IMPROVING INTAKE AND PERFORMANCE OF DAIRY COWS DURING HEAT STRESS CONDITIONS

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INTRODUCTION

Cows have a natural heat balance which must be maintained for optimal physiological performance. This balance is achieved only when heat loss equals net heat gain for the body. When heat gain exceeds heat loss, body temperature rises and heat stress is the result. The effects of heat stress on animal production are well known and have been researched for a number of years. Pioneering research at the Climatology Laboratory in Missouri established the relationships between high ambient temperature and increased rectal temperature of dairy cows (Kibler and Brody, 1949), and the impact on feed and energy intake and on milk yield (Johnson et al., 1963; Ragsdale et al., 1953). The effects of high environmental temperature in the summer are costly in terms of milk production. The effects are mediated primarily through reduced dry matter intake (DMI). Further complicating the effects of high ambient temperature is relative humidity (RH). The combined effects of ambient temperature and relative humidity can be calculated using a temperature-humidity index (THI). When the THI exceeds 72, DMI and milk yield decline, and the effect worsens as the THI increases. In addition, increasing THI affects higher producing cows more than lower producers (Johnson, 1987). This is logical, because higher producers have a greater metabolic heat production and have more heat to dissipate. Adjustments to alleviate heat stress in cows are necessary if producers are to maintain DMI and milk yield during the summer months.

HEAT STRESS EFFECTS ON DMI

Environmental factors that are associated with heat stress (primarily ambient temperature, RH, andl radiant energy) affect the physiological systems governing thermal regulation and the maintenance of a positive heat loss. As environmental temperature nears the cow's body temperature, the effectiveness of radiation, convection, and conduction for dissipation of body heat declines, and the reliance upon evaporation of moisture (from sweating and panting) increases. This avenue for cooling is compromised by high RH. High environmental temperature, often coupled with high RH, can overwhelm the cow's cooling capability and body temperature rises. Increasing the THI in the range of 71 to 81 reduced milk yield and the intake of TDN and water for dairy cows, and the effect was greatest when THI exceeded 76 (Johnson et al., 1963). Much of the effect of high environmental temperature on milk yield occurs because of reduced DMI. The NRC (1981) predicts that the DMI for a 1323 lb cow producing 59.5 lb of milk will decline from 40.1 lb at 68° F to 36.8 lb at 95° F, and maintenance costs for the cow will increase by 20%. The effect of high ambient temperature on performance apparently is mediated through the body temperature of the cow. Each 1° F increase in body temperature above 101.5° F resulted in 4 and 3 lb decreases in milk yield and TDN intake, respectively (Johnson et al., 1963). Thus, the first step toward improving DMI during heat stress is to influence the environment so as to moderate increases in the cow's body temperature.

Because radiant energy from the sun may increase the heat load of an unshaded cow in excess of her own metabolic heat production (Collier, 1979), the first imperative is to provide adequate shade. Unshaded cows in Florida had higher rectal temperatures than shaded cows (106.2 vs. 103.1° F), lower DMI (41.2 vs. 47.4 lb/day) and lower milk yield (31.1 vs. 38.1 lb/day; Mallonee et al., 1985). Shading reduces black globe temperature, lowers rectal temperature and respiratory rates, and improves the DMI and

Table 1. Effect of shade on heat stress indicators in lactating dairy cows.

Measurement	Shade[a,b]	No shade[a,b]	% Change	Shade[c]	No shade[c]	% Change
Black globe temperature, °F				84.4	105.8	25.4
Rectal temperature, °F				102.6	105.4	2.7
Respirations/minute				83	133	60.2
Daily feed intake, lb	48.2	45.3	6.4	45.6	37.0	23.2
Daily milk yield, lb	68.4	63.6	7.5	42.8	37.5	14.1

[a]Adapted from Armstrong and Wiersma, 1986. Proc. Southwest Nutr. Conf., Tempe, AZ.
[b]Shaded vs. unshaded feedbunks. All cows had access to identical corral shades.
[c]Adapted from Scheider et al., 1984. J. Dairy Sci. 67:2546.

milk yield of cows (Table 1). Cooling in addition to shade is beneficial. In Florida work, a combination of sprinklers and fans improved DMI from 39.2 to 42.1 lb/day (7.3%) and milk yield from 39.9 to 44.5 lb/day (11.6%) (Strickland et al., 1988). Discussions of methods for cooling cattle are available (Beede et al., 1990; Armstrong and Wiersma, 1986). The primary motivation behind cooling is to minimize the increase in body temperature associated with hot weather conditions, thus improving DMI.

CRUDE PROTEIN DURING HOT WEATHER

Intake of digestible protein declines proportionally with DMI during hot weather. Increased dietary crude protein (CP) content is necessary to supply the quantity of protein necessary for high milk production. Cows in hot, humid conditions (Louisiana) fed higher CP diets (14.3 or 20.8% CP) consumed more DM (30.9 vs. 34.3 lb) and yielded more milk (39.3 vs. 42.0 lb) (Hassan and Roussel, 1975). Cows fed the high protein diets had lower respiratory rates and numerically lower rectal temperatures, possibly related to improved digestion of the diet or altered metabolism. Further analysis of the data revealed that the improved milk yield was correlated with improved feed and energy intake, but not with CP intake. The improved intake of feed, which can occur with greater CP supplementation, must be balanced with the increased energy which is required to metabolize excess ammonia from a very high protein diet to urea. Metabolizable energy intake was decreased by 12 kcal per gram of digested nitrogen consumed above requirements (Moe and Tyrrell, 1972). Cows offered diets of two protein solubilities during thermoneutral and heat-stress conditions had greater feed intake and milk yield for the less soluble protein diet for both environments (Zook, 1982). Cows fed high and low CP diets (18.4 and 16.1% CP), with high and medium degradabilities (65.1 and 59.3% of CP) during hot weather in Arizona, had lower DMI degradability diet (Higginbotham et al., 1989). Cows shaded or evaporatively cooled did not change DMI with low or high protein degradability, but milk yield was greater for low degradability diets, provided the protein was of high quality (Taylor et al., 1991). Finally, cows that were either evaporatively cooled or shaded were offered diets containing high quality or low quality proteins (Chen et al. 1993). Although protein quality did not affect DMI, milk yield was greatest for high quality protein diets, and the response to protein quality was greater for cows in the evaporatively cooled versus the shaded environment (Table 2). Huber (1994), in a summary of this research, indicated that during heat stress, rumen degradable protein should not exceed 61% of total CP, or that intake of rumen degradable protein should not exceed NRC (1989) by 100 g N/day. He emphasized that protein quality is an important factor, especially lysine content of the diet.

FIBER FEEDING DURING HOT WEATHER

Production of heat energy, accounting for 31% of total consumed energy (Coppock, 1985), is an obvious liability during hot weather. Digestion of forages produces a significant heat of fermentation in the cow, adding to the overall heat load. Cows given a choice consumed less hay when subjected to heat stress (Johnson et al., 1963). Such behavior should reduce metabolic heat production, given that lower heat production was reported in beef heifers fed pelleted diets containing 75% concentrate compared with 75% alfalfa (Reynolds et al., 1991). Cows fed high and low forage diets in hot weather, with the difference made up by concentrates, produced more fat-corrected milk, had lower body temperatures (.51° F lower), and had reduced respiration rates (14.1 fewer breaths/min) for the low fiber diets (Stott and Moody, 1960). Intake of DM and milk yield were greater for cows fed diets containing 14 versus 17 or 21% ADF, and milk yield was less

sensitive to changes in daily minimum temperature for cows fed the 14% ADF diet (Cummins, 1992). At any given temperature DMI was higher for cows fed lower ADF diets. The DMI declined more rapidly with increasing daily minimum temperature with the lower ADF diets, but one must remember that total DMI was higher for the low fiber diets. A possible explanation for this response is that the greater DMI for cows fed the low fiber diets contributed to greater metabolic heat production, causing a more rapid decline in intake with rising environmental temperatures. The data suggest that feeding lower fiber diets during hot weather will improve DMI and milk yield, and possibly reduce heat stress. This must be balanced, however, with the need for adequate fiber in ruminant diets. Attention to fiber quality for hot weather diets is critical, since lower heat production occurs with the fermentation of high quality forages when compared with lower quality forage. Maintenance of adequate fiber (19 to 20% ADF) is recommended to maintain good rumen function and DMI.

Table 2.   Effect of protein quality and evaporative cooling on performance of lactating cows.

| Item | Treatment | | | | |
| | Shaded | | Evaporatively cooled | | |
	LQ[1]	HQ[2]	LQ[1]	HQ[2]	Effect
DMI, lb/d	50.0	52.7	53.6	56.2	C[3]
3.5% FCM, lb/d	53.8	60.0	58.6	66.6	P[4]**, C*
Rectal temp.,°F	102.4		101.5		
Respiratory rate/min	82		64		

[1]Low quality protein - corn gluten meal.
[2]High quality protein - blood, fish, and soybean meals.
[3]Cooling effect.
[4]Protein effect.
Chen et al. 1993. J. Dairy Sci. 75:819.

ADDING FAT TO HOT WEATHER DIETS

Although the addition of fat to the diet during hot weather does not have a consistent effect on DMI, added fat can have significant effects on milk yield. Because the partial efficiencies of conversion to milk fat for acetate (70 to 75%) and dietary fat (94 to 97%) favor added dietary fat, the addition of dietary fat to diets fed during hot weather may hold special promise (Baldwin et al., 1985). Cows fed diets with supplemental fat during hot weather had greater FCM yield (Knapp and Grummer, 1991; Skaar et al., 1989). In both studies, cows also were fed fat during cool weather. Knapp and Grummer (1991) reported no environment by diet interaction, suggesting that no additional benefits occurred from fat feeding during hot weather over those seen in cool temperatures; however, Skaar et al. (1989) found added dietary fat to be beneficial only to cows that calved during the warm season. Huber reported that during heat stress in Arizona a prilled fat increased milk yield by 2.6 lb/day, and in another study increased milk yield by only 1.5 lb/day in cooled or non-cooled cows (Huber, 1994). The Arizona results suggested less response from the added fat in heat-stressed than in cool cows, even though they had hypothesized that the added fat would reduce heat production, thus lowering heat stress (Huber, 1994).

MINERAL SUPPLEMENTATION

The requirement for mineral elements such as K and Na increases during heat stress, and DMI was improved when dietary K was greater than NRC recommendations during hot weather (Schneider et al., 1986; West et al., 1987). Although dietary K levels and treatment responses varied, the recommendation for K content in diets fed during heat stress ranges from 1.2 to 1.6% of diet DM. Schneider et al. (1986) also reported that DMI was greater when diets contained .55 vs. .18% sodium during hot weather. However, current knowledge suggests that a ratio or balance of ions may affect animal performance by influencing buffering systems in the body. Escobosa et al. (1984) were the first to evaluate diets fed during heat stress using the electrolyte or cation balance equation. They reported greater DMI for diets containing 320 meq Na + K - Cl/kg of feed DM vs. diets containing 195 and -144 meq. This suggested that the dietary cation-anion balance (DCAB) might be more important than concentration of the individual elements. The concept upon which DCAB is based is the maintenance of the desired physiological acid-base status, which was placed third on the list of homeostatic priorities by Kronfeld (1979), behind the need for oxygen and for dissipation of heat, and ahead of CO_2 elimination and water retention. Thus, maintenance of the desired physiological pH ranks very high on the list of priorities.

Kentucky work indicated that increasing DCAB improved DMI and that alteration of the equation using any of the three elements (Na, K, Cl) was equally effective in improving performance (Tucker et al., 1988). Increasing dietary DCAB was associated with a linear increase in blood pH, serum cation-anion balance, and blood bicarbonate concentrations, indicators of improved blood buffering. West et al. (1991) reported improved DMI and milk yield with increasing DCAB in both cool and hot environments, indicating a response to the practice regardless of environment. Measures of blood acid-base status showed improvements in buffering with increasing DCAB. Work conducted during heat stress conditions demonstrated that DMI was improved as DCAB increased from 120 to 464 meq Na + K - Cl/kg feed DM, regardless of whether Na or K was used to increase DCAB (West et al., 1992). This suggests that the DCAB equation is more significant than the individual element concentrations (barring deficiencies), and may cloud the issue of K content necessary in diets fed during hot weather. Additional research is needed to more closely define the desired DCAB for lactating dairy cows, and to resolve the issue of K vs. Na supplementation. Note that the DCAB for lactating cows is highly positive, or alkaline, as opposed to the negative, or acidic, diets used for dry cow diets.

bST USE DURING HOT WEATHER

Because metabolic heat production increases in association with greater milk yield and impacts DMI, it is logical to question whether the greater

Table 3. Response to bST administration in hot environments.

Temperature, °F		Relative humidity, %		Milk yield, lb		% change	DMI, lb		% change	Reference
Max	Min	Max	Min	Control	bST		Control	bST		
84.0	...	55	...	45.2	+1.8	3.9	...	...	...	Mohammed and Johnson. 1985.
95	71.6	65	60	63.5	+13.4	21.2	...	...	...	Johnson et al. 1991.
95	75.2	65	55	46.3	+16.1	34.8	32.0	+5.9	18.6	
82.6[1]	...	...	...	37.2[2]	+5.7	15.4	...	...	...	Staples et al. 1988.
94.3	72.0	100	59.8	38.6[3]	+18.7	48.6	33.5	+3.1	9.2	West et al. 1990.
				48.5[4]	+10.4	21.4	35.9	0	0	
				58.4[5]	+2.0	3.4	38.1	-2.9	-8.1	
90.3	...	...	...	50.0	+4.6	9.2	39.2	-1.1	-2.9	Zoa-Mboe et al. 1989.
102.6[6]	...	...	...	41.4	+5.5	13.3	...	...	...	Elvinger et al. 1992.

[1] Black globe temperature; mean of six measures daily between 0800 and 1800 h.
[2] 3.5% FCM.
[3] Cows at low production pretreatment.
[4] Cows at medium production pretreatment.
[5] Cows at high production pretreatment.
[6] Approximate black globe temperature mean.

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milk yield resulting from the use of bST during hot weather will elicit a similar response. A summary of several studies conducted in hot environments (Table 3) shows a wide range of responses in DMI and milk yield when bST was administered. Improvements in milk yield ranged from 3 to 49% and averaged 19%. The wide range of response may have occurred because of the differing environments of the studies. West et al. (1990) reported that cows at low, intermediate, and high production (49, 61, and 72 lbs. FCM, respectively) prior to administration of bST, had improved milk yield when given bST, but the response was greatest for low producers, with lower response to bST as pretreatment production increased. A similar trend for DMI was noted. Cows administered bST had significantly higher body temperatures than the control cows, although all cows had temperatures above normal, indicative of heat stress. Elevated body temperatures probably resulted from the heat of metabolism associated with increased milk yield with bST use, and from the very hot, humid environmental conditions which compromised the dissipation of body heat by the cows. Missouri workers reported that greater heat dissipation occurs with the use of bST, effectively maintaining heat balance (Manalu, 1991). Arizona workers (Sullivan et al., 1992) reported elevated body temperatures with use of bST during hot weather, with the greatest increases occurring on the more humid days. However, yield of FCM was maintained during the summer months. West et al. (1990) also reported sustained milk yield despite higher body temperatures with bST, but also saw declining body condition scores. Intake of DM did not improve sufficiently to support the improvements in milk yield, and body condition was lost. These results suggest that providing a protective environment during heat stress conditions is a key to maintaining DMI, thus allowing greater responsiveness to technologies such as bST.

SUMMARY

The reduction in milk yield associated with heat stress occurs primarily because of declining feed intake. Increased maintenance costs during hot weather magnify the energy deficit of the heat-stressed cow. The reduced DMI and increased maintenance costs which occur are due, at least partially, to elevated body temperatures, so that protection from the ambient environment is the first step toward maintaining DMI and milk yield during hot weather. Shading and cooling (using fans and sprinklers or evaporative cooling, depending on the climate) are effective ways to improve DMI during hot weather.

Diets low in fiber and high in grain encourage greater DMI, and also increase the energy density of the ration. Diets low in fiber may cause digestive upsets, and dietary additives such as buffers are desirable with low fiber diets and during heat stress conditions. Addition of fat to the diet increases energy density and may reduce the need for very high concentrate diets. Use of low starch, highly digestible feed by-products may also enhance utilization of low fiber diets.

Recent research indicates that there are dietary adjustments which improve DMI during hot weather. Work suggests that an ideal CP and rumen escape protein content for hot weather diets exists, and that an "optimum" DCAB improves intake during hot weather. Continued work is needed to refine these recommendations for the dairy cow subjected to heat stress conditions.

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