Evaluation of a Mobile Computerized Grain Feeder for Lactating Cows Grazing Grass Pasture

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ABSTRACT

The objective of this study was to evaluate a mobile computerized grain feeder for use to feed individually Holstein cows grazing grass pasture. Thirty-two Holstein cows averaging 95 d of lactation and 39.3 kg/d of milk were rotationally grazed on predominantly *Dactylis glomerata* pastures for 9 wk starting in early May. Cows were blocked according to parity, days of lactation, and milk yield. Cows were randomly assigned to a control group in which cows were individually fed grain twice daily at milking or to a group that was offered grain four times daily using a mobile grain feeder in the pasture. Cows in both groups were offered 1 kg of grain/3 kg of milk; pasture was the only source of forage. Cows fed using the mobile grain feeder consumed less grain than did control cows (9.3 vs. 11.3 kg/d) and tended to yield less milk, but with a higher fat content. A separate analysis was conducted using data from only those cows that were fed using the mobile grain feeder and that consumed, in four relatively equal amounts, at least 75% of the allotted grain of their respective pairmates (7 per group) in the control group. When cows that were using the mobile grain feeder consumed amounts of grain comparable with that of the controls, more frequent grain feeding did not alter milk yield or composition. Plasma samples (five per cow per treatment) were collected at 2-wk intervals to measure glucose, urea N, and nonesterified fatty acids (NEFA). Plasma glucose and urea N were not affected by treatment and averaged 54.9 and 19.9 mg/dl for all cows, respectively. Cows fed grain using the mobile feeder had higher (212.4 vs. 170.5 meq/L) concentrations of NEFA than did control cows, but, when cows consumed greater than 75% of their allotted grain from the mobile feeder, concentrations of NEFA were similar. The mobile grain feeder can be used to feed cows individually on pasture; however, adaptation of the cows to the mobile grain feeder appears to be important.

(**Key words**: grazing, grain supplementation, mobile grain feeder, lactating cows)

Abbreviation key: **BCS** = body condition score, **CF** = computerized grain feeder, **CGI** = cumulative grain intake during a 24-h period, **CI** = consistency index, **G6H** = grain intake in a 6-h period, **IVDMD** = in vitro DM digestibility, **PUN** = plasma urea N, **SP** = soluble protein, **TDMI** = total DMI, **TNC** = total nonstructural carbohydrates.

INTRODUCTION

Interest in the utilization of pasture as the primary source of forage for lactating dairy cows has been renewed. Many dairy producers are adopting feeding programs and strategies, such as grazing, that are more energy efficient, require less labor, and demand less financial input than do confinement operations. A survey (7) showed a mean savings of $153/yr per cow for 15 dairy farms in central New York compared with dairy farms using nongrazing systems. Parker et al. (26) concluded that an average Pennsylvania dairy farm could reduce operating costs by $6000 to $7000 annually through intensive grazing, but net income might not be improved if yield per cow fell more than 450 kg per lactation. Most of the research performed with grazing cattle has been done in Europe, Australia, and New Zealand where grain prices and availability often make grain less economical to include in the diet than in the US.

Pastures are often high in RDP, particularly in the spring (10, 11, 12), and contain insufficient nonstructural carbohydrates (34) for lactating dairy cows. Coupling the supply of N and energy-yielding substrates has been suggested as a means to optimize microbial growth and metabolism and, in turn, milk yield (2, 14, 15, 24). Because the end products of rumen fermentation (microbial protein and VFA) supply the majority of the requirement for protein and energy to the cow, rations must be formulated and fed to optimize microbial growth rate. The supplementation of pastures with various grain sources

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to provide ruminally available carbohydrate is common when grain is available and economical and is needed to optimize ruminal fermentation.

Grain is normally fed twice daily to cows on pasture, usually when cows are milked. McLachlan et al. (21) reported increased milk yield when cows on pasture were fed grain twice daily versus once daily. An increase in the frequency of grain feeding to more than twice daily for cows on pasture has not been reported. Previous research (28, 31) has shown that feeding twice daily causes an alteration in ruminal fermentation (i.e., fiber digestion) that might limit the amount of pasture that a cow can consume. Multiple daily feedings of concentrates may provide a daily synchrony of N and carbohydrate sources, may stabilize ruminal fermentation patterns (28), and may result in a more favorable environment for the growth of ruminal microbes.

High moisture feeds such as pasture can reduce the amount of saliva production per unit of intake by 50% when compared with the saliva production of cows that consume dry hay (4). This reduction in saliva flow to the rumen reduces the buffering ability because of the decrease in ruminal pH that is normally observed when grain is fed twice daily. The proper range and consistency of ruminal pH is critical to maximize fiber digestion, concentration of ruminal VFA, and DMI of cows fed high forage diets. Increased feeding frequency resulted in less daily variation in ruminal pH (31). Extreme daily variations in ruminal pH can be more harmful to ruminal microbes than a constant low pH (22) because of continuous metabolic readjustments by ruminal microbes. An increase in the frequency of grain feeding from two to four times per day may minimize the variation in ruminal pH, increase ruminal microbial efficiency by matching degradation of N and carbohydrates, and, thereby, improve performance.

A mobile computerized grain feeder (**CF**) allows grain to be fed more frequently than twice daily to lactating cows on pasture. The hypothesis tested in this study was that more frequent grain feeding using a mobile CF (8) would improve performance of lactating cows under a grazing system compared with performance of cows fed grain twice daily.

MATERIALS AND METHODS

Cows and Pasture

Thirty-two Holstein cows, averaging 39.3 kg of milk and 95 d of lactation at the start of the trial, were blocked according to parity, calving date, and milk yield and randomly assigned to one of two treatment groups. Each group contained 9 multiparous cows and 7 primiparous cows. The treatment groups consisted of twice daily grain feeding at milking time (control) and grain offered four times daily from the CF located on the pasture. Grain was fed at a rate of 1 kg/3 kg of milk yielded throughout the 9-wk trial. The trial began May 2 when cows began grazing high quality spring pasture growth. The available pasture was in excess of 2300 kg/ha at the start of the trial.

To adapt to the CF, cows were allowed access to the CF for approximately 4 h/d for 3 wk prior to the start of the trial. Initially, cows were adjusted to the CF in a lot near the barn and, when moved to pasture, were allowed to adjust for about 1 wk. Cows were milked twice daily at 0530 and 1800 h, and control cows were then brought into a tie-stall barn and fed grain twice daily in two equal feedings. During the trial, some cows fed from the CF had not adjusted to the CF and did not consume all of the allotted grain. The majority of the adjustment problems were with primiparous cows. When a cow did not consume at least 50% of the daily grain allotment from the previous day, she was brought into the barn and offered 50% of her daily grain allotment after the a.m. milking. This procedure was done every other day to maintain the milk yield and body condition of cows that were not accustomed to using the CF.

The same finely ground grain ration (Table 1) was fed to both groups. The grain ration was formulated to balance the nutritional attributes of pasture (23).

Pastures were located at The Pennsylvania State University Dairy Cattle Research and Education Center (University Park). A botanical survey (12) indicated that pastures contained approximately 38% orchardgrass (*Dactylis glomerata* L.), 34% Kentucky bluegrass (*Poa prateneis* L.), 18% smooth bromegrass (*Bromus inermis* L.), and small amounts of assorted herbaceous weeds. Cows were offered pasture as the sole forage source in a rotational grazing system in which cows were rotated to a new paddock approximately every 2 d. Pastures were divided into a replicated paddock system with eight paddocks per treatment group, and the two groups grazed adjacent paddocks. Rest intervals between grazing times were the same for each treatment group, which allowed a stocking rate of 4.4 cows/ha. Pastures were fertilized with urea at a rate of 56 kg of N/ha on April 12 and with 45 kg of N/ha after the second grazing cycle. Pastures were also clipped after each grazing cycle to remove any uneaten herbage and weeds. To facilitate adaptation to the new diet and the grazing system, 1 wk prior to the start of the trial, cows were allowed to graze for about 10 h/d and were fed a TMR at night.

TABLE 1. Ingredient and nutrient composition of the grain ration fed to cows grazing pasture.

Composition	
	(% of DM)
Ingredient	
Dry shelled corn, finely ground	54.9
Barley, finely ground	14.8
Whole roasted soybeans	12.7
Molasses	4.6
Animal protein blend[1]	4.0
Animal and vegetable fat blend	2.1
Limestone	1.6
Sodium bicarbonate	1.2
Dynamate®[2]	1.1
NaCl	1.0
Monosodium phosphate	0.8
Magnesium oxide	0.5
Trace mineral premix[3]	0.4
Premix[4]	0.2
Vitamin premix[5]	0.1
Nutrient[6]	
CP	15.6
RDP	7.1
Soluble protein	2.0
RUP	8.4 (54.2)[7]
NDF	12.5
ADF	4.2
Total nonstructural carbohydrates	53.4
Ether extract	6.5
Ash	8.1

[1]Contained 68% CP (66% RUP as a percentage of CP). Ingredients included meat and bone meal, blood meal, feather meal, poultry by-product meal, and fish meal.

[2]Pitman Moore, Inc. (Mundelein, IL).

[3]Contained 5455 ppm of Cu, 17,172 ppm of Mn, 20,202 ppm of Fe, and 54,545 ppm of Zn.

[4]Contained 606 ppm of Se.

[5]Vitamins were added to the grain mix at a rate of 6322 IU/kg of vitamin A, 2917 IU/kg of vitamin D, and 11 IU/kg of vitamin E.

[6]Composition is based on the mean of nine weekly grain samples during the trial.

[7]Percentage of CP that is RUP.

Estimates of total pasture DM available to the cows were obtained by clipping the pasture to a height of 5 cm from five quadrates (20 cm × 125 cm) per paddock during each rotation cycle. Pasture DM available to the cows averaged about 2100 kg/ha during the trial. Paddocks were examined by visual observation every 12 h, and cows were moved to a new paddock when pasture availability was estimated to be less than 1300 to 1400 kg/ha based on a pasture height of about 6 to 8 cm.

Mobile CF

The features and design of the mobile CF have been reported by Gardner et al. (8). The capacity of the grain bin was 2500 kg of grain. The CF dispensed grain at a rate of 0.36 kg/min into one feeding station. This dispensing rate was checked periodically and recalibrated as needed. The CF was powered by eight 6-V batteries that were recharged by solar panels and by a diesel-powered electrical generator when needed. The battery system was able to power the CF for a mean of 4 d. Then, the CF required about 8-d to recharge the batteries. During this 8 d recharging period, a diesel generator was used to power the CF.

The CF was programmed to start a 24-h feeding day at 2400 h and provide each cow with 25% of her total grain allotment every 6 h. The CF was designed to allow a 100% carry-over of all grain that a cow did not consume within each day. For example, if a cow was offered 2.7 kg of grain every 6 h but ate 2, 2, and 3 kg of grain, respectively, for the first three 6-h periods, she would be able to consume 3.8 kg (10.8 kg of allotted grain –7 kg of consumed grain) during the last 6-h period of a 24-h feeding period. Grain intake measurements were obtained at 6-h intervals from the CF for a period of 56 d, and these grain intake measurements were used to develop regression equations to predict grain intake during each 6-h period (**G6H**) and cumulative grain intake during a 24-h period (**CGI**) for cows grazing grass pasture. The CF was moved to the new paddock when the cows were moved and was unavailable for feeding only when the grain tank was being refilled. The CF was also located near the water tank in each paddock.

Experimental Measures and Sample Analyses

Herbage samples were obtained during each rotation cycle prior to grazing by plucking the grass by hand to the approximate height to which the cows grazed. Grain samples were taken twice daily and composited by week. Pasture samples were freeze-dried, and grain samples were oven-dried at 55°C and ground through a 1-mm screen. Pasture samples from each grazing cycle were composited by treatment prior to analysis. Pasture and grain samples were analyzed for DM, ash, CP, and ether extract (3). Soluble protein (**SP**) and RDP were determined according to the methods of Krishnamoorthy et al. (18, 19). The total nonstructural carbohydrate (**TNC**) content of the feeds was analyzed according to the method of Smith (30). The ADF and NDF contents were measured according to the methods of Goering and Van Soest (9) and in vitro DM digestibility (**IVDMD**) was measured according to the methods of Tilley and Terry (33).

Milk yield was recorded daily. Milk samples were taken twice weekly at consecutive a.m. and p.m. milkings to determine fat, protein, and SCC. Milk samples were analyzed for fat and protein by the Pennsylvania DHIA (Foss 605B Milko-Scan; Foss Electric, Hillerød, Denmark). Cows were weighed on 2 consecutive d (mean BW for the 2 d was used for analysis) at the beginning of the trial and at 14-d intervals thereafter. Two independent observers determined the body condition score (**BCS**) of cows every 2 wk based on a five-point scale (1 = thin to 5 = fat) (37). As with BW, the mean BCS assigned by the observers was used for analysis.

Five blood samples per cow were obtained by jugular puncture after the a.m. milking and prior to grain feeding at 2-wk intervals. Blood samples (10 to 15 ml) were placed in crushed ice until centrifugation. Plasma was removed, placed in 12-mm × 75-mm glass tubes, and stored at –20°C until assay. Samples were analyzed for concentrations of plasma urea N (**PUN**), glucose, and NEFA. Glucose was analyzed using Sigma glucose procedure no. 510, and PUN was analyzed using procedure no. 535 (Sigma Chemical Co., St. Louis, MO). A procedure developed by Johnson and Peters (16) using a Wako NEFA-C kit (no. 990-75401; Wako Chemicals USA Inc., Richmond, VA) was used to analyze concentrations of NEFA in plasma.

Five cows were administered controlled-released capsules of Captec® (batch no. 920318-1; Nufarm Ltd., Auckland, New Zealand) Cr_2O_3 (68% wt/wt) as an indigestible fecal marker to estimate DMI during two 7-d periods. Cows were dosed with the capsules 5 d prior to the start of fecal sampling to allow for a steady-state release of Cr_2O_3 from the Captec® capsules. The mean release rate of Cr from the Captec® capsules was 1.01 g/d. The batch release rate of Cr_2CO_3 was calculated by plotting the disappearance of the matrix over time in ruminally fistulated cows grazing ryegrass and white clover at the Chiswich Research Station (Armidale, New South Wales, Australia). Fecal grab samples were taken twice daily after milking for 7 d and placed in a freezer at –20°C until the end of the sampling period. Fecal samples were dried at 55°C, ground through a 1-mm screen, and composited daily on an equal weight basis prior to analyses. Fecal composites were analyzed for Cr by atomic absorption spectroscopy according to the procedure of Parker et al. (25). Estimates of DMI were made on the second and fourth pasture rotation cycles (16-d pasture rotation cycle) from the same pastures. Total DMI (**TDMI**) was estimated using the equation: TDMI = fecal output/(1 – IVDMD), where fecal output = Cr dosed per day (grams) per gram of fecal DM (grams). The first run of TDMI calculations utilized the IVDMD values from pasture alone. Pasture DMI was determined by subtracting the known grain consumption from the TDMI. Once the pasture DMI was estimated and the diet DMI of the grain was known, a weighted mean IVDMD of the diet was calculated. The second calculation used the IVDMD of the diet rather than the IVDMD of pasture for a more accurate estimate of TDMI. Only values from this second set of calculations are presented.

Statistical Analyses

The experimental design was a split plot (method of feeding was the main plot effect; experimental week was the split-plot effect). The model used for all the cow data was Y = treatment + cow (treatment) + time + time × treatment + error. The Y variable was a weekly mean for all yield variables and grain intake data and individual observations for BW, BCS, and concentrations of plasma metabolites. The cow (treatment) term was used as an error term to test the effect of treatment. Time refers to week of experiment when milk data were analyzed and to day when BW and BCS were analyzed. The model used to test pasture composition data was Y = treatment + grazing cycle + error. The Y variable was the mean concentration of each variable in the pasture during each grazing cycle. Data were analyzed using the general linear models procedure of SAS (29); therefore, all means presented are least squares means unless otherwise indicated.

A consistency index (**CI**) was calculated for each cow fed using the CF to determine the uniformity of consumption during a 24-h period:

$$CI = \sum_i 1/1 + [(\text{meal size}_i - \text{mean meal size})/\text{mean meal size})].$$

Meal size refers to the G6H of each cow. The upper bound for the CI when grain was fed four times daily was 4.0, and the upper bound for the CI when grain was fed twice daily was 2.0. Any intake pattern other than a uniform pattern (same each period) would result in a CI that was less than the upper bound. Large variation in meal size resulted in a smaller CI. A mean CI was calculated for each cow that was fed using the CF, and only data from those 7 cows that consumed at least 75% of their daily grain allotment and had a CI of at least 3.0 were chosen for a second data analysis. This analysis was used to determine the effects of grain feeding at two versus four times daily on milk yield, composition, BW, BCS, and blood parameters for cows in a rotational grazing system when cows consumed similar amounts of grain.

Multiple regression procedures of SAS (29) were used to develop models to estimate CGI and G6H of cows fed using the CF. The R^2 and Mallows' goodness of fit statistic for reducing variance (20) were used to determine the best fit model. Data from all cows fed using the CF and data from those cows consuming greater than 75% of their daily grain allotment in four relatively equal feedings (CI + 3.0) were used to predict CGI and G6H. Predictor variables used included day on paddock. Total amount of time cows grazed a given paddock was divided by 2. The first half of the time was set to 0, and the second half was set to 1. The period during the day when grain measurements were taken (0 to 0600 h, 0600 to 1200 h, 1200 to 1800 h, and 1800 to 2400 h) was indicated by using indicator variables (0 or 1). Lactation of the cow was also used as a predictor variable (0 = second lactation or greater; 1 = first lactation) to determine differences in CF usage between older and younger cows. The amount of grain fed in the barn to cows not using the CF properly was also included to determine its effects on CGI.

RESULTS AND DISCUSSION

The nutrient composition of pasture sampled during the four grazing cycles is presented in Table 2 as pooled means across treatments. Pasture quality based on CP and fiber was high during the 9-wk study. Although the CP was high (26.4%) during the trial, 83% of the CP was degradable, and 44% of the CP in pasture was SP. Other researchers (1, 34) have shown, by both in vitro and in situ techniques, that fresh forages have high amounts of RDP. These values, along with those provided by previous research (11, 12, 13), further confirm the imbalance of protein (high RDP and low RUP) in spring pastures for high yielding cows. Holden et al. (12) have also shown that dry cows had higher ($P < 0.05$) ruminal NH_3 N concentrations when grazing pasture (13.7 mg/dl) compared with values when cows were fed grass hay (10.9 mg/dl) or silage (11.0 mg/dl).

The increase in SP as the temperature became warmer was not expected and might have been related to sample handling procedures. Pasture samples were collected and frozen at –10°C and stored until the end of the trial when they were lyophilized prior to analysis. Kohn and Allen (17) showed that freezing fresh smooth bromegrass reduced the amount of SP by 41%; however, the length of time that the samples were frozen did not reduce concentrations of SP further, which would suggest that factors other than freezing caused the increase in SP. The addition of N fertilizer to the paddocks prior to the start of the trial and after the second grazing cycle might have been related to the increase in SP.

The concentrations of TNC in pasture and grain (Tables 1 and 2) averaged 18.1 and 53.4%, respectively. Based on estimated TDMI (Table 3) for the control and CF groups, the total diet consumed averaged 35% TNC. This TNC concentration is relatively low to maximize microbial protein yield and potential milk yield (15). Based on our estimates of pasture intake and actual grain intakes (Table 3), the CP content of the total ration consumed was estimated to be over 21%, primarily because of the high protein content of pasture.

TABLE 2. Nutrient composition of spring pastures during the four grazing cycles (16 d each).

Nutrient composition	Grazing cycle 1	2	3	4	Mean	SEM
	(% of DM)					
CP[a]	28.5	23.4	27.7	26.1	26.4	0.27
RUP[a]	4.2	3.5	4.9	5.4	4.5	0.13
RDP[a]	24.4	20.0	22.8	20.7	22.0	0.17
RDP,[a] % of CP	85.4	85.2	82.3	79.4	83.1	0.38
Soluble protein[a]	10.8	11.2	12.2	12.1	11.6	0.15
Soluble protein,[a] % of CP	37.7	47.6	43.8	46.5	43.9	0.44
NDF	40.4	42.4	41.9	43.2	42.0	0.81
ADF	23.2	24.0	23.3	24.5	23.8	0.42
TNC[1,a]	18.2	21.5	17.9	14.8	18.1	0.23
Ether extract[a]	6.1	5.2	5.5	6.5	5.8	0.14
Ash	8.6	7.9	8.8	8.5	8.4	0.14

[a]Means differ because of grazing cycle period ($P < 0.03$).

[1]Total nonstructural carbohydrates.

Health data were collected for both treatments during the trial. The control and CF groups each had three cases of mastitis, and 2 cows from the control group were treated for foot problems. In general, the health of all cows on the trial was excellent.

Performance of Cows

Milk yield and milk component data are presented in Table 4 and in Figures 1 and 2. Figures 1, 2, 3, and 4 contain two graphs. The top graph in each figure contains data for all 32 cows (16 per treatment). The bottom graph contains data from those cows (7 cows per treatment) that consumed greater than 75% of their allotted grain in four relatively equal allotments from the CF and their respective control pairmates from the group fed grain twice daily. Only data from multiparous cows in each treatment group are contained in each of the bottom graphs because the primiparous cows in general consumed less than 75% of their allotted grain from the CF. On average, control cows consumed 2 kg/d more grain (11.3 vs. 9.3 kg/d). During each week, grain intake was considerably higher for control cows than for cows fed using the CF (Figure 3). However, grain intake was only greater during wk 1 and 3 among cows that consumed greater than 75% of their allotted grain from the CF.

A comparison of all cows (Table 4), showed that control cows tended to have higher milk yields. Milk fat was lower for control cows than for cows fed using the CF (Figure 2). Thus, 3.5% FCM and fat yield did not differ over the 9-wk trial. However, the control group had higher FCM yields during wk 4, 6, 7, and 9 (Figure 1). No differences in milk protein content or yield were observed between treatments (Table 4).

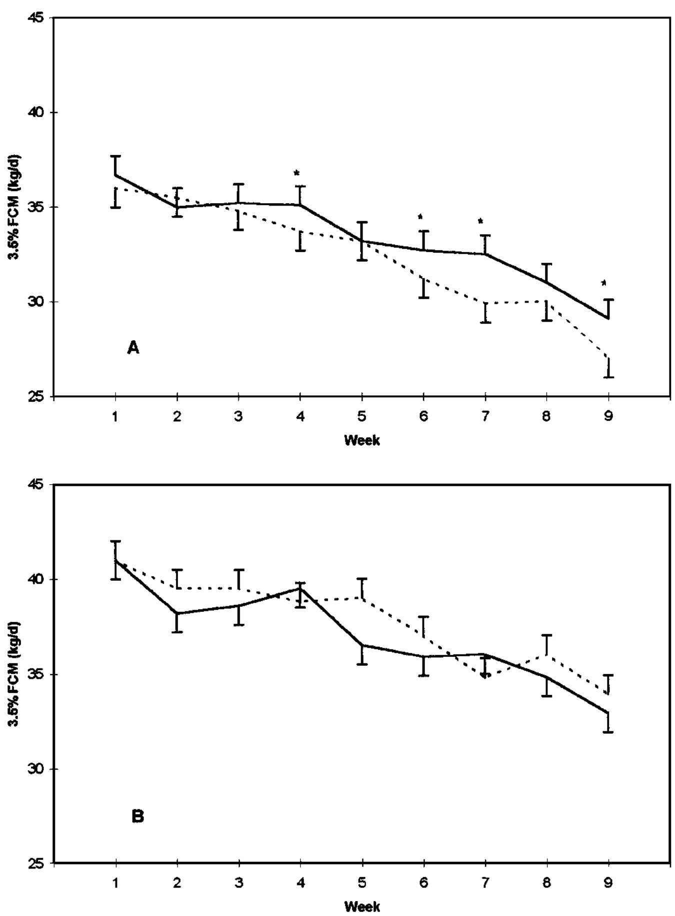

Figure 1. Daily 3.5% FCM yield of cows fed grain twice daily (control; ———) and of those offered grain four times daily by a computerized grain feeder (CF; – – – –). A. Data from all cows. B. Data from cows that were fed using the CF and that consumed greater than 75% of allotted grain and data from their respective control pairmates. *$P < 0.05$.

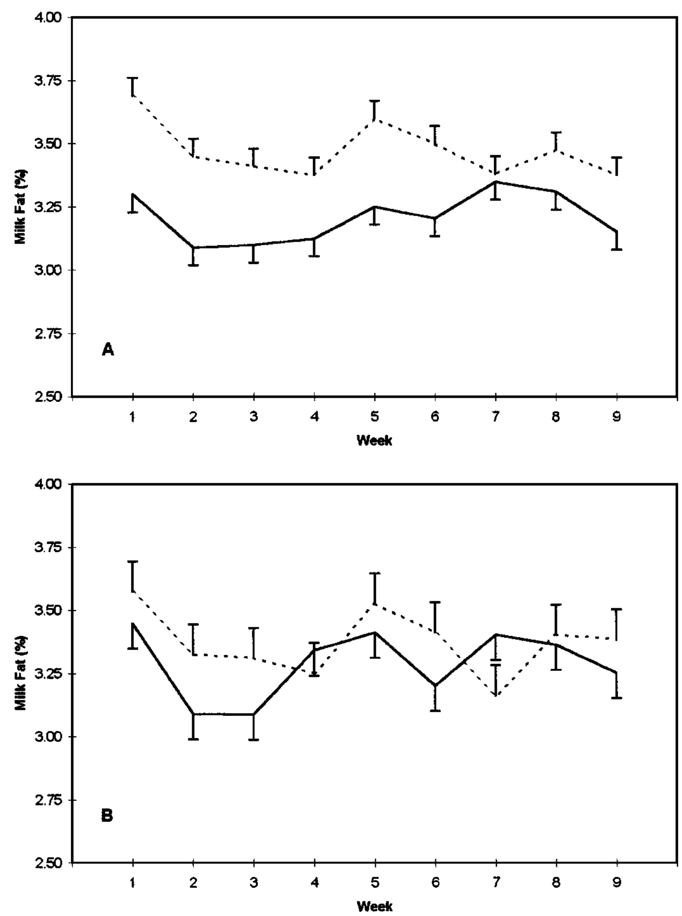

Figure 2. Daily milk fat percentage of cows fed grain twice daily (control; ———) and of those offered grain four times daily by a computerized grain feeder (CF; – – – –). A. Data from all cows. B. Data from cows that were fed using the CF and that consumed greater than 75% of allotted grain and data from their respective control pairmates.

TABLE 3. Effect of grain feeding frequency on estimated DMI[1] of cows grazing pasture.

	Treatment			
Item	Control[2]	CF[3]	$\overline{X}$	SEM
Cows, no.	3	3		
Total DMI, kg/d	28.1	25.7	26.9	0.86
Grain intake, kg/d	13.0	12.4	12.7	0.31
Pasture,[4] kg/d	15.1	13.3	14.2	0.68
DMI, % of BW	4.7	4.3	4.5	0.17
Total NDF intake, % of BW	1.35	1.19	1.27	0.06
TNC[5] Intake, kg/d	8.7	8.0	8.4	0.26
Forage NDF, % of BW	1.05	0.91	0.98	0.05
Milk yield,[6] kg/d	33.6	31.8	32.7	1.30
4% FCM,[6] kg/d	30.3	30.4	30.4	1.24
BW, kg	594	601	597	7.8

[1]Estimates of mean DMI are based on 3 cows per treatment from one 7-d period (June 30 to July 6) using Cr_2O_3 as the fecal marker during wk 9 of the trial.

[2]Control cows received grain twice daily after milking.

[3]Cows grazing pasture received grain four times daily using the computerized grain feeder.

[4]Pasture intake = Total DMI − grain intake.

[5]Total nonstructural carbohydrates.

[6]Mean milk yield and 4% FCM yield are from the 7-d intake measurement period.

Even though grain intake was higher for cows in the control group, changes in BW and BCS did not differ during the 9-wk trial (Table 4), which would suggest that cows fed using the CF either consumed more nutrients from pasture or were more efficient in utilizing consumed nutrients. Somatic cell counts tended to be higher for control cows, primarily because of 1 cow with a consistently high SCC.

Cows consuming greater than 75% of their allotted grain from the CF and their respective controls were generally multiparous cows. No significant differences in performance parameters were detected; multiparous cows yielded over 38 kg/d of milk and consumed 12 kg of grain (Table 4). Allocating this amount of grain into four feedings per day was not beneficial compared with twice daily feeding at the time of milking for high yielding cows on pasture. No previous research has evaluated the feeding of grain more than twice daily for cows on pasture, and no previous study has evaluated the amount of grain fed in this study. During early lactation, twice daily feeding versus once daily feeding of up to 8 kg/d of grain with tropical pastures resulted in increased milk yield (21). Neither our study nor the study of McLachlan et al. (21) evaluated data on rumen fermentation to know whether it was altered by feeding frequency.

Estimates of TDMI were not calculated during the first period because 7 of 10 cows administered the Captec® capsules lost the capsules by regurgitation while grazing pasture. During the second intake period, 4 of the 10 cows regurgitated the bolus while grazing. Based on the limited number of cows (per treatment) used to estimate pasture intake (Table 3), intakes could not be critically compared but are presented because of the limited intake data published for high yielding dairy cows grazing pasture.

TABLE 4. Effect of grain feeding frequency (FF) on milk yield variables, grain intake, BW, and body condition score (BCS).

	All cows					Cows consuming >75% from CF[1]				
Item	Control[2]	CF[3]	SEM	FF	FF × Time	Control	CF	SEM	FF	FF × Time
				P					*P*	
Cows, no.	16	16				7	7			
Milk, kg/d	35.0	32.8	1.4	0.29	0.22	38.5	38.6	1.3	0.93	0.44
3.5% FCM, kg/d	33.4	32.5	1.4	0.64	0.02	37.0	37.7	1.1	0.70	0.28
Fat										
%	3.21	3.46	0.10	0.09	0.15	3.38	3.28	0.19	0.70	0.48
kg/d	1.12	1.12	0.05	0.98	0.02	1.26	1.29	0.06	0.66	0.32
Protein										
%	2.97	2.93	0.05	0.63	0.14	3.01	2.95	0.10	0.69	0.05
kg/d	1.04	0.96	0.04	0.20	0.38	1.16	1.13	0.02	0.46	0.32
SCC, $\times 10^3$	302	142	96	0.24	0.10	430	226	180	0.44	0.48
Grain intake, kg/d	11.3	9.3	0.6	0.03	0.01	12.5	12.1	0.4	0.50	0.02
BW, kg	590	564	15	0.22	0.35	603	589	17	0.57	0.03
BW Change, kg	7.3	9.0				13.6	12.7			
BCS[4]	2.3	2.3	0.02	0.87	0.01	2.0	2.1	0.02	0.67	0.24
BCS Change	0.4	0.3				0.4	0.3			

[1]Multiparous cows that consumed greater than 75% of allotted grain from the computerized grain feeder (CF).

[2]Control cows offered grain twice daily after milking.

[3]Cows grazing pasture received grain four times daily using the CF. Measurements include grain fed in the barn for those cows not using the CF properly.

[4]Scored on a five-point scale where 1 = very thin to 5 = obese.

Daily pasture, grain, and TDMI averaged 14.2, 12.7, and 26.9 kg, respectively (Table 3) across both treatments. The TDMI averaged 4.5% of BW, and forage NDF averaged 0.98% of BW. Estimates of daily pasture and TDMI previously reported (11) were 12.9 and 22.4 kg, respectively, at approximately the same time during the grazing season. Possible reasons for differences between these studies include different pasture growing seasons and method of marker administration. Pasture quality was similar in both trials because of the similar grazing management systems used; thus, differences in intake were probably attributed to differences in the milk yield obtained between the two trials. In the current study, 4% FCM yield averaged 30.4 kg/d, and, in the trial conducted by Holden et al. (11), 4% FCM yield averaged 22.4 kg/d during a comparable intake measurement period. The DMI is generally considered to be governed by the capacity of the digestive tract (gut fill) of the cow fed a diet with low digestibility and by metabolic control (energy requirements of the cow) for a diet that is highly digestible (5, 6). In the current study, total IVDMD averaged 71.4%, which was higher than the 66.7% that Conrad et al. (6) considered to be the transition point at which DMI was controlled by gut fill, rather than energy requirements, for a 454-kg cow yielding 16.8 kg/d of milk. However, this transition point is not fixed but could occur at a higher level of digestibility for higher yielding cows (5, 6, 36). Pasture quality was high (low NDF and high CP) during the intake measurement period (grazing cycle four) (Table 2), which perhaps contributed to the greater DMI of the cow to meet her increased energy requirements for maintenance and

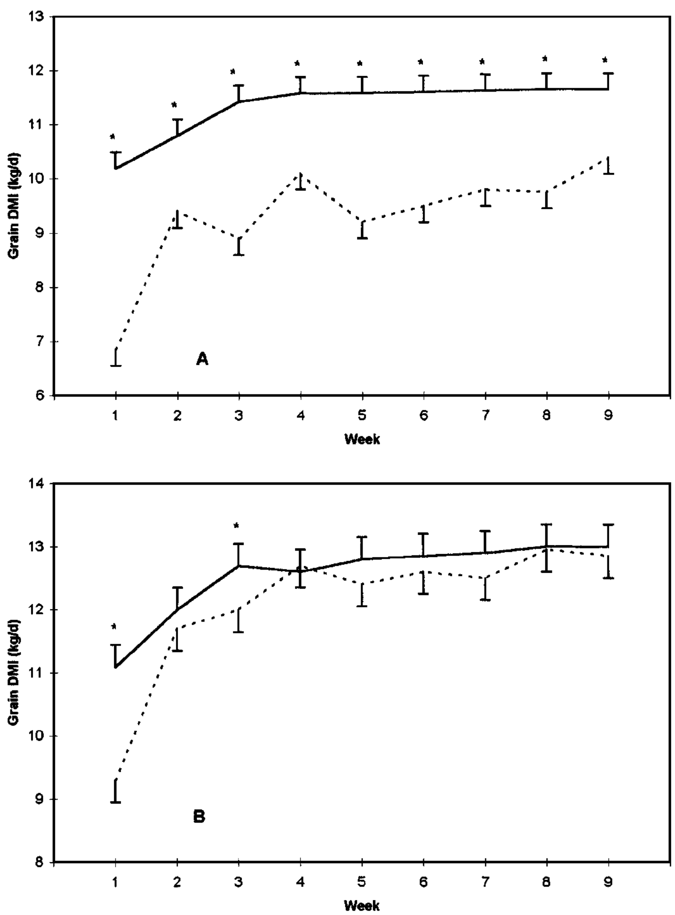

Figure 3. Daily grain DMI ($\bar{X} \pm SD$) of cows fed grain twice daily (control; ———) and of those offered grain four times daily by a computerized grain feeder (CF; – – – –). A. Data from all cows. B. Data from cows that were fed using the CF and that consumed greater than 75% of allotted grain and data from their respective control pairmates. $^*P < 0.05$.

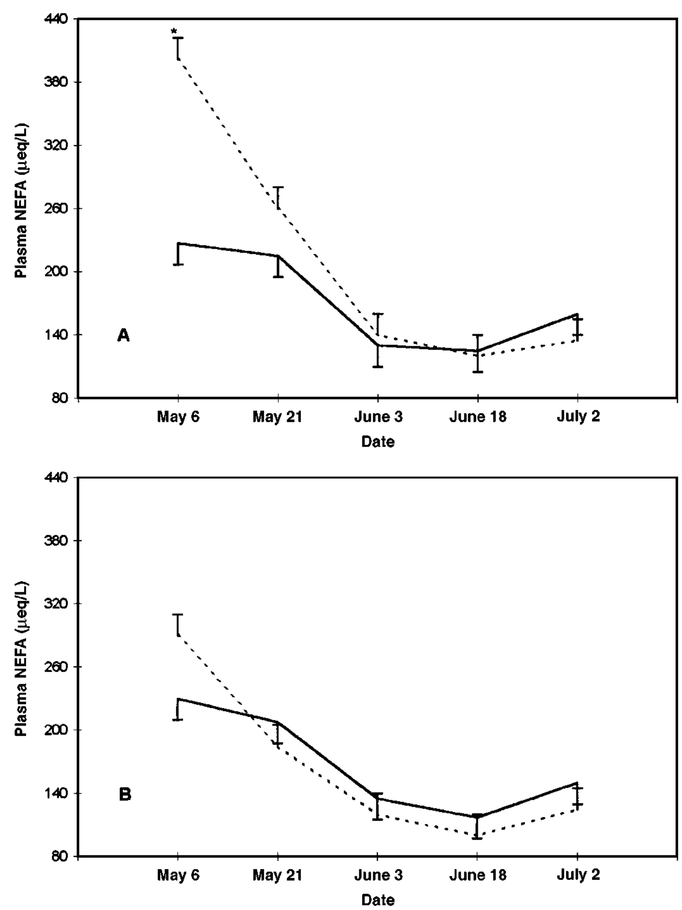

Figure 4. Concentrations of plasma NEFA of cows fed grain twice daily (control; ———) and of those offered grain four times daily by a computerized grain feeder (CF; – – – –). A. Data from all cows. B. Data from cows that were fed using the CF and that consumed greater than 75% of allotted grain and data from their respective control pairmates. $^*P < 0.01$.

milk yield. Also, forage NDF intake as a percentage of BW (0.98) was similar to the forage NDF intake reported by Rippel (27) to 1.0 to 1.1% of BW, which suggests that forage DMI of pasture may be regulated by ruminal capacity similar to that with nonpasture forages (5), at least when availability is not limiting.

Plasma glucose and PUN were not affected by grain feeding frequency and averaged 54.9 and 19.9 mg/dl, respectively for all cows (Table 5). Plasma glucose was within the normal range for dairy cows (32). Concentrations of PUN were high but comparable with values from other grazing studies and were higher during wk 3 for cows fed using the CF (Figure 4). In general, the lack of treatment differences in PUN suggested that, even though cows fed using the CF consumed less grain, the ruminally available carbohydrate might have been available at the correct time in the rumen so the microbes could effectively capture the high amounts of rapidly degradable protein from the pasture to maximize microbial protein (15), which could possibly explain why there were no differences in milk yield, BW, and BCS loss even though the cows fed using the CF consumed 2.0 kg less grain DM.

When data for all cows were analyzed, cows fed using the CF had higher (212.4 vs. 170.5 meq/L; $P < 0.05$) concentrations of plasma NEFA than did controls (Table 5; Figure 4). A significant interaction of treatment and week showed that cows fed using the CF had higher NEFA concentrations ($P < 0.01$) during the first blood sampling (Figure 4). However, when data from only those cows that were fed using the CF and that consumed greater than 75% of their grain were compared with their control pairmates, there were no differences in plasma NEFA concentrations (Table 5; Figure 4). This result would suggest that the cows consuming less than 75% of their allotted grain might have been mobilizing more body fat as indicated by higher plasma NEFA during the first blood sampling.

Behavior of Cows

When data from all cows using the CF were used to develop multiple regression models to estimate CGI and G6H, the regression equation only accounted for 68.6% of the variation associated with CGI and only 22.6% of the variation associated with G6H (Table 6). When data from only those cows that were fed using the CF and that consumed greater than 75% of their grain in approximately four equal allotments during a 24-h day were used to estimate CGI, the regression equation explained 88.5% of the variation associated with CGI and only 16.2% of the variation associated with G6H (Table 6). These models were fairly accurate at estimating both CGI and G6H for multiparous cows and multiparous cows that consumed greater than 75% of their grain in four equal allotments and were less accurate for primiparous cows as shown in Table 7. Figure 5 contains the projected grain intakes of primiparous cows, multiparous cows, and multiparous cows that consumed greater than 75% of their grain from the CF. The top graph contains the estimated cumulative CGI, and the bottom graph contains the estimated G6H. Primiparous cows had lower CGI, probably because of their reluctance to use the CF when the multiparous

TABLE 5. Effect of grain feeding frequency on plasma metabolites of cows (n = 5 per treatment) grazing pasture.[1]

	All cows			Cows consuming >75% from CF[2]		
Metabolite	Control[3]	CF[4]	Trt × Week[5]	Control	CF	Trt × Week
			P			P
PUN,[6] mg/dl	19.4	20.4	0.22*	20.3	19.7	0.60*
Glucose, mg/dl	56.1	54.1	0.20	54.7	53.2	0.57
NEFA, μeq/L	170.5	212.4	0.04***	168.2	165.0	0.89

[1]Samples (n = 5 per cow) were taken at 14-d intervals during the trial.

[2]Multiparous cows that consumed greater than > 75% of allotted grain from the computerized grain feeder (CF).

[3]Control cows received grain twice daily after milking.

[4]Cows grazing pasture received grain four times daily using the CF.

[5]Interaction of treatment and week.

[6]Plasma urea N.

*$P < 0.05$.

***$P < 0.001$.

TABLE 6. Best fit multiple regression models to estimate cumulative grain intake (CGI) and grain intake in each 6-h period (G6H) during the day for cows grazing pasture and using a mobile computerized grain feeder.[1]

Model	Cp[2]	R^2	Equations[3]
All cows (n = 16)			
CGI	13.1	0.686	2.53 − 0.22(PD) − 1.37(L) + 2.60(T2) + 6.32(T3) + 8.92(T4) − 0.13(BG × T2) − 0.14(BG × T3) − 0.19(BG × T4) − 1.12(L × T2) − 2.64(L × T3) − 3.93(L × T4)
G6H	7.5	0.226	2.61 − 0.18(PD) − 0.03(BG) − 1.32(L) + 0.16(T2) + 1.48(T3) − 0.04(BG × T2) − 0.28(L × T3)
Multiparous cows (n = 7) consuming >75% of their grain in four equal allotments			
CGI	7.6	0.885	2.77 − 0.08(BG) + 3.04(T2) + 6.76(T3) + 9.72(T4) − 0.24(BG × T2) − 0.13(BG × T4)
G6H	8.4	0.162	2.85 − 0.07(BG) + 0.31(T2) + 1.18(T3) − 0.15(BG × T2) + 0.21(BG × T3)

[1]Coefficients obtained from maximum R^2 procedure of SAS (29).

[2]Mallows' goodness of fit statistic based on total squared error.

[3]PD = Day on paddock (0 = first half of total time spent on a particular paddock; 1 = second half of total time spent on a particular paddock); L = lactation number (0 = second or greater lactation; 1 = first lactation); BG = kilograms of grain received in the barn (only those cows that were not using the computerized grain feeder were provided 50% of their daily grain allotment every other day to help maintain milk yield and body condition); and T2, T3, and T4 = 6-h time periods during the day when grain intake was measured (T2 = 1 if measured between 0600 and 1200 h, 0 otherwise; T3 = 1 if measured between 1200 and 1800 h, 0 otherwise; and T4 = 1 if measured between 1800 and 2400 h, 0 otherwise).

cows were nearby (Table 7; Figure 5). Grain intake between 1200 and 1800 h was consistently higher for all three groups (Table 7; Figure 5). The increase in this G6H might have been due to the high environmental temperatures that occurred during this period of the day and because of the 100% carry-over of grain that was not consumed during the two previous 6-h periods. Cows generally do not graze much during this period (1200 to 1800 h) and tried to seek shade. The CF would have offered some shade from the sun and was generally placed near the water troughs in each of the paddocks on which the cows grazed.

TABLE 7. Actual and estimated cumulative grain intake (CGI) and grain intake in each 6-h period (G6H) during the day for cows using a mobile computerized grain feeder on pasture.

Cows and period	CGI		G6H	
	Actual	Estimated[1]	Actual	Estimated[2]
	(kg of grain DM)			
Primiparous				
0000 to 0600 h	1.0	1.2	1.0	1.3
0600 to 1200 h	2.2	2.6	1.2	1.5
1200 to 1800 h	4.3	4.8	2.3	2.8
1800 to 2400 h	5.5	6.1	1.2	1.3
Multiparous				
0000 to 0600 h	2.4	2.5	2.4	2.6
0600 to 1200 h	4.9	5.1	2.6	2.8
1200 to 1800 h	8.6	8.9	4.0	4.1
1800 to 2400 h	11.2	11.4	2.6	2.6
Multiparous consuming >75% of grain in four equal allotments				
0000 to 0600 h	2.7	2.8	2.7	2.8
0600 to 1200 h	5.7	5.8	3.1	3.2
1200 to 1800 h	9.5	9.5	4.1	4.0
1800 to 2400 h	12.4	12.5	2.9	2.8

[1]The CGI regression model for primiparous and multiparous cows had an R^2 of 0.686, and the regression model for multiparous cows that consumed greater than 75% of their grain in four equal allotments had an R^2 of 0.885.

[2]The G6H regression model for primiparous and multiparous cows had an R^2 of 0.226, and the regression model for multiparous cows that consumed greater than 75% of their grain in four equal allotments had an R^2 of 0.162.

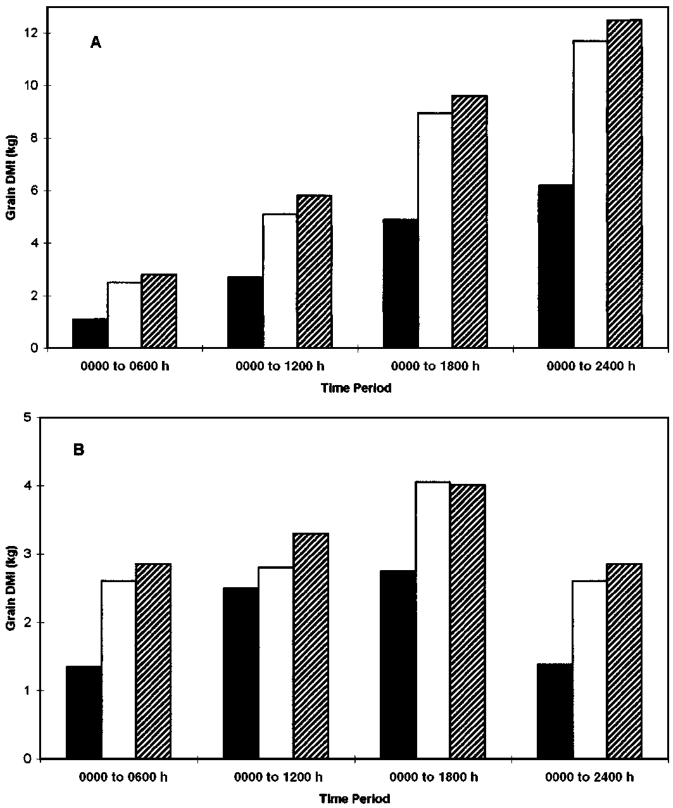

Figure 5. Estimated grain intakes for primiparous cows (solid bar), multiparous cows (MP; open bar), and MP that consumed greater than 75% of allotted grain (hatched bar). Graph A contains daily cumulative grain intake; graph B contains estimated grain intakes in each 6-h period during the day.

CONCLUSIONS

A mobile CF was developed to provide grain to cows grazing pasture (8). The mobile CF provided grain to cows individually in four allotments per day. In this trial, cows offered grain four times per day using a CF yielded similar amounts of 3.5% FCM even though they consumed 2 kg/d less grain DM. Only 7 of 16 cows fed using the CF consumed at least 75% of their grain in four equal allotments. All primiparous cows fed using the CF consumed less than 75% of their daily grain allotment, indicating that cow behavior or adaptation to the CF might have limited grain intake. Although the CF effectively provided grain for multiparous cows individually, there was no nutritional advantage over feeding grain twice daily at milking.

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