BALANCING DIETS FOR DAIRY CATTLE DURING HEAT STRESS CONDITIONS

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INTRODUCTION

A well-known dairy scientist once wrote that "compared with an effective environmental management system, manipulation of the cow's diet specifically for heat stress will have a relatively small effect on productivity" (Beede and Shearer, 1992). Indeed many dietary adjustments made during heat stress feeding are to compensate for reduced feed intake or to maintain physiologic homeostasis in the cow. Yet despite advances in cow cooling, barring total environmental control such as air conditioning, some reduction in cow performance will occur during hot weather. Once economically realistic attempts have been made to modify the cow's environment, then dietary alterations become necessary.

The effects of heat stress on animal production are well documented. Pioneering research in Missouri established the relationship 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). Effects of high ambient temperature are magnified by high relative humidity (RH). Combined effects of ambient temperature and RH are calculated using a temperature-humidity index (THI). Increasing THI in the range of 71 to 81 reduced milk yield and intake of TDN and water for dairy cows (Johnson et al., 1963), and the effect was greatest when THI exceeded 76. Elevated THI affects high producing cows more than lower producers (Johnson, 1987) because of the greater metabolic heat production of high producing dairy cows. Making adjustments to alleviate heat stress in cows is necessary if producers are to maintain dry matter intake (DMI) and milk yield during the summer months.

DISCUSSION

Heat Stress Effects on DMI

High environmental temperatures are costly in terms of reduced milk yield. High environmental temperatures reduce the differential between the cow's body temperature and the environment, compromising the cow's ability to dissipate excess body heat. High RH further compromises the cow's evaporative cooling (sweating, panting), causing body temperature to rise. Much of the effect of high environmental temperature on milk yield occurs because of reduced DMI. The NRC (1981) predicts that 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% (Table 1). At 104°F maintenance increases by 32% and DMI falls to about 56% of that eaten by cows in thermoneutral conditions. The effect of hot environments on cow 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). Minimizing environmental effects on DMI is critical to maintaining productivity in a heat stress environment.

Cows often modify behavior in an attempt to maintain intake while avoiding stressful conditions. Changes in eating patterns from day to night feeding occur with hot days and cooler nights. Unfortunately the greater night time intake usually does not compensate fully for reduced daytime intake. A practical approach to maintaining intake is more frequent feeding of cows, which provides fresh feeds and stimulates the cow's natural curiosity. Cooling systems which cool the cow at the feed bunk also encourage intake. Modifying how cows are handled can help to minimize heat stress. Cows walked for .62 miles prior to milking to simulate being brought from pasture during hot weather had body temperature increases of about 3.5°F and 2.9°F for Holsteins and Jerseys, and temperatures remained elevated for about 10 and 6 hours, respectively (Coppock et al., 1981). Effects of exercise on body temperature can be minimized by avoiding moving cows long distances from pastures, and by grazing cattle during cooler evening hours and providing cooling during hot daytime hours.

Cows modify feeding behavior during hot weather. Intake of concentrate and hay declined by 5% and 22% for Holstein cows as the environmental temperature increased from 64 to 86°F McDowell (1972). This could be related to the heat producing potential, or heat increment, of the diet. The effects of this preferential selection of feeds seriously impacts ration formulation and creates the potential for acidosis. Dietary selection can be offset somewhat by feeding total mixed rations (TMR) which minimize the selection of feed ingredients and stabilize rumen fermentation, minimizing depressions of ruminal pH.

Water, The Forgotten Nutrient

Water is undoubtedly the most important nutrient for lactating cows subjected to heat stress. Milk contains about 87 percent water, and water is critical for dissipation of excess body heat. Water intake is highly correlated with milk yield and DMI (correlation coefficients of .94 and .96, respectively) (Dado and Allen, 1994). Generally cows consume 2 to 4 pounds of water for each pound of DMI, and rations high in salt or protein increase water intake (Harris and Beede, 1993). Note that the consumption of water increases sharply as the environmental temperature increases (Table 1) because of greater water losses from sweating and from water vaporization with more rapid respiratory rates (panting), both efforts aimed at increasing evaporative cooling for the cow.

Practical considerations are to supply unlimited clean water under shade within easy walking distance for the cow. Water in tanks long distances from the feeding area, especially if tanks are not shaded or the area between the feeding area and the tank is not shaded may force the cow to choose shade over water, limiting performance. A survey of drinking water tanks in west central Florida indicated that average water temperature was 86°F, and ranged from 77 to 97°F (Bray et al., 1991). Shading lowered temperature from 87 to 81°F. Clean water free of algae and feed contamination are necessary. A good rule of thumb is, would you drink the water? If not, perhaps it is too dirty for the cows also.

Several research studies at Texas A&M University showed that cows offered well water (81 to 86°F) or chilled water (51°F) generally consumed more DM and produced more milk when offered the chilled water. However cows tended to consume less of the chilled water, and when allowed the choice would choose warm well water over chilled water. Research in Florida showed no benefit to offering chilled water compared with normal well water (Bray et al., 1991). It should be noted that cows in the Florida field studies had access to fans and sprinklers (Bray et al., 1991) or to cooling ponds (Bray et al., 1990). These cooling opportunities may have negated any benefits to be derived from offering chilled water. At the very least, offering cool well water in a shaded environment will minimize the increase in water temperature due to direct sunlight and will encourage cows to go to water.

Heat Increment of Feedstuffs

Following a meal heat production increases. This increase is called the heat increment, and consists of heat of fermentation (important in ruminants) and heat of nutrient metabolism (Maynard et al., 1979). Different feedstuffs have varying heat increments, largely because of the efficiency of utilization of the nutrient or the end-products of its digestion, or because of the heat of fermentation. In moderate to high producing dairy cows, the heat increment can represent approximately two-thirds of total heat production (Chandler, 1994). Dietary fat has a low heat increment relative to acetate because of a greater partial efficiency of utilization (Baldwin et al., 1980). Because of a high efficiency of utilization, heat production is low. Fiber has a high heat increment relative to concentrates, again because of a lower partial efficiency for acetate relative to propionate and glucose (Baldwin et al., 1980) and because of the heat of microbial fermentation.

Perhaps heat increment can be exploited for hot weather feeding. An obvious advantage of reduced heat production by the cow is that less heat must be dissipated. This is especially beneficial in very hot, or hot, humid conditions where heat dissipation is compromised by the environment. Lower heat increment also means improved efficiency of energy utilization, because energy is used for

productive purposes and is not lost to heat production. Following are discussions of fat and fiber feeding during heat stress, with potential benefits relative to heat increment.

Fiber Feeding During Hot Weather

Fiber digestion may add significantly to the cow's heat load. Cows given a choice between hay and concentrate consumed less hay when subjected to heat stress (Johnson et al., 1963). Such behavior could reduce metabolic heat production. Lower heat production was reported in beef heifers fed pelleted diets containing 75% concentrate (low fiber) compared with 75% alfalfa (high fiber) (Reynolds et al., 1991). This suggests that high fiber diets do have a greater heat increment than diets low in fiber.

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 fewer respirations (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 greater for cows fed the lower ADF diets. However as daily minimum temperature increased, DMI declined more rapidly for the lower ADF diets. Important to remember is that total DMI was greater for the low fiber diets. A plausible explanation for this response is that greater total DMI for cows fed the low fiber diets contributed to increased metabolic heat production, causing a more rapid decline in intake with rising environmental temperatures.

Cows offered diets with no hay, and low, medium, and high levels of Tifton 85 bermudagrass (NDF content of 27.3, 29.7, 32.2, and 34.6%, respectively, had lower DMI as NDF level of the diet increased (Table 2,[West et al., 1995]). The DMI was lower with increasing NDF during both cool and hot weather. However, when hot weather DMI was adjusted for cool weather treatment effects, differences in DMI between diets disappeared, suggesting that intake differences among treatments were due primarily to the dietary fiber content. Lack of an interaction between hot weather intake and treatments suggests that heat increment associated with fiber level in the diet was not a factor during heat stress. However, intake was lower on high fiber diets and total fiber intake did not differ as much as fiber percentages suggest. Results in this study, like those of Cummins (1992), suggest that total DMI was a greater factor affecting heat stress response than was fiber content of the diet.

The data indicate that feeding lower fiber diets during hot weather will improve DMI and milk yield, and possibly reduce heat stress. However, this must be balanced 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 compared with lower quality forage. Feeding high quality fiber is preferred over minimal fiber diets during hot weather. Maintence of adequate fiber (19 to 20% ADF) is recommended to maintain good rumen function.

In addition, cows will reduce forage intake relative to concentrate intake under heat stress conditions if allowed to select. Total mixed rations help to minimize forage selection while at the same time stabilize rumen fermentation. Water added to a dry TMR improves palatability and binds feed particles together, reducing the cow's ability to sort ingredients.

Adding Fat to Hot Weather Diets

Early lactation cows were less subject to heat stress than mid-lactation cows, despite greater milk yield (Maust et al., 1972). Early lactation cows consumed less total feed and feed energy than mid-lactation cows and relied heavily on body stores. This is consistent with reports that body tissue reserves are used for milk production with an efficiency of 82.4%, compared with a 64.4% efficiency for metabolizable energy (Moe et al., 1971). Tissue reserves are primarily fat, and implied is an improved efficiency for utilization of fats in general. Because the primary difficulty in feeding heat-stressed cows is inadequate energy intake, the obvious advantage to including fat in the diet is improved efficiency of energy use and the greater energy density (2.25 times greater) when compared with carbohydrates.

Addition of fat to the diet during hot weather does not consistently affect DMI, but can improve milk yield. Partial efficiencies of conversion to milk fat for acetate (70 to 75%) and dietary fat (94 to 97%) favor dietary fat, and addition of fat to diets during hot weather is promising (Baldwin et al., 1985). A diet supplying 25.6% of ME intake as protected tallow improved metabolic efficiency, reaching 87.5% efficiency (Kronfeld et al., 1980). Diets with supplemental fat during hot weather improved FCM yield (Knapp and Grummer, 1991; Skaar et al., 1989). In both studies fat was also fed during cool weather. In one study, no environment by diet interaction occurred (Knapp and Grummer, 1991), suggesting no additional benefits from added fat during hot weather over those seen in cool temperatures; however Skaar et al. (1989) reported dietary fat to be beneficial only to cows that calved during the warm season. 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 et al., 1994). The Arizona work suggested less response to added fat in heat-stressed than in cool cows, even though they had expected that added fat would reduce heat production, thus lowering heat stress (Huber et al., 1994). The data further suggest that modification of the cow's environment is necessary to achieve full benefits of dietary adjustments such as dietary fat addition.

Although cows may not show signs of reduced heat stress in response to added dietary fat, cows benefit from greater energy density during periods of depressed intake. Practical applications are to add fat, not exceeding 5 to 7% total fat in the diet. Fat levels beyond these should be supplied using a rumen inert fat. As a general guideline, no more than 30 to 40% of total dietary fat should come from whole oil seeds (a source of unsaturated oils), 40 to 45% from other basal ingredients, and 15 to 30% ruminally inert fats. Another commonly used guideline is that 1/3 of dietary fat come from fats contained in the feedstuffs, from oilseeds, and from ruminally inert fats.

Crude Protein During Hot Weather

Digestible protein intake is reduced with declining DMI during hot weather and cows often experience negative N balances. It is necessary to increase dietary crude protein (CP) content to supply the quantity of protein necessary to sustain milk yield. Cows fed diets containing 14.3 or 20.8% CP during hot, humid weather consumed more DM (30.9 vs. 34.3 lb) and yielded more milk (39.3 vs. 42.0 lb) for the high CP diet (Hassan and Roussel, 1975). Greater DMI occurred despite the low CP diet being adequate for the level of production (NRC, 1989). Further analysis revealed that improved milk yield was correlated with feed and energy intake, but not with CP intake. Cows fed high CP diets had lower respiratory rates and slightly lower rectal temperatures, possibly related to improved digestion of the diet or altered metabolism.

The improved intake of feed which can occur with greater dietary CP must be balanced with the increased energy required to metabolize excess ammonia to urea. Excess protein (above the digestible protein requirement) fed to lactating cows decreased their energy balance by 7.2 kcal of metabolizable energy per gram of excess N (NRC, 1989). Cows offered diets of two protein solubilities (40% and 20%) during thermoneutral and heat-stress conditions had greater feed intake and milk yield for the less soluble protein diet for both environments (Zook, 1982) and milk yield declined from 54.0 to 50.9 lb when dietary CP was increased from 19 to 23% (Danfaer et al.,1980). Calculations revealed that the energy cost of synthesizing and excreting urea accounted for the reduced milk output (Oldham, 1984). Thus formulations with either inadequate or excess CP can reduce performance by lactating cows.

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 had lower DMI and milk yield when fed the high CP, high degradability diet (Higginbotham et al., 1989). Shading or evaporative cooling did not change DMI for low or high protein degradability, but milk yield was greater for low degradability diets, provided protein was of high quality (Taylor et al., 1991). When cows were either evaporatively cooled or shaded and offered diets containing high quality or low quality proteins, 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 (Chen et al., 1993; Table 3). Huber (1994), summarized this research and indicated that during heat stress the 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.

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). Schneider et al. (1986) also reported that DMI was greater when diets contained .55 vs. .18% sodium during hot weather. Current ranges for mineral supplementation during heat stress include 1.3 to 1.6% K, .35 to .4% Na, and about .35% Mg.

A ratio or balance of dietary ions may affect performance by influencing the body's buffering systems. Escobosa et al. (1984) were the first to evaluate diets fed to lactating cows 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, suggesting that the dietary cation-anion balance (DCAB) might be more important than content of the individual elements. The concept that DCAB is based upon is the maintenance of the desired physiological acid-base status, which was placed third by Kronfeld (1979) on the list of homeostatic priorities, behind the need for oxygen and heat dissipation, and ahead of CO_2 elimination and water retention. Thus, maintenance of the desired physiological pH ranks very high on the list of priorities.

Increasing DCAB improved DMI and change of the equation using any of the three elements (Na, K, Cl) was equally effective in improving performance (Tucker et al., 1988). Increasing DCAB raised blood pH, serum cation-anion balance, and blood bicarbonate, 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 regardless of environment. During heat stress conditions DMI was improved as DCAB was increased from 120 to 464 meq Na + K - Cl/kg feed DM, regardless of whether Na or K was used to increase DCAB (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. However, 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. The need for alkaline diets is consistent with addition of buffers to the diet, since the ideal means to increase DCAB for lactating cows is with Na or K in association with a metabolizable ion such as bicarbonate. The diet cannot be made more alkaline by the use of salt (NaCl) or potassium chloride (KCl). Use of dietary buffers is a common practice, especially during hot weather, and DCAB may provide further justification for the use of buffers during hot weather. Work with potassium

carbonate as a source of supplemental K and dietary buffering showed positive results during heat stress (West et al., 1987).

Feed Additives for Heat Stress

In addition to formulating diets for adequate nutrient intake by the cow, a number of "non-nutritive" additives are available which have potential to improve performance during hot weather. An additive is only good if it works in your herd, in your situation. Additives purchased to solve problems due to poor ration formulation are purchased for the wrong reasons. This section is not to be considered all inclusive, but serves to mention some feed additives that may have a place in hot weather feeding.

Sodium bicarbonate is a frequently used feed additive that is especially useful during hot weather. Because high concentrate, low forage rations are often fed to encourage DMI during hot weather, or because cows selectively reduce fiber intake in response to high temperatures, the potential for acidosis due to inadequate dietary fiber content is real. Buffers minimize pH fluctuations, usually enhance fiber digestion, and often encourage greater DMI.

Huber et al. (1994) reviewed the use of fungal cultures added to diets during heat stress conditions. The species for which the heat stress data were available were of strains of *Aspergillus oryzae* (AO). In several of the studies summarized, rectal temperatures were lower in AO supplemented cows although there was no change in some studies. A number of studies also reported greater milk yield with AO use during heat stress. Ruminal effects associated with AO use include increased fiber digestion, greater numbers of cellulolytic bacteria, increased turnover rate of lactic acid, and less diurnal variation in rumen pH, ammonia, and VFA (Huber et al., 1994). Improved ruminal efficiency and reduced heat production could contribute to greater performance and reduced heat production. Any product which improves ruminal efficiency should contribute to improved performance during hot weather.

Cows fed diets supplemented with 6 grams niacin per day during summer had about 2 lb greater milk yield (Muller et al., 1986). However when data for cows averaging more than 75 lb milk were analyzed, those cows yielded 5.3 lb more milk. This illustrates that additives can benefit specific cows. Returns can be maximized when the additive is delivered only to those cows that need it.

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. Other steps to enhance performance during hot weather include:

- **Environmental modifications should be made to encourage maximum DMI cows.**
- **Increase density of energy and other nutrients to compensate for reduced DMI.**
- **Increase energy density by increasing content of concentrates in the diet, but avoid excessive fermentable carbohydrates which can lead to acidosis.**
- **Add fat to the diet to improve energy density and possibly improve efficiency.**
- **Make sure adequate dietary fiber is present to maintain rumen function. Use high quality forage as a fiber source, minimize reduction in overall forage content in the diet by emphasizing the use of high quality forage.**
- **Be attentive to rumen escape protein, avoiding excessive rumen degradable protein. Protein quality is important during hot weather.**
- **Provide unlimited quantities of clean drinking water within easy access for the cow.**
- **Consider specific mineral supplementation that has proven beneficial during hot weather. Evaluate K, Na, and Mg contents.**
- **Use additives that have a proven reason and benefit for your herd situation.**

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Table 1. Changes in maintenance requirements and DMI for 1323 cows producing 59.5 lb of 3.7% fat milk at various temperatures.

	Required for 59.5 lb production				
Temperature (°F)	Maintenance (% of requirement at 50°F)	DMI needed (lb/d)	Expected DMI (lb/d)	Expected Milk (kg/d)	Water intake (gal/d)
-4	151	46.9	45.0	44.1	13.5
14	126	43.6	43.6	55.1	15.3
32	110	41.4	41.4	59.5	16.9
50	100	40.1	40.1	59.5	16.9
68	100	40.1	40.1	59.5	18.0
77	104	40.6	39.0	55.1	19.5
86	111	41.7	37.3	50.7	20.9
95	120	42.8	36.8	39.7	31.7
104	132	44.5	22.5	26.4	28.0

Adapted from NRC (1981).

Table 2. Effect of increasing dietary NDF from bermudagrass on DMI of lactating cows subject to cool and hot, humid conditions.

		Added hay[1,2]				
Item	Environment	Control	Low	Medium	High	Effect
DMI, lb/d	Cool	51.4	48.1	45.4	41.9	L**
	Hot	40.3	39.2	38.4	36.1	L*
	Hot-adjusted	37.3	38.1	39.5	39.0	L×W**
Milk, lb/d	Cool	71.2	71.9	69.2	63.7	L†
	Hot	54.2	56.9	58.2	50.0	Q*
	Hot-adjusted	52.7	55.3	58.0	53.6	L×W*

[1]Bermudagrass hay added at 0, 7.6, 15.2, and 22.8% of diet DM yielding 30.2, 33.8, 37.7, and 42.0 % NDF for control, low, medium, and high diets, respectively.

West et al., 1995. J. Dairy Sci. 78(Suppl.1):208

Table 3. Effect of protein quality and evaporative cooling performance of lactating cows.

	Treatment				
	Shaded		Evaporatively cooled		
Item	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.