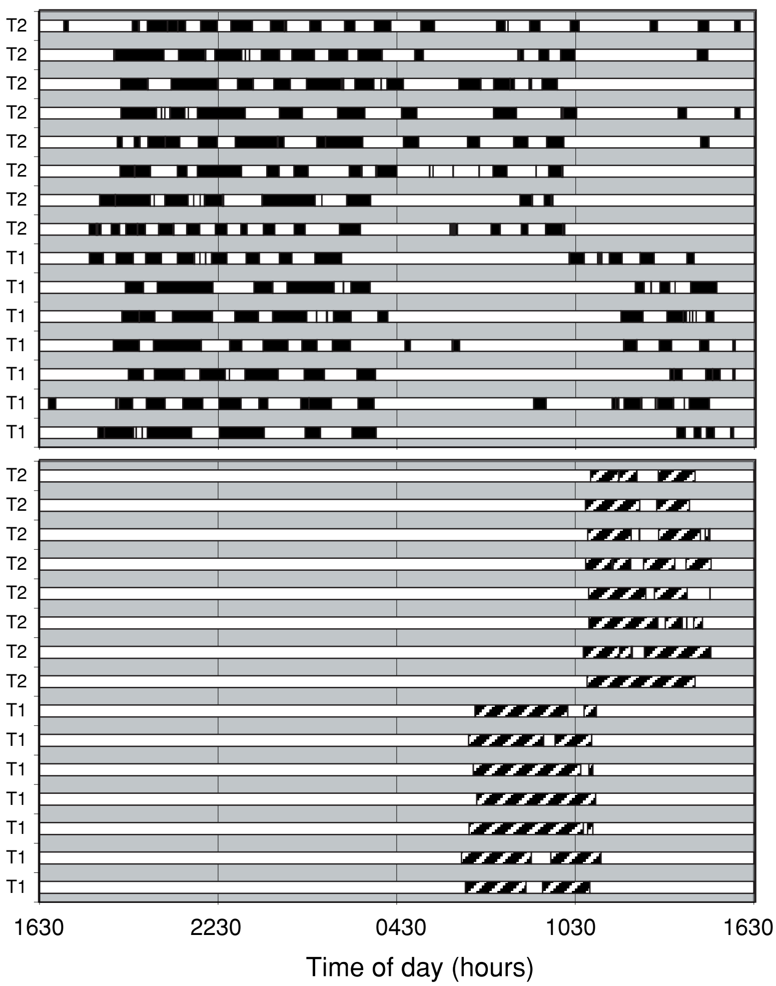

Fig. 1. Distribution of grazing (striped bars) and rumination (solid black bars) activities for cows that grazed from 0700 to 1100 hours (T1) or from 1100 to 1500 hours (T2). Each horizontal line represents the mean of an individual cow (i.e. 2 cows/day measured at 1-week intervals on the same paddock). From Mattiauda *et al*. (2003*c*) with a change of the originally listed time of 0230 to 0430 hours, as the original value of 0230 hours was incorrect (D. A. Mattiauda, pers. comm.).

Short-term fasting with ample availability of pasture

At some times of the year, most pasture systems have available pasture allowances that are sufficient to fully meet the nutrient requirements of the cows. In such circumstances, a fast will always be terminated by a grazing session (*v.* a meal of a supplemental feed), although it is possible to create more than one grazing session if grazing sessions are restricted. Interactions between the length of the allowed grazing sessions and sward allowances are important to understanding and selecting optimal grazing management strategies when pasture allowances are sufficient (Appendix 1).

Mattiauda *et al*. (2004) examined interactions between allowed grazing time and sward allowance by allowing cows to graze white clover (50%), lotus (30%) and tall fescue (15%) pasture for 8 h (GT8) from 1800 to 0200 hours with either a high (40 kg/cow.day) or low (25 kg/cow.day) pasture allowance, or for 16 h (GT16) in two periods each from 1800 to 0200 hours and 0700 to 1500 hours, with either a high (40 kg/cow.day) or low (25 kg/cow.day) pasture allowance. This study occurred in late spring–early summer when heat stress negatively impacted animal performance (Aldama *et al*. 2003). Estimated pasture DM intake was similar among groups, and there were no differences in milk production (average 13.6 kg/day) and milk composition among treatments. However, herbage ingestion patterns differed among groups (Mattiauda *et al*. 2004) with GT16 cows expending 453 min grazing while GT8 cows grazed for only 384 min. Although GT16 cows had the opportunity to graze for 8 h more than GT8 cows, they only exploited about 1 h extra (i.e. 69 min). Although the GT8 cows used almost 80% of their available time in the plot in grazing activities (384 min *v.* the 480 available), it seems that they did not compromise diet quality, since NDF and ADF contents of hand plucked herbage samples (37.3 and 21.3% of DM for NDF and ADF, respectively), did not differ between GT8 and GT16 groups (Aldama *et al*. 2003). The number of prehension bites for GT16 cows was higher than for GT8 cows, thereby suggesting more herbage searching time and probably smaller bites, although without differences on the fibre content of the selected bites. All of these observations are consistent with previous research (Greenwood and Demment 1988; Chilibroste *et al*. 1997; Patterson *et al*. 1998), since GT8 cows were fasted for 16 h before the start of the grazing session (i.e. 0200 to 1800 hours).

The different impacts of the ingestive patterns of GT16 *v.* GT8 cows on rumen metabolism are clear. For example, GT8 cows had a similar decline in pH when allowed high or low pasture allowances (pH declined from 7.1 to 5.9 and from 7.1 to 6.3, respectively). In both cases, minimum values occurred after about 8.5 h of grazing (i.e. near the end of the afternoon grazing session), suggesting an almost continuous input of fermentable nutrients to the rumen and an increase in VFA concentrations throughout grazing. The GT16 cows had a similar trend of declining pH, with a similar minimum of 6.2. After this minimum was reached, pH increased in all treatments. Since GT16 cows grazed the next morning in the same strip as the day before, further changes in pH were moderate, reflecting a slower and more selective herbage ingestion pattern. Rumination times were longer for GT16 *v.* GT8 cows (480 *v.* 419 min), but the lack of an effect of sward allowance on other components of grazing time and jaw movements suggests that aspects of sward structure, such as height and density, may have imposed limitations on more efficient, and eventually deeper, sward utilisation.

To test the hypothesis that pasture allowance and length of allowed grazing time would have a bigger impact on higher producing cows, Chilibroste *et al*. (2004) examined the interaction between allowed grazing time and sward allowance by allowing cows to graze legume (45%), grass (19%) and chicory (8%) pasture for 8 h (GT8) from 1800 to 0200 hours with either a high (60 kg/cow.day) or low (30 kg/cow.day) pasture allowance, or for 16 h (GT16) in two periods each from 1800 to 0200 hours and 0700 to 1500 hours, with either a high (60 kg/cow.day) or low (30 kg/cow.day) pasture allowance. This study was completed in early spring with mild weather when animal performance should have been optimal. Estimated pasture DM intake was similar among groups but, with these higher producing cows, there were effects of allowed grazing time (23.4 *v.* 20.6 kg/day) and sward allowance (23.4 *v.* 20.6 kg/day) on milk production and composition.

The GT16 cows grazed longer than GT8 cows either at a high pasture allowance (509 *v.* 332 min) or low pasture allowance (481 *v.* 379 min). Although the GT16 cows were allowed to graze for 8 h longer than GT8 cows, they only used 140 min, or 30%, of the allowed extra time for grazing activities. The high efficiency of the low pasture allowance GT8 cows, which grazed for about 75% of the allowed grazing time during the afternoon grazing session, is likely due to the long (16 h) fast before grazing and good sward conditions (i.e. it was undisturbed at the beginning of the grazing session). The fast clearly induced hunger and the good sward conditions may have induced these cows to express a high instantaneous IR, with long uninterrupted grazing bouts, compared with the short fasted GT16 cows.

Both the GT16 and GT8 cows were continuously grazing during the first 90 min of the afternoon grazing session. Differences in ingestive behaviour did not become apparent until the latter parts of the grazing session, a time when satiety signals would be expected to appear (Erhard *et al*. 2001) or the declining quality of the sward being grazed had an effect on grazing behaviour (Barrett *et al*. 2001). Rumination time during the afternoon session was 144 min for GT16 cows, but only 64 min for GT8 cows. This is consistent with previous observations (Chilibroste *et al*. 1997, 1998, 1999; Soca *et al*. 1999) that increases in IR occur at the expense of rumination time. Bite rate did not differ among treatments, with a general decline throughout the grazing session, and the total number of bites during the day did not differ.

Rumen pH was a good indicator of the impact of the cows' ingestive pattern on rumen fermentation. In GT8 cows, pH declined from the beginning (1800 hours) to the end (0200 hours) of the afternoon grazing session, but thereafter pH increased continuously until the next grazing session commenced at 1800 hours. For GT16 cows that returned to graze in the morning, pH reached a minimum at about 2300 hours, which may be because these cows stopped active grazing (F. Elizondo, pers. comm.) before the GT8 cows during the afternoon grazing session. Changes in rumen pool sizes during the day were consistent with this observation, since GT8 cows had the largest pool of rumen contents removable by hand (80.1 kg) at the end of the afternoon grazing session, even though at the beginning of grazing session these cows had the lowest DM rumen pool (41.0 kg). Lower initial rumen pool sizes of GT8 cows is a probable consequence of the longer fasting period before grazing, while the higher values for the GT8 *v.* GT16 cows at the end of their respective grazing sessions support the hypothesis that rumen fill is not the main factor that defines eating patterns of grazing dairy cows (Chilibroste 1999), since GT16 cows were more productive at a lower rumen fill *v.* GT8 cows.

It is clear that changes in the length of the grazing session (and the linked length of fasting before grazing), as well as pasture allowance, changed ingestion and digestion patterns of grazing dairy cows. However, it seems that the impact of these changes on milk production may depend on the cows' need for nutrients (i.e. production level). Further research is needed to determine the potential to express these changes, as well as their impact on DM intake, milk production and milk composition in cows with higher production levels.

Conclusions

Grazing time length and/or intake rate have been proposed as indicators of feeding motivation. Short-term changes in cows' physiological condition (e.g. a period of fasting) induce changes in foraging strategy. In most cases, a period of fasting increased herbage intake rate (Dougherty *et al.* 1989*a*) and grazing time in either the first bout (Chilibroste *et al.* 1997; Patterson *et al.* 1998), or on a daily basis (Greenwood and Demment 1988; Soca *et al.* 2002). Increased intake rate has been associated with a reduction in ingestive mastication of forage (Laca *et al.* 1994), which causes ingestion of longer particles and longer retention time of these particles in the rumen.

Eating and fasting naturally alternate in grazing systems, since rumination, idling and resting events alternate during the day. In grazing dairy systems, the movement of cows to be milked provides another modifier of the ingestive pattern. Knowledge of the effects of fasting on grazing behaviour have implications for management decisions. For example, the extent and timing of the grazing session induces changes in ingestive behaviour and digestive patterns. Management practices that provide shorter grazing sessions (i.e. longer fasting periods before grazing) and occur in the afternoon generally result in longer initial grazing bouts, higher intake rates, reduced rumination time during the grazing session, larger declines in rumen pH, as well as increased concentrations of rumen fermentation metabolites and rumen DM load. All of these changes have been associated with improvements in animal performance under the grazing conditions of the publications referenced in this review. However, further integrated research on interactions of sward state and short-term physiological conditions of dairy cows on ingestion and digestion patterns are warranted.

These findings are relevant in the quest to define efficient grazing management strategies. This could occur in situations where there is a limited amount of herbage available (and/or when it is of a low nutritional quality), making supplementation with other feeds a requirement to support milk production and/or minimise bodyweight loss, as well as when ample herbage is available. By using effective grazing management strategies, it is possible to integrate herbage production and cattle performance.

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Appendix 1. A general description of five of the referenced experiments that were completed with grazing dairy cows exposed to different fasting regimes

BW, bodyweight (kg); DIM, days in milk (days); SM, sward mass (kg DM/ha); FM, fresh matter; SH, sward height (cm)

	Chilibroste *et al*. (1999)	Chilibroste *et al*. (2001)	Mattiauda *et al*. (2003*a*)	Mattiauda *et. al.* (2004)	Chilibroste *et al*. (2004)
Experimental setup					
No. of animals per treatment	12	6	7	12	12
Parity	2.5	1.0	2.3	2.7	2.4
Duration (weeks)	5 (May–June)	5 (May–June)	5 (June–July)	9 (Oct.–Dec.)	5 (Sept.–Oct.)
Design	Randomised block	Randomised block	Randomised block	Randomised block	Randomised block
Model	Repeated measurements in time	Repeated measurements in time	Repeated measurements in time	Repeated measurements in time	Repeated measurements in time
Animals					
Breed	Holstein	Holstein	Holstein	Holstein	Holstein
BW (kg)	488 ± 44	553 ± 64	550 ± 48	548 ± 47	537 ± 56
Milk (L/day)	16.4 ± 2.2	20.1 ± 2.6	25.3 ± 2.5	13.6 ± 3.1	23.9 ± 5.7
DIM (days)	33 ± 7.8	33 ± 8.0	60 ± 10.3	199 ± 77	122 ± 112
Pasture					
Type	Oats	Oats	White clover	White clover (50%); lotus (30%); tall fescue (15%)	Legumes (45%); grasses (19%); chicory (8%)
SM (kg DM/ha)	1600	1784	1600	2800	2750
Allowance (kg DM/cow.day)	15	15	19	25–40	30–60
SH (cm)	–	–	–	12.5	12.5
Forage					
Type	Corn silage	Corn silage	Corn silage	Nil	Nil
Daily offer (kg FM/cow.day)	12	15	16		
Concentrates					
Type	Compound feed	Compound feed; cotton seed	Compound feed	Nil	Nil
Daily offer (kg FM/cow.day)	7	3.5; 2.0	7		