See pages 103 and 104 for information regarding heat stress and balancing rations for RUP and rumen undegraded lysine.

Nutrient and Feeding Strategies to Enable Cows to Cope with Heat Stress Conditions

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Summary

- Formulate diets to contain slightly greater NDF and ADF concentrations in order to minimize the risk of ruminal acidosis which is more prone to occur during heat stress.
- Inclusion of fat in higher fiber diets may help maintain energy intake. Rectal temperature and milk production can be improved.
- Providing cool, clean water in ad libitum amounts will encourage water intake, feed intake, and milk production.
- Recommended ranges of dietary concentrations of macrominerals for warm weather feeding include K at 1.5 to 1.6%, Na at 0.45 to 0.60%, and Mg at 0.35 to 0.4% of DM.
- Overfeeding total and degradable protein during times of hot weather have reduced cow performance, possibly due to increased energy costs of N excretion.
- Feeding fungal cultures has improved cow performance in about half of the studies reviewed.
- Feeding in the early morning hours and late evening hours will prevent the rise in body heat from DM intake coinciding with the rise in ambient temperature, thus reducing the maximum heat load on the animal.

Introduction

The breeds predominantly used by the U.S. dairy industry were developed in temperate climes, and are most productive between the temperatures of 41 and 59°F. As temperatures increase from 59 to 77°F, cows experience a small degree of loss in production (Hahn, 1985). However as temperatures exceed 77°F, dramatic reductions in feed intake and milk production can occur. As a result, 78°F is usually considered the upper critical temperature for lactating dairy cows (Berman et al., 1985).

In addition to ambient temperature, relative humidity should be considered when assessing the heat-stressing effect of the environment on dairy cows. The use of a temperature-humidity index (THI) has been developed which helps better define the environmental conditions under which productivity and well being of animals are likely to be compromised. This THI is also called the "Discomfort Index." High producing cows are thought to experience no stress when THI is less than72 and severe stress when THI exceeds 88. These guidelines may shift somewhat depending on amount of milk produced, degree of air movement, and direct solar radiation. THI can be calculated using the following equations (Chambers, 1970) (temperature is expressed in °F or °C and relative humidity is expressed in decimal form):

$$THI = (0.81 \times \text{dry bulb temperature, } C^{\circ}) + (\text{relative humidity} \times (\text{dry bulb temperature} - 14.4)) + 46.6$$

THI = (dry bulb temperature, F° × 0.45) + (0.55 × dry bulb temperature × relative humidity) – (31.9 × relative humidity) + 31.9

While THI is a useful tool to assess the degree of heat stress potential on the cow, her own responses to the hot weather are truer indicators of her degree of heat stress. When rectal temperature is greater than 102.5°F and breaths exceed 60 per minute, cows on the verge of experiencing significant heat stress; points at which the cow will heat up exponentially if exposed to increasing temperature and humidity. Management strategies should be initiated to prevent further increases in body temperatures or significant economic losses will likely occur.

In order to help the cow cope with the additional stress of high heat and/or humidity, the environment surrounding the cow can be modified (shades, fans, sprinklers, coolers, etc.). An excellent review describing a variety of environmental modifications and their benefits is that of Shearer et al. (1996). Environmental modification will have a greater impact on minimizing losses of milk production and feed intake due to ongoing and severe heat stress than will modifying the diet. Nevertheless strategic changes in feeding management and formulation can have a significant impact on cow production and well being during heat stress.

Nutritional Management Changes to Moderate Heat Stress Effects

Feed Intake and Feeding Management. At the upper critical temperature of 78°F, at and above which temperature the cow has difficulties dissipating her heat load, she begins eat less feed. Elevating body temperature may signal the hypothalamus to reduce voluntary intake. Table 1 illustrates the challenge lactating cows face to maintain milk production during elevated ambient temperatures. As the temperature increases, the amount of energy expended by the cow to maintain homeothermy increases (eg. 20% more at 95° compared to 68°F). Panting increases the maintenance requirement by 7 to 25% (NRC, 1981). Therefore DM intake must increase from 40.1 to 42.8 lb/d to cover this additional energy cost. However, during hot weather, DM intake decreases to 36.8 lb/d. Therefore the energy status of the cow gets a double hit - greater energy costs to try to maintain homeothermy and lower energy intake. Thus, it is not surprising that milk production goes down.

Table 1. Relative changes in maintenance requirements and needed dry matter intakes (DMI) as temperatures increase with resulting effects on actual DMI and milk production (NRC, 1981).

Temperature	Maintenance energy[1]	Needed DMI, lb/d	Actual DMI, lb/d	Milk, lb/d
68°F	100	40.1	40.1	59.5
77°F	104	40.5	39.0	55.1
86°F	111	41.7	37.3	50.7
95°F	120	42.8	36.8	39.7

[1] As a percentage of the maintenance energy requirement of a dairy cow at 65-68°F producing 59.5 lb of milk.

Not only the amount but also the pattern of eating differed during cool (50 ± 12.6°F) and hot conditions (86 ± 12.6°F). Under hot conditions, steer intake decreased from 17.9 to 16.3 lb/d and the number of eating events increased from 8 to 13 per day. Despite lower intakes spread out over smaller meals, the hot steers experienced a greater net rise in inner ear temperature after eating compared to cooler cows (approximately 2.7 vs. 0.8°F under cooler conditions) (Hahn, 1999). Under hot conditions, cows may eat more frequent meals of smaller size resulting in a lower intake per day, yet experience a greater increase in body temperature.

What can be done to reverse in part the depression in DM intake brought on by hot weather? By physically cooling the cows and by feeding early in the day and late in the afternoon after the worst of the heat stress has passed can lessen the intensity of the heat load on the cow.

By reducing rectal body temperatures from an average of 104.7 to 102.4°F, average DM intake was increased from 35.7 to 43.2 lb/d, and average milk production was increased from 38.8 to 44.5 lb/day (Johnson et al., 1991; Mallonee et al., 1985; Schneider et al., 1984; Schneider et al., 1986; Schneider et al., 1988). These cows were obviously lower producing cows. Since higher producing cows are more susceptible to heat stress, the decrease in milk will likely be even greater. Cows producing 76.7 lb/d dropped to 61.5 lb/d and rectal temperatures increased from 101.3 to 104.5°F when they were placed in chambers with a diurnal temperature change (Knapp and Grummer, 1991). Intake of DM decreased from 44.1 to 32.0 lb/d. Cooling Jersey cows with fans and sprinklers decreased the temperature of the udder by 3.3°F (99.0 vs. 95.7°F), decreased respiration rates from 102 to 80 breaths per minute, and increased milk production from 42.2 to 49.4 lb/day (Keister et al., 2002).

Hotter cows voluntarily avoid consuming the bulk of their ration during times of peak heat stress. In two Florida studies, lactating dairy cows having rectal temperatures averaging 105.8°F consumed 79% of their total daily DM intake during the cooler period of the day (1600 to 0800 h) whereas cooler cows, having rectal temperatures averaging 102.8°F, consumed 59% during this cooler time (Mallonee et al., 1985; Schneider et al., 1984). In addition, total DM intake was lower by 15 to 23% for the hotter cows. Although the period of primary feed consumption shifted from day to evening, the amount of feed consumed at night under conditions when the THI still exceeded the upper critical THI of 72, did not compensate for the greatly depressed intake during the day. Very warm evenings (i.e., lack of night cooling) can prevent cows from making up the DM intake they lost during the day. Daily intake of DM began decreasing when the minimum environmental temperature was above 66°F for lactating Holstein cows (Cummins, 1986). Arizona workers reported that DM intake and milk production by Jersey cows dropped precipitously (6.2 lb of milk per day) once the nighttime THI remained above 75 (Keister et al., 2002). The ability of cows to cool off at night is likely an important factor influencing their ability to eat well the next day.

Peak heat production by the cow occurs about 3-4 hours after eating, although this is influenced by the amount of feed consumed in the meal. Therefore feeding at 5-6 a.m. will allow the cows to be on the downward portion of their heat production curve as peak heat stress from the environment approaches. Offering feed after the worst part of heat stress has passed should prevent the rise in body heat from DM intake coinciding with the rise in ambient temperature, thus reducing the maximum heat load on the animal at one time. Feeding cows just prior to the expected rise in THI can aggravate the negative effects of THI on animal performance. Yearling Hereford heifers were fed a high- or a low-energy dense diet in the morning or afternoon. Rectal temperatures measured during the heat of the day of unshaded animals appeared to be greater for animals fed the high-energy dense diet in the morning versus the afternoon (~103.1 vs. 102.6°F) (Brosh et al., 1998). Therefore morning feeding increased the heat load on these heifers during the heat of the day. In a different study, Holstein steers fed in the cooler part of the day (2000 h) gained 18% faster and were 17% more efficient than those fed at 0800 h (Reinhardt and Brandt, 1994). Since steers were limit-fed, the more efficient gain by night-fed steers may have been due to less energy expended for cooling themselves during the hot part of the day when heat from digestion would coincide with highest environmental temperatures. These results were not confirmed in a short-term heat stress study using lactating Holstein cows housed in environmentally controlled chambers (Ominski et al., 2002). In this study, lactating Holstein cows were exposed to a neutral (75°F) or a heat stress (90°F) environment for about 11 hours a day (0700 to 1800 h). They were exposed to 68°F the rest of the day. Cows were fed a TMR (alfalfa hay and concentrate) once daily at either 0830 or 2030 h. Exposing cows to the hotter environment increased average vaginal temperature by 1.2°F (from 100.3 to 101.5°F), decreased DM intake by 3.1 lb/day, and decreased milk by 3.6 lb/day regardless of feeding time. However during the days of heat stress, the pattern of vaginal temperatures during the day was affected by time of feeding. Cows fed at 0830 h tended to be hotter between 1800 and 0200 h whereas those fed at 2030 h tended to be hotter between 0200 and 1000 h. When the 90°F weather was "turned off" at 1800 h, the cows fed in the morning did not cool down over the following 8 hours as quickly as those fed at 2030 h (0.5 versus 1.0°F decrease). The time of daily feeding during short-term, moderately hot weather did not affect the amount of feed consumed, milk produced, or average vaginal temperature in this study. However the pattern of feed intake over most of the day was steadier when cows were fed at 2030 versus 0830 h. Cows fed in the morning showed a second big jump in intake when the chambers had cooled down. A more consistent pattern of feed intake did improve steer performance by allowing a more efficient use of nutrients (Soto-Navarro et al., 2000). If cows are too hot during the day to eat and cows prefer to eat fresh feed (especially rations containing wet and/or fermented feeds), then it makes sense to feed cows fresh feed very early in the morning and late in the evening. Coinciding heat production from the digestion of feed with the coolest part of the day through timely feeding management makes biological sense.

The amount of water a cow drinks is closely tied to her feed intake, milk production, and body temperature. By reducing the heat load on the cow by feeding during the cooler times of the day, cows may drink less water for the day. Yearling British crossbred steers were housed in feedlots without overhead sprinklers and fed an 81% concentrate diet at either 0800 or 1400 h (Mader and Davis, 2004). Feed intake was the same for both groups of steers; however, steers drank 11% less water (8.9 vs. 10.0 gallons/day) if feed was offered at 1400 versus 0800 h. Reduced water consumption may be an economic benefit to the dairy farm in areas where water is costly as long as milk production is not compromised. This pattern was not repeated by lactating cows in the Ominski et al. (2002) study described above, but vaginal temperatures were not affected by feeding time in their study.

Sometimes it is the intermittent heat waves that are more dangerous than the regular episodic thermal stress. In 1997, more than 100 feedlot cattle died due to extreme THI over a 4-day period. It was the third such heat wave in 3 weeks. What made the third heat wave so lethal may have been an increased DMI of animals just prior to the third event. Relatively cool weather had come in right after the second heat wave so the animals had compensated for their reduced intake during the second heat wave by eating much more feed. Greater gut fill during the third heat wave increased their metabolic heat load on top of the environmental heat load that may have prevented the animals from dissipating the heat needed to survive (Hahn, 1999).

Dietary Fiber and Acidosis. Some have suggested that the fiber content of diets should be reduced during times of heat stress in order to reduce the metabolic heat load on the cow because fiber has a greater heat increment than does concentrate. Yet total intake and digestibility of the diet has a direct bearing on the total heat load as well. Yearling Hereford heifers fed an 80% concentrate diet had a greater heart rate (94 vs. 52 beats per minute) and a greater expenditure of energy (653 vs. 380 kJ/kg of $BW^{.75}$) compared to heifers fed a 100% forage diet (Brosh et al., 1998). Table 2 suggests that the production of metabolic heat from the diet is greater for lactating cows fed diets of greater energy density. Cows fed the diet of greatest energy density (low ADF diet) needed to cut back the greatest on DM intake in order to reduce her metabolic heat load to tolerable levels during times of greater THI.

Table 2. Effect of heat stress on DM intake of cows fed diets differing in ADF concentrations.

Reference	% ADF of diet	Warm THI DMI	Hot THI DMI	Difference between warm and hot THI
West et al., 1999	16.0	4.75 % of BW	3.80 % of BW	0.95 % of BW
	17.9	4.58 % of BW	3.84 % of BW	0.74 % of BW
	19.4	4.30 % of BW	3.70 % of BW	0.60 % of BW
	21.2	4.06 % of BW	3.55 % of BW	0.51 % of BW
Cummins, 1992	14.0	49.4 lb/d	45.6 lb/d	-3.7 lb/d
	16.1	48.3 lb/d	47.4 lb/d	-0.9 lb/d
	19.0	49.2 lb/d	50.5 lb/d	+1.3 lb/d

West et al. (1999) fed lactating dairy cows one of four diets differing in ADF concentration during periods of either warm (64 to 77 THI) or stressful (72 to 84 THI) conditions. The ADF concentration of the diets was changed by partially replacing corn silage with Tifton 85 bermudagrass. Under the more stressful THI, intake of DM was reduced as expected but the decrease was more dramatic for cows fed the diets of lower ADF concentration (higher energy density). Intake decreased 0.95% of BW for the low ADF diet but decreased only 0.51% of BW for the high ADF diet (Table 2). This suggests that total energy intake and diet digestibility may be a more important factor influencing metabolic heat production and resulting DM intake reduction than is dietary fiber concentration alone. This pattern of a greater decrease in DM intake under heat stress conditions as the energy density of the diet increases is in agreement with work done at Auburn University (Cummins, 1992) (Table 2).

If cows are being fed a diet that is not on the verge of being deficient in effective fiber (eg. a diet for lower producing cows), then it seems reasonable to increase the concentrate portion of the diet during times of heat stress in order to try to maintain energy intake. However, if cows are being fed a diet that currently is at the NRC minimum recommendation for ADF, then obviously it is not advisable to decrease the fiber even further. To do so may not increase energy intake and may increase the risk of initiating clinical or subclinical ruminal acidosis, a condition that cows are more inclined toward during heat stress.

Cows subjected to heat stress may be at increased risk to ruminal acidosis. It appears that heat-stressed cows can have lower ruminal fluid pH, less ruminating activity, low milk fat %, and reduced buffering capability by the saliva. Fistulated Holstein cows were kept at either 65°F and 50% relative humidity or at 84.9°F and 85% relative humidity for five weeks. Ruminal fluid was measured 12 times postfeeding for pH and lactic acid concentration. Cows kept in the hotter environment had lower ruminal pH (~5.8 vs. ~6.3) and greater lactic acid (~1.9 vs ~0.45 meq/L) (Mishra et al., 1970). Again mean ruminal fluid pH (24 h average) was lower (6.53 vs. 6.66) for Holstein cows denied access to shade (Niles et al., 1980). Mean ruminal pH was not different between lactating cows exposed to different temperatures using environmental chambers although the number of hours (n = 26 total) below pH 6.0 approximated 15 for hot cows and 11 for cool cows (Schneider et al. 1988). Fecal pH was lower (5.92 vs. 6.08) for unshaded compared to shaded lactating cows (Schneider et al., 1986).

Workers at Florida (Collier et al., 1981) reported that elevated environmental temperatures negatively affected ruminal contractions. The number of ruminal contractions decreased from 2.4 to 1.7 per minute when lactating cows were not provided shade (rectal temperatures of 101.7 vs. 103.3°F). These results support the earlier work at Missouri (Attebery and Johnson, 1969). Ruminally-fistulated Holstein cows kept at an ambient temperature of 100.4°F for 5 days compared to 64.4°F (rectal temperatures of 105.6 vs.101.1°F) had less rigorous ruminal contractions as evidenced by a 50% reduction in the average amplitude. The frequency of contractions (2.2 vs. 1.7 per minute) closely followed the pattern reported by Collier et al. (1981) but was not significant. A lower DM intake by cows at the higher temperatures in the Missouri study was not responsible for the difference in rumen movement because DM intakes were equalized by placing uneaten feed into the rumen via fistula. Likewise, goats kept at 95°F in chambers consumed alfalfa hay at a similar rate (~16 minutes/hour) but had lower remastication rates (80 vs. 90 per minute) compared to goats kept at 86°F (Appleman and Delouche, 1958). A decreased number or intensity of ruminal contractions as well as reduced ruminations due to heat stress may have a negative effect on saliva production thereby reducing the buffering activity in the rumen, resulting in a lower ruminal pH. This decreased activity of the rumen musculature of heat-stressed cows may be related to a reduced concentration of volatile fatty acids (VFA) in the rumen. That ruminal VFA may play an essential role in stimulating rumen motility by influencing the neural receptors in the rumen wall may partially explain the reduced motility noted under heat stress conditions. Ruminally-fistulated Holstein cows were kept at either 64.8 or 99.9°F, with equal DM intakes assured by placing uneaten feed into the rumen (Kelley et al., 1967). Concentration of VFA decreased by more than 50% in heat-stressed cows despite their equal intake of DM.

An additional physiological mechanism operating during heat-stress conditions also may contribute to ruminal acidosis. As cows become heat stressed and respiration rates increase, CO_2 is eliminated from the lungs faster than it is produced. This results in a decrease in blood CO_2. In an attempt to keep the CO_2 to bicarbonate (HCO_3) ratio constant in the blood, the kidney excretes more HCO_3. With more CO_2 leaving from the lungs and more bicarbonate leaving in the urine, bicarbonate concentration in the blood drops and blood pH becomes more alkaline (termed respiratory alkalosis). This drop may, in turn, reduce the bicarbonate concentration in saliva, thus reducing the buffering activity in the rumen and increasing the risk of ruminal acidosis. In order to correct this situation, the kidney excretes more acid (H+) which helps resorb HCO_3 back into the blood in an attempt to normalize blood pH.

Adequate fiber may be more important in warm weather due to the tendency of cows to be more susceptible to ruminal acidosis when heat-stressed. Again in the study of West et al. (1999), cows fed the two lowest fiber diets were actually consuming fiber-deficient diets according the NRC guidelines of 19 to 21%. These marginal ADF diets did not appear to be detrimental to milk production when fed during the warm environment. However milk production followed a quadratic pattern when cows were subjected to heat stress conditions, with milk production lower when dietary ADF was below 19% of dietary DM (Table 3). Authors speculated that a slight acidosis was corrected with the higher fiber diet that improved ruminal efficiency and digestion. The milk fat concentrations would support this explanation. Milk fat % was unchanged by diet during the period of warm temperatures but prior to heat stress. However, cows subjected to heat stress produced milk of reduced fat content as the fiber content of the diet decreased, especially so when fed the fiber-deficient diets (Table 3).

Table 3. Effect of heat stress on milk production (lb/d) and milk fat % of cows fed diets differing in ADF concentrations (West et al., 1999).

	Milk production, lb/d			Milk fat, %	
% ADF of diet	Warm THI[1,a]	Hot THI[2,b]		Warm THI[1]	Hot THI[2,a]
16.0	71.2	54.2		3.24	3.21
17.9	71.9	56.9		3.49	3.28
19.4	69.2	58.2		3.58	3.50
21.2	63.7	50.0		3.62	3.69

[1] Minimum and maximum THI was 64 and 77 respectively.
[2] Minimum and maximum THI was 72 and 84 respectively.
[a] linear effect; [b] quadratic effect.

Some (Bandaranayaka and Holmes, 1976; Mohammed and Johnson, 1985; Moody et al., 1967 60% grain; Rodriguez et al., 1985) but not others (Collier et al., 1981; Knapp and Grummer, 1991) have reported milk fat % to decrease when cows are subjected to heat stress conditions. A study involving nearly 23,000 observations on Florida dairy farms examined the relationships between many variables, including milk composition and environmental temperature. As temperatures increased from 49 to 97°F, authors reported that milk fat dropped from 3.85 to 3.31% and milk protein dropped from 3.42 to 2.98% (Beede et al., 1985). Milk constituents were not influenced by the degree of relative humidity. The difference in results among these studies may be due to differences in the forage to grain ratio of the diets fed. Stanley et al. (1975) found that milk fat concentration was depressed to a greater degree during heat stress when the diet contained a greater proportion of concentrate. Cows that are fed diets bordering on adequate fiber may produce milk of lower fat content during hot weather.

Another factor that can potentially increase acidosis is the habit of cows to selectively reduce their intake of forage to a greater degree than their intake of concentrate under heat-stress conditions (McDowell, 1972). Feeding a well-mixed TMR can minimize the practice of selecting concentrate over forage, especially when fed feedstuffs are fed separately and thus aggravating the risk of acidosis.

In conclusion, feeding diets of sufficient effective fiber are even more important during heat stress due to the increased risk of ruminal acidosis due to changes in ruminal physiology. Although feed intake is reduced during hot weather, formulate diets to contain slightly greater NDF and ADF concentrations in order to maintain good ruminal health. Treating the rumen well will allow the cow to bounce back when the weather cools. Use the highest quality forage available.

Water. Without question, water is the nutrient of greatest importance in hot weather. Cows drink more water under heat stress conditions. This undoubtedly aids in cooling the body core of the cow. In addition, the cow loses additional water from the skin and lungs as she works to minimize her rise in body temperature. Intake of drinking water by lactating cows increased 29% (37.0 lb/d; 4.6 gallons/d) and loss of water via the skin and respiration increased 59 and 50% respectively when ambient temperature increased from 64.4 to 86°F (Table 4).

Table 4. Intake and excretion routes of water by lactating cows at two environmental temperatures (Collier et al., 1982).

Measurement	64.4°F	86°F	% difference
Water drank, lb/d	127.6	164.7	29.0
Feed water, lb/d	3.5	3.1	-14.3
Urine volume, lb/d	24.5	28.2	15.0
Fecal water, lb/d	39.5	26.5	-33.0
Evaporation			
Surface, $g/m^2/h$	94.3	150.6	59.3
Respiration, $g/m^2/h$	60.6	90.7	50.0

Providing cool, clean water in ad libitum amounts is simply good management. Any management factor that may inhibit cows from drinking must be eliminated. If water intake is restricted in hot weather, the drop in milk production will be precipitous. The cows will become hotter than normal and DM intake will decrease to a greater extent as intake of DM and water are closely linked. Make sure that all watering units are in good operation prior to the arrival of hot weather and check them regularly for good working order throughout the summer months. Water units should be cleaned daily of feed and algae. Algae grow quicker in warm weather and feed spoils water quicker in warmer weather so the cleaning routine may need to be speeded up in the summer. Location of the water can be important to its intake. Water should be kept under the same shade that cows are kept. If they have to leave the shade in the heat of the day to walk to the water trough, they will normally stay in the shade and stay thirsty. This was made very clear on a commercial dairy in Florida in which the shade structures for the cows were separate from the water tanks. Water intake was monitored from May into September. As the ambient temperature increased, water intake decreased from a high of ~34 gallons/cow/d in May to a low of ~18 gallons/cow/d in September (Beede, 1991). Water temperature can have an impact on consumption. Lactating cows drinking water chilled to 51°F had lower respiration rates (70 vs. 81/minute), lower rectal temperatures in the p.m. (103.7 vs. 104.4°F), and greater milk production (57.1 vs. 54.5 lb/d) than cows drinking nonchilled water at 80.6°F in a Texas experiment (Wilks et al., 1990). In a second study by the same authors to test cow preference, over 97% of the water consumed was that of warm water. In a Florida study, cows drinking water at either 75 to 80°F or 52 to 57°F drank similar amounts of water (21.7 vs. 23.2 gal/d) and produced similar amounts of milk (63.1 vs. 64.2 lb/d) over a 2-month period in the summer (Beede, 1991). Responses at this time have not justified the expense of chilling water but placing water tanks under shade and insulating water tanks should be seriously considered.

Fat supplementation. Dietary fatty acids appear to be an ideal supplement during times of heat stress because fats are utilized with a higher efficiency for milk production and have a lower heat increment than nutrients like starch and fiber; thus they should generate less of a heat load on the animal than the other major feedstuffs. This improvement in efficiency is partly due to less production of methane by ruminal microbes during digestion (Chilliard, 1993). This results in more metabolizable energy left from the diet for the cow. Fats are not digested in the rumen so production of heat in the rumen from fat digestion is minimal. Another factor leading to improved feed efficiency from fat supplementation is that fat for milk fat synthesis or body fat storage can be provided directly by the fat supplement so that the tissues including the mammary gland do not need to make fat from the small building blocks of acetic acid and butyric acid. Therefore internal heat produced per unit of energy consumed should be less for cows supplemented with fat. Total heat loss was reduced by 4.9 and 7.0% when cows were fed whole cottonseed at 15% of dietary DM or whole seed plus 1.2 lb/d of calcium salts of palm oil distillate (Holter et al., 1992). Rectal temperatures tended to be reduced in lactating cows fed calcium salts of palm oil distillate (Jennings-Croci, 2002) or a yellow grease-based fat (Drackley et al., 2003) and was lower in crossbred British breed steers fed whole cottonseed (O'Kelly, 1987). Although these data are encouraging, the effect of fat supplementation on milk production has been inconsistent.

As discussed earlier, lactating dairy cows are more susceptible to ruminal acidosis during heat stress conditions. Concentration of dietary fiber may be increased during this time. Fat may be added to a higher fiber diet in order to maintain the energy density of the diet. Milk production was the same between cows (greater than 150 days in milk) fed a diet of 50% forage:50% concentrate and those fed a diet of 65% forage:35% concentrate supplemented with tallow at 2.3% of dietary DM (60.3 vs. 61.8 lb/day; Vazquez-Anon et al., 1997). Diets were of equal energy density but DM intake of the higher forage diet tended to be lower (47.5 vs. 49.5 lb/day) resulting in better efficiency of milk production by cows fed the higher forage diet. Body weight gain over the 17-week trial was the same for both groups. Therefore fat supplementation may be a good strategy to use along with slightly higher fiber diets in order to minimize the risk of ruminal acidosis and maintain milk production of midlactation cows. Whether this strategy works with cows in early lactation needs to be examined.

Two questions should be asked. Is fat-supplementation effective during hot weather? Secondly, is fat-supplementation more effective when fed during hot versus cool weather? In regards to the first question, lactating cows fed fat supplements during hot weather appear to respond well at times but not at other times. Midlactation cows fed "Qual-Fat Dairy Blend" (a commercial product based upon yellow grease) at 3% of dietary DM produced 4.2 lb/day more milk (1.8 lb/day of 3.5% FCM) during an Illinois summer (Drackley et al., 2003). Intake of feed DM was reduced by 2.1 lb/day by fat feeding so efficiency of milk production was improved without changing body weight or condition. Arizona cows during summer produced 2.6 lb/day more milk when fed a prilled fat (2.5% of dietary DM) in one study (75.0 vs. 72.4 lb/day) but did not respond to the same fat supplementation in a second study (summarized by Huber et al., 1994).

It is very difficult to conduct a well designed study to determine if fat supplements are more likely to benefit milk production during warm versus cool weather because the two environments need to be available simultaneously in the same location. Because this is physically impossible, experiments have been conducted using environmental chambers. Using environmental chambers, cows fed a mixture of prilled fat and tallow at 5% of dietary DM improved production of 3.5% FCM by 6 lb/day when housed at thermoneutrality and 4 lb/day when housed under heat stress conditions (rectal temperatures of 101.3 vs. 104.5°F, respectively) (Knapp and Grummer, 1991). The diet by environment interaction was not significant. Maryland workers, using environmental chambers, found similar results as Knapp and Grummer (1991). When cows were fed either soybean oil or a saturated vegetable oil at about 6.1% of dietary DM, fat-corrected milk production was increased by the saturated fat source (3.1 lb/day) but not the soybean oil when cows were housed in neutral or hot conditions (rectal temperatures of 101.5 vs. 103.7°F) (Moody et al., 1967). In a study conducted across two seasons, cows fed prilled fats (Energy Booster) at 5% of dietary DM starting in the dry period ate about 4.4 lb/day more feed and produced 21.4 lb/day more milk during the warm season (April through July) than during the cool season (November through March) in Wisconsin (Skaar et al., 1988). Fat may have been more effective in warm weather because cows calving at that time appeared to be under greater metabolic stress as evidenced by greater plasma concentrations of NEFA and β-hydroxybutyric acid. Obviously, more studies need to be conducted to better evaluate the effects of supplemental fat on milk production during hot weather.

Minerals. *Potassium*. As shown in Table 4, excretion of water via the skin increases about 59% under heat stress conditions. Unlike man, the primary electrolyte lost in skin secretions of cattle is K (K_2CO_3 and $KHCO_3$) rather than Na. The greater the heat stress conditions, the greater the production of secretions by the skin and the greater the concentration of K in the secretions resulting in an exponential loss of K. Because of greater loss of K and reduced intake of DM in hot weather, it seems reasonable to increase the dietary concentrations of K above 1% of DM (NRC, 1989).

Increasing the K concentration in the diet from 1.0 to 1.5% using KCl increased milk production from 39.7 to 40.8 lb/d of Florida cows either shaded or unshaded without changing DM intake (Schneider et al., 1984). Diets of 1.08% K were as effective as 1.64% K to increase milk production of dramatically heat-stressed cows in Florida compared to a control diet of 0.66% K (32.0 and 31.3 vs. 29.8 lb/d, respectively). However, greater dietary K was not effective to increase milk production of cows provided shade (diet by environment interaction) (Mallonee et al., 1985). Just the opposite response was found in cows fed diets of 1.3 or 1.8% K using KCl in another Florida study. Shaded cows (rectal temperature of 103.6°F) produced more FCM (42.3 vs. 38.6 lb/d) when fed additional K but unshaded cows (rectal temperatures of 105.1°F) did not respond to more K (38.4 vs. 39.0 lb/d) (Schneider et al., 1986). Cows fed more K consumed more DM. It's possible that the severely heat-stressed cows required even more K than what was offered. In a summer study conducted at Texas A & M, cows fed diets of 1.53% K supplied as KCl and K_2CO_3 consumed more DM (42.3 vs. 39.7 and 39.5 lb/d) but did not produce more milk (53.6 vs. 48.7 and 46.5 lb/d) than cows fed diets of 0.93 or 1.29% K (West et al., 1987). Potassium carbonate and potassium bicarbonate may be superior choices to potassium chloride to increase dietary K because increased intake of Cl has been shown to depress DM intake and milk production in summer (Sanchez et al., 1994b). Feeding diets having a cation-ion difference (K + Na - Cl) of 25 to 45 mEq/100 g DM should result in optimum lactating cow performance (Sanchez et al., 1994b).

Sodium. Heat stressed cows excrete more Na in the urine. The Na accompanies increased HCO_3 in the urine during respiratory alkalosis rather than K, potentially to preserve the K for sweating purposes. This factor along with reduced DM intake suggests a justification for increasing the dietary concentration of Na for lactating dairy cows. Increasing the Na concentration from 0.67 to 0.96% of dietary DM ($NaHCO_3$ at 0.85% of dietary DM) increased DM intake (39.9 to 42.8 lb/d) and milk production (39.5 to 40.8 lb/d) of cows fed a 75% concentrate:25% cottonseed hull diet in a Florida summer (Schneider et al., 1984). In a second Florida study conducted in the summer, dietary Na was increased from 0.18 to 0.55% of dietary DM using either NaCl or $NaHCO_3$. Diets were 38% corn silage and 62% concentrate. Milk production was increased from 35.3 lb/d to 39.9 and 41.7 lb/d by NaCl and $NaHCO_3$, respectively (Schneider et al., 1986). Milk production was not increased further by feeding a diet of 0.88% Na. In a Florida study that straddled the cool and hot seasons, production of FCM increased in a linear fashion as dietary Na increased from 0.31 to 0.89% of dietary DM (Sanchez et al., 1994a). Because of the extra need for Na and for bicarbonate in hot weather, dietary Na concentration should be increased.

In summary, recommended ranges of dietary concentrations of K and Na for warm weather feeding include K at 1.5 to 1.6% and Na at 0.45 to 0.60% of DM. Dietary Mg should be at 0.35 to 0.4% of DM in order to minimize the risk of animals developing a hypomagnesemic tetany-like condition due to the higher feeding of K.

Protein. Due to the decrease in DM intake during hot weather, the crude protein (CP) concentration of the diet may need to be increased in order to maintain daily intake of amount of nitrogen. When an alfalfa hay-based diet was increased from 14.3 to 20.8% CP using soybean meal, cows consumed more DM and produced more milk in a Louisiana summer without a corresponding increase in rectal temperature (Hassan and Roussel, 1975). Rectal temperatures averaged 102.5°F at 1030 h. Although others have reported better performance by feeding more protein at thermoneutral conditions, the uniqueness of this paper is their reporting of a positive correlation between rectal temperature and serum nonprotein nitrogen (NPN) ($r = 0.36$). Although a correlation does not imply cause and effect, one can speculate that the process of detoxification of ammonia (from excess deaminated amino acids) to urea by the liver generated enough extra heat to raise the body temperature. The energy cost of converting ammonia to urea appears as heat increment and decreases the proportion of metabolizable energy going to net energy of lactation (NRC, 1989). In addition, the loss of dietary nitrogen as urea in the urine decreases the proportion of digestible energy going to metabolizable energy (NRC, 1989).

The ruminal degradability of the dietary protein may have an influence on the amount of ammonia generated in the rumen and detoxified to urea by the liver thus potentially adding to the heat load of heat-stressed cows. Cows were managed in either shaded or shade plus evaporatively cooled pens during an Arizona summer and fed diets that differed in ruminal degradability of the CP (Taylor et al., 1991). Soybean meal was replaced with corn gluten meal and blood meal to decrease the ruminally degradable protein (RDP) from 61 to 47% of dietary CP (10.8 to 8.5% of dietary DM). As RDP was decreased in the diet, milk production increased for cows managed in both housing systems but the increase was greater for cows in evaporatively cooled pens (diet by cooling system interaction). Milk response may have been less under greater heat stress conditions because more dietary protein may have been metabolized for energy purposes and the deaminated ammonia converted to urea costing the cows more energy. A second study of similar design was conducted by these same scientists except no blood meal was used in the lower RDP diet and cows were not as heat-stressed as in the first study (rectal temperatures of 102.2 vs. 103.1°F) (Taylor et al., 1991). Contrary to the first study, cows fed the diet of greater RDP content (64 vs. 55% of CP) produced more milk (1.5 to 4.4 lb/d) in both heat abatement systems. Apparently quality of dietary protein and degree of heat stress are important factors influencing the effect of degradable protein on cow performance in hot weather.

Another set of Arizona studies (n = 3) was conducted between May and September to determine the effect of amount and degradability of dietary protein on cow performance (Higginbotham et al., 1989). Cows were in moderate heat stress, as rectal temperatures taken between 1300 and 1500 h averaged 102.2°F across diets and experiments. On average, dietary CP was either 18.4 or 16.1% of DM. In addition, either corn gluten meal or brewers grains plus meat and bone meal replaced soybean meal to decrease the RDP content from 65 to 59% of dietary CP. Cows fed the 18.4% CP, 59% RDP diet produced ~6.6 lb/d less 3.5% FCM than the cows fed the other 3 diets (51.8 vs. 58.4 lb/d). Even the 16.1% CP diets provided more than the CP requirement of the cows based upon their average milk production. Overfeeding protein, especially RDP, may lower cow performance.

To test whether the amino acid profile of the diet would interact with environmental cooling effects, cows were fed diets similar in RDP content (57.5% of CP) but managed under shade or shade plus evaporative cooling in an Arizona summer (Chen et al., 1993). Diets were characterized as delivering a low (corn gluten meal) or a high (soybean, menhaden fish meal, and blood meal) amount of lysine. Rectal temperatures taken at 1400 h indicated that cows managed in an evaporative cooling system were cooler compared to those offered just shade (101.5 vs. 102.4°F). Cows fed diets supplying more lysine produced 6.9 lb/day more milk (66.7 vs. 59.8 lb/day) and the benefit occurred for both the shaded only and the shaded plus cooled cows. Feeding more lysine increased milk by 8.4 lb/day for cows evaporatively cooled and 5.3 lb/day for shaded cows. Despite this difference, the interaction of diet and cooling method was not significant.

In summary, great care should be taken to avoid overfeeding total and degradable protein during times of hot weather. The intake of N beyond the requirement of the cow will need to be incorporated into urea and excreted in the urine. These processes demand energy and generate heat, both of which put an additional drain on the cow at a stressful time.

Microbial Additives. Huber et al. (1994) summarized several studies in which Aspergillus oryzae were fed to lactating dairy cows in heat stress environments. Rectal temperatures were reduced significantly in 5 of the 12 studies and elevated in 1 study. Milk yields were increased significantly in 6 of 14 studies when 3 grams/day of A. oryzae were fed as reviewed by Huber et al. (1994). During a South Dakota summer (91°F average high), cows produced milk more efficiently when fed yeast culture (60 g/day) compared to those not fed yeast culture.(1.49 vs. 1.39 lb of FCM per lb of DMI)

(Schingoethe et al., 2004) although DM intake and milk production were not different between the groups. Feeding A. oryzae (3 g/day) during an Arizona summer did not influence performance of lactating cows fed steam-flaked or steam rolled corn (Yu et al., 1997). Some fungi have esterase enzymes that can break the cross links between hemicellulose and lignin. This allows fungi a unique advantage in degrading lignified forages. These organisms can access plant cell walls that have not been chewed well and therefore can aid ruminal bacteria in digesting carbohydrates. Improved digestion may have been the reason for improved milk production in the studies above.

Summary

Lactating dairy cows begin to seriously experience the negative effects of heat stress when rectal temperatures exceed 102.5°F. Although feed intake is reduced during hot weather, formulate diets to contain slightly greater NDF and ADF concentrations in order to minimize the risk of ruminal acidosis which is more prone to happen during heat stress. Ruminal pH may be lowered because of reduced buffering of the rumen and reduced number and intensity of ruminal contractions. Milk fat % may be lowered during the summer season and changing dietary fiber may help. Inclusion of fat in higher fiber diets may help maintain energy intake. Fat supplementation may lower rectal temperature and improve milk production during hot weather but studies have reported inconsistent responses thus justifying the need for more research. Feeding in the early morning hours and late evening hours will prevent the rise in body heat from DM intake coinciding with the rise in ambient temperature, thus reducing the maximum heat load on the animal. Providing cool, clean water in ad libitum amounts will encourage water intake, DM intake, and milk production. Mechanical chilling of water may improve cow cooling but economic benefits are doubtful. Recommended ranges of dietary concentrations of macrominerals for warm weather feeding include K at 1.5 to 1.6%, Na at 0.45 to 0.60%, and Mg at 0.35 to 0.4% of DM. Great care should be taken to avoid overfeeding total and degradable protein during times of hot weather. The intake of N beyond the requirement of the cow will need to be incorporated into urea and excreted in the urine. These processes demand energy and generate heat, both of which put an additional drain on the cow during a stressful time. Feeding fungal cultures has improved cow performance in about half of the studies conducted.

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