Effects of prepartum roughage neutral detergent fiber levels on periparturient dry matter intake, metabolism, and lactation in heat-stressed dairy cows

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ABSTRACT

Heat stress of lactating cattle results in dramatic reductions in dry matter intake (DMI). As a result, energy input cannot satisfy energy needs and thus accelerates body fat mobilization. Decreasing the level of roughage neutral detergent fiber (NDF) in prepartum diets, and thereby increasing the amount of nonfiber carbohydrates, may provide an adequate supply of energy and glucose precursors to maintain and minimize the decrease in DMI while reducing mobilization of adipose tissue. The effects of 3-wk prepartum diets containing different amounts of roughage NDF on DMI, blood metabolites, and lactation performance of dairy cows were investigated under summer conditions in Thailand. Thirty cross-bred cows (87.5% Holstein × 12.5% Sahiwal) were dried off 60 d before their expected calving date and were assigned immediately to a nonlactating cow diet containing the net energy for lactation recommended by the National Research Council (2001) model. The treatment diets contained 17.4, 19.2, and 21.0% DM as roughage NDF from banna grass (*Pennisetum purpureum* × *Pennisetum glaucum*) silage. Levels of concentrate NDF were 39.8, 40.2, and 38.6% of dietary NDF, so the levels of dietary NDF were 28.9, 32.1, and 34.2% of DM. After parturition, all cows received a lactating cow diet containing 12.7% roughage NDF and 23% dietary NDF. During the entire experiment, the minimum and maximum temperature-humidity index averaged 77.7 and 86.8, respectively, indicating conditions appropriate for the induction of extreme heat stress. As parturition approached, DMI decreased steadily, resulting in a 12.9, 25, and 32.8% decrease in DMI from d –21 until calving for nonlactating cows fed prepartum diets containing 17.4, 19.2, and 21% roughage NDF, respectively. During the 3-wk prepartum period, intakes of DM and net energy for lactation and concentrations of plasma glucose and serum insulin were higher for cows fed diets containing less roughage NDF. In cows fed the 3-wk prepartum diets containing

less roughage NDF, calf birth weights, milk yield, and 4% fat-corrected milk were higher, whereas periparturient concentrations of serum nonesterified fatty acids and plasma β -hydroxybutyrate were lower. There was a carryover effect of the prepartum diet on serum nonesterified fatty acids and plasma β -hydroxybutyrate during the first 7 d in milk, and therefore on milk production. These results suggest that feeding diets containing decreased amounts of roughage NDF during the 3-wk prepartum period may minimize the decrease in DMI and lipid mobilization as parturition approaches. This strategy may thus minimize the effect of hormonal factors and heat stress on periparturient cows.

Key words: neutral detergent fiber, heat stress, dairy cow, dry matter intake

INTRODUCTION

The transitional period of dairy cows is a time of substantial physiological adaptations associated with parturition and lactogenesis (Bauman and Currie, 1980). The decrease in DMI, combined with the normal homeorhetic processes, causes an increase in circulating NEFA because of lipid mobilization from adipose tissue (Bertics and Grummer, 1999). An increased concentration of plasma NEFA and their uptake by the liver may be accompanied by hepatic lipidosis and metabolic and digestive disorders (Grummer, 1995). These metabolic diseases may be caused in part by heat stress and nutrient imbalances or deficiencies or by depressed DMI before parturition. A heat-stressed animal may experience deficiencies in energy and nutrients because DMI will not satisfy energy needs (Collier et al., 1982a). To compensate for the increased energy demands that result from growth and lactogenesis, NEFA are released from adipose tissue (Grummer 1995). If heat-stressed cows are not managed properly during the transitional period, their risk of developing fatty liver, ketosis, and other associated metabolic disorders may increase significantly.

Thermal stress is a major factor that limits the productivity of dairy cattle in the tropics. During heat stress, the body temperature of a cow increases and feed intake, particularly intake of roughage, decreases,

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thereby decreasing milk production (Coppock and West, 1986). Although the effect of climatic conditions on thermoregulatory responses may be different for nonlactating cows, the greater costs of maintenance associated with heat stress reduce the efficiency of energy utilization by cows (NRC, 2001). In general, the concentration of roughage NDF shows a negative association with that of dietary NFC and energy content (Mertens, 1997). Increased fermentation of NFC results in increased concentrations of propionic acid and subsequently glucose. Both propionate and glucose promote secretion of insulin, which is an antilipolytic hormone. The additional energy supplied by NFC may help to offset the negative energy balance that develops before parturition. Under conditions of heat stress, the content of roughage NDF in the diet is therefore critical, and it may limit the supply of glucose precursors and energy to dairy cows. Cows fed a low forage diet (27.8% DM) during the periparturient period were not metabolizing as much energy from their body fat stores compared with cows fed a high forage diet (70% DM; Holcomb et al., 2001). However, information on the severity of the reduction in DMI during the transitional period of dairy cows under conditions of heat stress is limited. The objectives of the present study were to determine the effects of prepartum diets containing different amounts of roughage NDF derived from bana grass (*Pennisetum purpureum* × *Pennisetum glaucum*) silage on DMI, blood insulin, and metabolites and to establish whether the 3-wk prepartum feeding strategy affects postpartum DMI and lactation performance of dairy cows under hot and humid conditions.

MATERIALS AND METHODS

Experimental Design and Management of Cows

A study was conducted during summer months, from the beginning of April to the beginning of June 2008. The ambient temperature and relative humidity (RH) were recorded continuously by a thermograph (Classell, London, UK) placed in the feeding area. The maximum and minimum ambient temperatures and RH were determined for each day. The temperature-humidity index (THI) was calculated using the equation $THI = (1.8 \times td + 32) - (0.55 - 0.0055 \times RH) \times [(1.8 \times td + 32) - 58]$, where td is the dry bulb temperature ($^{\circ}C$) (NOAA, 1976).

Thirty cross-bred cows (87.5% Holstein × 12.5% Sahiwal) in their second and third lactations were dried off 60 d before their expected calving date and assigned immediately to a nonlactating cow diet with energy content close to the NE_L requirement defined by NRC (2001). Cows were kept in a 3-sided barn and fed as a

group during this period. They were chosen based on BCS of approximately 3.31 ± 0.04 (on a scale of 1 to 5), which was in the acceptable range of 3.25 to 3.50 at dry off recommended by current industry.

The experimental diets contained 17.4, 19.2, or 21.0% DM as roughage NDF from bana grass silage. Levels of concentrate NDF were 39.8, 40.2, or 38.6% of the dietary NDF; thus, the levels of dietary NDF were 28.9, 32.1, and 34.2% DM (Table 1). The 3 diets differing in NDF were fed only for the 3 wk before expected calving date. Bana grass was harvested at a 45-d defoliation frequency and wilted for approximately 3 h before ensiling. The forage was packed tightly in double-layered plastic bags. Before the bags were tied, the air was removed by using a vacuum pump. The experimental diets were mixed daily and fed as a TMR. Approximately half of each day's TMR was fed in the morning (0700 h) and the other half in the afternoon (1730 h). Refused feed was weighed before the morning feed, and the amount of feed offered was adjusted daily to allow 10% refusal. To reduce the dietary cation-anion difference, $MgCl_2$ at 60 g/d per cow was added to the experimental diets for 2 wk before the expected date of parturition. After calving, all the cows received a lactation diet (Table 1).

The animals were moved to a 3-sided barn approximately 21 d before their expected calving date and were fed individually throughout the experimental period. Nonlactating cows were moved with their feed to a calving pen just before calving and returned to the experimental barn the following morning. Cows received no supplemental cooling from fans or misters. The cows had free access to water.

Data Collection and Sampling Procedures

Samples of TMR and silage were obtained weekly and analyzed for DM content. The samples collected each week were frozen at $-20^{\circ}C$ and composited monthly. Composite samples of TMR and silage were analyzed for their contents of CP, ether extract (EE), ash, NDF, and neutral detergent insoluble nitrogen (NDIN). Composite samples of silage were analyzed for pH and organic acids.

The cows were milked twice daily at 0430 and 1530 h with a portable milking unit and the milk weights were recorded. The BW of the cows were recorded weekly before feeding, and BCS were assigned weekly by the same individual for the entire experiment, using a 1 to 5 scale with quarter-point increments following the method of Wildman et al. (1982).

Milk was sampled twice weekly from consecutive morning and afternoon milking sessions. The milk samples were composited in proportion to milk production

Table 1. Ingredient and chemical composition of diets containing different contents of roughage NDF from bana grass silage fed to the 3-wk prepartum cows and of the lactation diet after parturition

Item	Diets containing roughage NDF, %			
	17.4 ¹	19.2 ¹	21.0 ¹	12.7 ²
Ingredient, % of DM				
Bana grass silage	27.2	30	32.8	19.8
Soybean meal	1.5	1.0	0.5	10.0
Full fat soybean meal	—	—	—	11.6
Palm oil	—	0.8	1.5	—
Wheat bran	28	28	28	5
Sesame seed meal	11	11	11	10
Soy sauce residues	3.2	3.2	3.2	3.2
Cassava chips	26.7	23.6	20.6	38
Minerals-vitamins ³	2.4	2.4	2.4	2.4
Chemical composition, %				
CP	13.1	13.0	13.2	16.8
RUP, ⁴ % of CP	32	32.4	32.6	38.1
Ether extract	2.1	2.5	2.8	3.9
Total NDF	28.9	32.1	34.2	23.2
Total NFC	37.0	33.3	30.9	45.0
NE _L , ⁵ Mcal/kg of DM	1.46	1.45	1.44	1.57

¹Diets for dry cows during the 3-wk period before expected calving.

²Diet for lactating cows during the first 5 wk of lactation.

³Contained (per kilogram of DM) 65 g of Ca, 10.1 g of K, 4.2 g of P, 2.8 g of Cl, 2.3 g of Mg, 2.3 g of S, 2.0 g of Na, 56 mg of Fe, 45.3 mg of Mn, 45.3 mg of Zn, 11.4 mg of Cu, 0.68 mg of I, 0.34 mg of Se, 0.11 mg of Co, 3,600 IU of vitamin A, 1,128 IU of vitamin D, and 28 IU of vitamin E.

⁴RUP = B [(k_p/k_d + k_p)] + C, where B is potentially degradable true protein, k_p is fractional rate of passage, k_d is fractional rate of degradation, and C is undegradable fraction. The values of each fraction and fraction rate are taken from Kanjanapruthipong (2006).

⁵NE_L (Mcal/kg) = 0.0245 × total digestible nutrients (TDN; %) – 0.12; the figure of TDN taken from Kanjanapruthipong (2006).

at each sampling and were preserved with 2-bromo-2-nitropropane-1,3-diol for analysis of their composition. Blood was sampled from the coccygeal vessels immediately after the morning milking, and all sampling was completed before the morning feed. During the 3-wk prepartum period, blood was sampled 3 times weekly on Monday, Wednesday, and Friday. Blood was also sampled immediately before calving. After calving, blood was sampled 3 times weekly during wk 1 and 2 on Monday, Wednesday, and Friday, and twice weekly during wk 3 to 5, on Monday and Wednesday. Blood samples were collected into serum separation tubes for analysis of NEFA, insulin, and urea nitrogen. Blood samples were also collected into tubes containing sodium fluoride for plasma glucose analysis, and into tubes containing potassium EDTA for assay of BHBA.

Laboratory Analyses, Calculations, and Statistical Analysis

Organic acids in the silage were measured using HPLC (Nitisinprasert et al., 2000). The contents of DM, CP, EE, and ash in the experimental diets were measured according to methods described by AOAC (1980). Neutral detergent fiber and NDIN were deter-

mined following the method of Van Soest et al. (1991). The level of NFC was calculated using the equation NFC = 100 – CP – EE – (NDF – NDIN) – ash. Milk components were assayed for fat, total protein, and lactose using a MilkoScan (Bentley 2000, Bentley, Chaska, MN). The serum insulin concentration was measured according to a 2-site chemiluminescent immunometric assay (ImmLite/Immolute 1000 Insulin, LKIN1, EURO/DPC, Siemens Medical Solutions Diagnostic Ltd., Llanberis, UK). Commercial kits (Roche Diagnostics, Indianapolis, IN) were used in the analysis of NEFA (Randox kit no. FA115). The Vitros slide method (Vitros 950/950T, Buckinghamshire, UK) was used in the analysis of plasma glucose (Vitros GLU slide kit 1) and serum urea nitrogen (Vitros BUN/UREA slide kit 1). Plasma BHBA concentrations were assayed using a kinetic enzymatic method (Ranbut kit no. RB 1007, Randox Laboratory, Antrim, UK).

Energy balance was calculated (NRC, 2001) individually for each cow. Net energy intake (NE_I) was determined by multiplying daily DMI by the calculated energy value of the experimental diets. Severe heat stress has been estimated to increase the maintenance energy requirement by 25% (NRC, 2001). The NE_M was calculated as BW^{0.75} × 0.10. Pregnancy require-

ments (NE_P) were calculated using the equation $NE_P = [(0.00318 \times \text{days pregnant} - 0.0352) \times (\text{calf birth weight}/45)]/0.218$. The equation used to calculate prepartum energy balance (EB_{PRE}) was $EB_{PRE} = NE_I - (NE_M + NE_P)$. The NE_L requirement was calculated as $(0.0929 \times \text{fat \%} + 0.0547 \times \text{CP \%} + 0.0395 \times \text{lactose \%}) \times \text{milk yield}$. The equation used to calculate postpartum energy balance (EB_{POST}) was $EB_{POST} = NE_I - (NE_M + NE_L)$.

The data for DMI, blood parameters, and milk yield were reduced to weekly means for each cow before statistical analysis. Pre- and postpartum data for DMI, blood insulin, and metabolites were analyzed separately. The data were subjected to ANOVA for a randomized design with repeated measures using the GLS function of R, version 2.9.0 (The R Foundation, 2009; <http://www.r-project>). The model included the fixed effects of diet and week and the interaction of diet and week. Cow nested within diet was designated as a random effect and was used as the error term to test the effects of diet. The covariance structure of repeated measurements that yielded the smallest Bayesian information criterion was chosen. The contrasts statement with the data frame "longa coding for tf" was used to test for the effects of diet at specific time point. The data on calf birth weights were assessed separately using ANOVA for a completely randomized design. The difference between treatment means was analyzed by least significant difference. Least squares means and standard error of the means were reported for all ANOVA results.

RESULTS

The chemical composition of bana grass silage on a DM basis was as follows: 10.2% CP, 2.08% EE, 64.0% NDF, and 9.8% ash. Bana grass silage contained 6.33 g of lactic acid/100 g of DM and 1.62 g of acetic acid/100 g of DM. Butyric acid was not detected. The pH of the silage was 4.14.

The chemical composition of the experimental diets is shown in Table 1. The prepartum dietary treatments contained a similar calculated energy value as expected. The values for analyzed CP and calculated RUP were similar for all the experimental diets.

During the experimental period, the average minimum and maximum temperatures were 25.7 and 37°C, respectively. The average minimum and maximum RH values were 48.0 and 95.0%, respectively. The combination of high temperature and RH led to significant minimum and maximum THI, which averaged 77.7 and 86.8.

Cows on diets containing 17.4, 19.2, and 21.0% DM as roughage NDF consumed their assigned diet for $19.6 \pm$

0.5 d, 19.4 ± 1.2 d, and 19.0 ± 1.1 d before parturition, respectively. The effects of the prepartum dietary treatments on the intakes of DM and NE_L , calf birth weight, and changes of BW and BCS are presented in Table 2. The prepartum intake of DM and NE_L and calf birth weight were greatest for cows fed the diets containing lower levels of roughage NDF, and the least for cows consuming the highest level of roughage NDF ($P < 0.01$). Dietary treatment had no effect on postpartum intakes of DM and NE_L and postpartum BW and BCS. Although postpartum intake of DM and NE_L decreased with increasing NDF, the quantitative dietary analysis did not show an effect. The P -values for the linear and quadratic effects of DMI were 0.11 and 0.54 and those of NE_I were 0.15 and 0.67, respectively. A treatment $\times$ week interaction ($P < 0.01$) showed that intakes of DM and NE_L a week before calving were higher in cows fed prepartum diets that contained less roughage NDF. The changes in periparturient DMI are shown in Figure 1.

The concentrations of blood metabolites and serum insulin are shown in Table 3. The prepartum concentration of plasma glucose was higher ($P < 0.01$) in cows fed diets containing less roughage NDF, whereas the prepartum concentrations of serum NEFA were lower ($P < 0.01$) in this group. The prepartum concentrations of serum insulin ($P = 0.03$) and plasma BHBA ($P = 0.04$) were affected by prepartum dietary treatment. Cows fed diets containing less roughage NDF had higher prepartum concentrations of serum insulin and lower prepartum concentrations of plasma BHBA. The postpartum concentrations of serum NEFA ($P = 0.04$) and plasma BHBA ($P = 0.03$) were also affected by prepartum dietary treatment. Cows fed diets containing less roughage NDF had lower postpartum concentrations of serum NEFA and plasma BHBA. A treatment $\times$ week interaction ($P < 0.02$) showed that serum NEFA concentrations in wk -1, at calving, and in wk 1 were lower in cows fed diets containing less roughage NDF. The changes in periparturient NEFA in serum are shown in Figure 2. The prepartum dietary treatments did not affect the periparturient level of urea-N in serum.

Production variables and energy balance are shown in Table 4. Milk yield ($P = 0.03$) and 4% FCM ($P = 0.04$) were affected by prepartum dietary treatment. Milk yield and 4% FCM were greater in cows fed diets containing less roughage NDF. Prepartum dietary treatment had no effect on milk composition, efficiency of milk production (FCM/DMI), or energy balance. A treatment $\times$ week interaction ($P < 0.03$) showed that energy balance 1 wk after calving was higher in cows fed prepartum diets containing less roughage NDF than

in those fed diets containing more roughage NDF. The changes in periparturient energy balance are shown in Figure 3.

DISCUSSION

Heat stress in late gestation reduces fetal growth and alters the endocrine status of the dam (Collier et al., 1982b). These alterations have carry-over effects into the postpartum period on milk yield and reproductive performance (Collier et al., 1982a). Under hot and humid conditions, optimal nutritional management during the nonlactating period is critical. The dietary modifications used to minimize the negative effect of heat stress on DMI by dairy cattle include substitution of nonforage fiber sources for roughage (Halachmi, et al., 2004) and reduction of roughage NDF (West et al., 1999; Kanjanapruthipong and Thaboot, 2006). The effect of prepartum carbohydrate source on the risk of fatty liver is unclear, partly because changes in carbohydrate source are often confounded with changes in energy concentration, energy balance, and, in particular, the level of body fat reserves at calving (Overton and Waldron, 2004). In general, nutrition in the nonlactating period that allows some gain in BCS has been considered beneficial, but overfeeding that al-

Figure 1. Changes in periparturient DMI in cows fed 3-wk prepartum diets containing different contents of roughage NDF (RNDf). Pre- and postpartum SEM were ± 0.33 and 0.64 kg/d, respectively. Prepartum roughage NDF effect, week effect, and roughage NDF $\times$ week interaction effect 1 wk before calving, $P < 0.01$. Postpartum week effect, $P < 0.01$; other effects, nonsignificant.

lows excessive BCS gain has been shown to increase the incidence of periparturient health problems (Grummer, 1993). In this study, a diet was fed during the early nonlactating period that was close to NE_L requirements (NRC, 2001). The experimental diets during the 3-wk prepartum period were formulated to be isonitrogenous and isocaloric. Therefore, dietary NDF concentration

Table 2. Dry matter and net energy intakes, calf birth weights, and changes in BCS and BW of cows fed 3-wk prepartum diets containing different contents of roughage NDF from bana grass silage

Variable ¹	Prepartum roughage NDF, %				P-value ²		
	17.4	19.2	21.0	SEM	D	Wk	D $\times$ Wk
DMI							
Prepartum, kg/d	12.9 ^A	11.5 ^B	10.2 ^C	0.33	<0.01	<0.01	<0.01
Postpartum, kg/d	19.1	18.4	17.9	0.64	0.26	<0.01	0.49
Prepartum, % of BW	2.2 ^A	2.0 ^B	1.8 ^C	0.02	<0.01	<0.01	<0.01
Postpartum, % of BW	3.67	3.55	3.51	0.11	0.34	<0.01	0.59
NE_L intake, Mcal/d							
Prepartum	18.8 ^A	16.7 ^B	14.7 ^C	0.69	<0.01	<0.01	<0.01
Postpartum	32.5	31.8	31.0	1.02	0.72	<0.01	0.82
BCS, ³ units							
Prepartum	3.41	3.38	3.30	0.10	0.18	0.26	0.31
Postpartum	2.44	2.41	2.34	0.07	0.44	<0.01	0.60
BCS change							
Prepartum	0.06	0.04	-0.01	0.06	0.25		
Postpartum	-0.35	-0.33	-0.33	0.09	0.48		
BW, kg							
Prepartum	586	574	566	15.02	0.08	0.41	0.60
Postpartum	522	518	510	13.13	0.46	<0.01	0.78
BW change							
Prepartum	17	14	10	1.18	0.34		
Postpartum	-22	-23	-26	1.90	0.55		
Calf birth weight, kg	37.7 ^A	34.2 ^B	30.6 ^C	2.11	<0.01		

^{A-C}Means within a row without a common superscript letter differ ($P < 0.01$).

¹For DMI, NE_L intake, BCS, and BW, prepartum = mean of d -21 to -1, and postpartum = mean of d 1 to 35. For BCS and BW change, prepartum = d -1 value minus d -21 value, and postpartum = d 35 value minus d 1 value.

²D = dietary treatment; Wk = week around calving.

³BCS on 1 = thin to 5 = obese scale with quarter-point increments.

Table 3. Concentrations of blood metabolites and insulin in cows fed 3-wk prepartum diets containing different contents of roughage NDF from bana grass silage

Variable ¹	Prepartum roughage NDF, %				P-value ²		
	17.4	19.2	21.0	SEM	D	Wk	D × Wk
Glucose, mg/dL							
Prepartum	66.9 ^A	64.0 ^B	62.4 ^C	0.64	<0.01	<0.01	0.09
Postpartum	63.2	63.0	63.3	0.71	0.33	<0.01	0.47
Insulin, μ IU/mL							
Prepartum	10.8 ^a	9.7 ^b	7.2 ^c	0.31	0.03	<0.01	0.07
Postpartum	8.1	8.0	7.9	0.35	0.20	<0.01	0.26
NEFA, mEq/mL							
Prepartum	0.160 ^C	0.287 ^B	0.368 ^A	0.01	<0.01	<0.01	0.02
Postpartum	0.340 ^c	0.431 ^b	0.489 ^a	0.03	0.03	<0.01	0.02
BHBA, mmol/L							
Prepartum	0.356 ^c	0.460 ^b	0.563 ^a	0.03	0.04	0.30	0.59
Postpartum	0.363 ^c	0.491 ^b	0.590 ^a	0.03	0.04	<0.01	0.10
Urea-N, mg/dL							
Prepartum	8.81	9.25	9.55	0.63	0.63	<0.01	0.98
Postpartum	13.90	13.55	13.61	0.54	0.60	<0.01	0.88

^{a-c}Means within a row without a common superscript letter differ ($P < 0.05$).

^{A-C}Means within a row without a common superscript letter differ ($P < 0.01$).

¹Prepartum = mean of d -21 to -1; postpartum = mean of d 1 to 35.

²D = dietary treatment; Wk = week around calving.

and energy concentration were unlikely to be confounded.

The minimum THI values in this study ranged from 75 to 80 and exceeded the upper critical point of 72 for optimal productivity, whereas the maximum THI values ranged from 85.7 to 87.9 and exceeded the lower end of the danger zone of 78 for survival of Holstein cows (Johnson, 1987). These environmental conditions indicate the presence of significant heat stress.

Heat stress reduces feed intake (Beede and Collier, 1986), and intake of roughage is reduced before that of concentrate (Coppock and West, 1986). Under hot conditions, the DMI of lactating cows decreases as the content of NDF in the diet is increased (West et al., 1999). With increasing amounts of roughage NDF fed during the 3-wk prepartum period, a similar result was observed for nonlactating cows in this study. As parturition approached, DMI decreased steadily, which resulted in a 12.9, 25, and 32.8% decrease in DMI from d -21 until calving for nonlactating cows fed the 3-wk prepartum diets containing 17.4, 19.2, and 21% roughage NDF, respectively. These cows showed patterns of decline in prepartum DMI similar to those reported in the literature (Grummer, 1995). However, the prepartum diets in this study contained much lower levels of roughage NDF compared with the typical levels of 25 to 30% roughage NDF fed to cows in temperate regions. The results suggest that under hot and humid conditions roughage NDF can be one of the primary factors limiting DMI and, therefore, nutrient intake in prepartum cows. Diets containing lower levels of NDF

produce higher proportions of propionic acid. These proportions can have greater hypophagic effects because of a combination of increased osmolality in the reticulo-rumen and specific effects of propionic acid (Allen, 2000). The results presented in this study suggested that the higher proportions of acetic acid and physical factors derived from higher dietary fiber have greater hypophagic effects than the higher proportions derived from lower dietary fiber on dairy cattle kept under hot and humid conditions.

Figure 2. Changes in periparturient serum NEFA in cows fed 3-wk prepartum diets containing different contents of roughage NDF (RNDF). Pre- and postpartum SEM were ± 0.02 and 0.02 mEq/mL, respectively. Prepartum roughage NDF effect and week effect, $P < 0.01$, and roughage NDF $\times$ week interaction effect 1 wk before calving, $P < 0.02$. Postpartum roughage NDF effect, $P < 0.01$; roughage NDF $\times$ week interaction effect 1 wk after calving, $P < 0.02$; other effects, nonsignificant.

Figure 3. Changes in periparturient energy balance in cows fed 3-wk prepartum diets containing different contents of roughage NDF (RNDF). Pre- and postpartum SEM were ± 0.09 and 0.13 Mcal/d, respectively. Prepartum roughage NDF effect and week effect, $P < 0.01$. Postpartum week effect, $P < 0.01$; roughage NDF $\times$ week interaction effect 1 wk after calving, $P < 0.03$; other effects, nonsignificant.

In temperate climates, researchers found no difference in the birth weights of calves born to cows receiving diets containing either adequate or deficient amounts of energy during the nonlactating period (Dann et al., 2006; Douglas et al., 2006). However, cows that were heat stressed during the prepartum period produced calves with reduced birth weights (Collier et al., 1982b). In this study, the prepartum changes in BW and BCS were not significantly different, but calf birth weights were significantly lower for cows fed the 3-wk prepartum diets containing higher amounts of roughage NDF compared with lower amounts. The mechanisms responsible for the reduction of calf birth weight observed in cows with lower DMI during the nonlactating period are not known. Heat stress during gestation alters hormone secretion by the placenta and may have significant implications for retardation of fetal and

mammary growth (Collier et al., 1982b). This alteration may be caused in part by an insufficient supply of nutrients. A heat-stressed animal may experience deficiencies in energy and nutrients because its DMI does not satisfy its energy needs (Collier et al., 1982a). Cows kept under conditions of heat stress generally produce additional heat because of greater physical activity, such as panting. Severe heat stress has been estimated to increase the energy maintenance requirement by 25% (NRC, 2001). This equates to 2.2 Mcal of NE_L /d for a 550 -kg cow. The average 3-wk prepartum energy balance in this study was 3.7 , 1.8 , or -0.1 Mcal/d, for cows fed diets containing 17.4 , 19.2 , or 21% roughage NDF, respectively. The mean NEFA concentration was greater in cows fed the 3-wk prepartum diets containing more roughage NDF. The cows fed the diet containing higher amounts of roughage NDF in this study must have mobilized a greater amount of maternal tissues to support fetal development during the nonlactating period. Under hot and humid conditions, the content of roughage NDF fed during the prepartum period is therefore critical for the supply of energy and other nutrients to the cow and the fetus.

The greater maintenance costs associated with heat stress reduce the efficiency of energy utilization by lactating cows (NRC, 2001). The concentration of roughage NDF is related negatively to the energy concentration (Mertens, 1997). Although blood NEFA concentration increases with increasing intake of fat (Andersen et al., 2008), the results from several experiments indicate that a greater prepartum concentration of NEFA is correlated with lower DM and energy intakes in the prepartum period (Grummer, 1995; Grummer et al., 2004). Blood NEFA is an important indicator in the evaluation of the energy balance of the cow. It is elevated when stored fat is mobilized. In this study,

Table 4. Production variables and energy balance for cows fed 3-wk prepartum diets containing different contents of roughage NDF from banana grass silage

Variable ¹	Prepartum roughage NDF, %				<i>P</i> -value ²		
	17.4	19.2	21.0	SEM	D	Wk	D $\times$ Wk
Milk, kg/d	29.0 ^a	27.4 ^b	26.3 ^c	0.59	0.03	<0.01	0.79
Milk fat, %	3.86	3.87	3.94	0.11	0.10	<0.01	0.99
Milk fat, kg/d	1.12	1.05	1.07	0.06	0.52	<0.01	0.45
Milk protein, %	3.07	3.07	3.05	0.04	0.70	<0.01	0.74
Milk protein, kg/d	0.89	0.87	0.83	0.05	0.88	<0.01	0.99
Milk lactose, %	4.83	4.81	4.81	0.04	0.40	0.44	0.46
Milk lactose, kg	1.40	1.32	1.27	0.07	0.38	<0.01	0.30
FCM, 4%, kg/d	28.4 ^a	26.7 ^b	26.1 ^c	0.59	0.04	<0.01	0.80
FCM/DMI	1.49	1.45	1.45	0.07	0.42	0.30	0.38
Energy balance, Mcal/d	-1.74	-1.63	-1.64	0.13	0.44	<0.01	0.55

^{a-c}Means within a row without a common superscript letter differ ($P < 0.05$).

¹Mean of d 1 to 35.

²D = dietary treatment; Wk = week around calving.

the concentrations of plasma glucose and serum insulin increased but the concentrations of serum NEFA and plasma BHBA decreased with decreasing contents of roughage NDF fed during the 3-wk prepartum period. The finding of a high concentration of serum insulin in cows fed diets containing less roughage is consistent with other studies reviewed by Grummer (1995). Increased prepartum concentrations of serum insulin reflect the higher plasma glucose concentrations. These variables were mainly caused by higher intakes of DM and NE_L . However, Reynolds et al., (1991a) demonstrated a positive relationship between the heat production of portal-drained viscera and intake of ME in growing heifers. Increasing intake of ME results in increased ruminal and intestinal growth via cellular hyperplasia (McLeod and Baldwin, 2000). The increase in intestinal mass response associated with intake of ME and roughage is largely (90%) a result of proliferation within the mucosa (McLeod and Baldwin, 2000). Baldwin et al. (2004) demonstrated that cellular oxidative capacity remained constant despite differences in gut cellularity. Changes in portal-drained viscera O_2 consumption are attributable to changes in mass rather than mass-specific activity (Baldwin et al., 2004). In addition, heifers fed a diet consisting of 75% concentrate had greater tissue energy retention than those fed a diet containing 75% alfalfa at equal ME intake (Reynolds et al., 1991b). Lactating cows under conditions of heat stress fed diets containing lower levels of roughage NDF are in lower oxidative stress (Kanjapapruthipong and Thaboot, 2006). Similarly, in this study, cow fed diets containing lower amounts of roughage NDF during the 3-wk prepartum period had lower serum NEFA and higher serum insulin concentrations. These results suggest that feeding prepartum cows a diet containing less roughage NDF may provide an adequate supply of nutrients to alleviate the influence of hormonal factors and heat stress.

In temperate climates, researchers have found no effect of prepartum energy intake, either adequate or deficient amounts of energy, on milk yield (Dann et al., 2006; Douglas et al., 2006). However, prepartum heat stress (Collier et al., 1982a) and BCS at parturition (Fronk et al., 1980) can affect periparturient DMI and subsequent performance. Heat stress did not affect pre- and postpartum BW, whereas postpartum plasma NEFA concentrations were elevated and milk yield was reduced in heat-stressed cows (Collier et al., 1982b). In this study, cows were allowed to over-consume energy from the lower roughage NDF diets during the 3-wk prepartum period. The change in BCS was less than 0.1 point and not biologically significant. Postpartum DMI and periparturient BW and BCS in this study were not affected by the prepartum dietary treatments, despite the differences in mean serum NEFA and plasma

BHBA concentrations. The greater serum NEFA and plasma BHBA concentrations in cows fed diets containing larger amounts of roughage NDF were unlikely to be a simple function of change in BW and BCS during the periparturient period. These greater concentrations showed significant and clear biological effects of the prepartum dietary treatment. Given that there was no difference in energy balance postpartum, the higher postpartum concentrations of serum NEFA and BHBA cannot be explained by a more negative energy balance. The generally higher plasma concentration of NEFA during the periparturient period may be associated with decreased insulin responsiveness (Oikawa and Oetzel, 2006) and an increased capacity for incomplete β -oxidation of long-chain fatty acids (Andersen et al., 2008), and thus increased plasma BHBA. These results suggest that DMI during the 3-wk prepartum period probably altered hepatic metabolic efficiency postpartum. In addition, the presence of heat stress alters endocrine dynamics during late gestation, and this alteration may have effects on mammary growth and thus subsequent milk yield (Collier et al., 1982b). Increased DMI in cows fed the lower amounts of roughage NDF during the 3-wk prepartum period in this study may have increased nutrient supply and thus alleviated the effects of heat stress on mammary growth. This alteration might have coincided with greater hepatic metabolic efficiency, and thus allowed increased production of 4% FCM despite no difference in calculated FCM/DMI.

CONCLUSIONS

Under temperate conditions, nonlactating cows have the ability to consume large amounts of feed, even at high energy densities (Grummer et al., 2004). Further, in temperate climates, researchers have found that allowing ad libitum access to diets containing moderate to high energy densities throughout the entire nonlactating period, or in the close-up period, to allow BW gain could be detrimental to postpartum performance, even when cows do not become over-conditioned (Dann et al., 2006; Douglas et al., 2006). However, under hot and humid conditions, roughage NDF constrains intake by dairy cattle (Kanjapapruthipong and Sawanon, 2007). In this study, cows fed diets containing the lowest amount of roughage NDF consumed 122% of the NE_L requirement, which was much lower than the 160% of NE_L requirement (NRC, 2001) reported by Douglas et al. (2006) and Dann et al. (2006). This study demonstrated that a diet containing less roughage NDF allowed maintenance of higher prepartum DMI, plasma glucose, serum insulin, calf birth weight, and 4% FCM and lower pre- and postpartum serum NEFA

and plasma BHBA. Under hot and humid conditions, feeding cows a diet containing less roughage NDF during the 3-wk prepartum period may provide sufficient nutrients to alleviate the influence of hormonal factors and heat stress on the nonlactating cows as parturition approaches. This may reduce the severity of negative energy balance that occurs during the periparturient period.

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