INTRODUCTION

Dairy cattle generate heat from two sources: the environmental temperature and humidity, and their internal body metabolism and digestion. Within the thermoneutral zone (-4 to 18.5°C), the production and loss of heat from a cow’s body is about equal. Within this zone, cows are able to maintain a normal body temperature of 38.5 - 39.3°C relatively easily. When more heat accumulates than the cow can dissipate, heat stress occurs.

Cows under heat stress will seek out shade, reduce their feed intake, increase their water intake and respiration rate, and increase their production of saliva, sweat and urine to try to cool down. The results of heat stress are a lower milk yield, reproduction disturbance and health problems in the dairy cows, and a severe economic loss of dairy business. High-producing cows are even more sensitive to heat stress, because of their high feed intake. NRC (1981) suggested that dry matter intake starts to decline, and energy used for maintenance starts to increase, when environmental temperatures exceed 25°C. When ambient temperatures exceed 32.2°C, the dry matter intake (DMI) of cows might drop by 8 - 12%, and milk yield may fall by 20 - 30%.

There are three management strategies that minimize the effects of heat stress. The first is physical modification of the environment. The second is the genetic development of heat-tolerant breeds. The third is improved nutritional management practices. In this paper, we focus on feed management for lactating dairy cows under heat stress.

WATER INTAKE AND ITS QUALITY

Water is the most important nutrient for animals. A loss of only one-fifth of body water is fatal. Cow bodies normally contain 55 - 65% of water (by weight). Lactating dairy cows need more water than other livestock, because 87% of milk is water. Drinking water
is the major source of water, and satisfies 80 - 90% of dairy cows’ total water needs. Water consumption is variable, and depends on ambient temperature, DMI, milk yield (MY), sodium intake (NaI), physiological stage, and other factors. Murphy et al. (1983) proposed an equation to predict water consumption:

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\text{Water intake, lbs/day} = 35.25 + 1.58 \times \text{DMI (lbs/day)} + 0.90 \times \text{MY (lbs/day)} + 0.11 \times \text{NaI (grams/day)} + 2.65 \times \text{average minimum temperature (°F/1.8 – 17.778)}.
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Under heat stress, water intake could significantly increase by 120 - 200%. This increased water intake helps dissipate heat through the lungs (respiration) and by sweating. Cows drank about three kg of water per kg of DMI when the temperature was below 5°C, but drank 7 kg of water per kg of DMI at high temperatures. High-producing cows are capable of consuming 190 liters of water each day (Beede 1992).

The drinking behavior of cows is interesting. Cows spend about six hours a day eating, but only five to ten minutes drinking. They drink mainly after being milked and when fresh feed is offered. To fit this special drinking pattern, water systems must be designed to deliver water to each station at the proper rate and keep up with peak demand. In arid areas, it is suggested that for groups of 200 cows or less, water stations should accommodate 15% of the herd at the same time, allowing 60 cm of accessible perimeter per cow (McFarland 2000). Since it is difficult to define how much water is adequate, it is crucial to supply abundant, clean and easily accessible drinking water to cows all the time.

Water quality may affect the water consumption and performance of cows. Total dissolved solids (TDS) refer to the level of salts dissolved in water. These include sodium chloride (NaCl), sulfate (SO₄), potassium (K), calcium (Ca), magnesium (Mg), etc. Of these salts, sulfate and chloride are more likely to have a negative effect than sodium (Na), perhaps because of their anionic characteristics. During warm weather, Challis et al. (1987) found that desalinated (reverse osmosis) drinking water increased milk yield by 28% (35 vs. 27.3 kg/day). It also increased water intake by 20% and grain intake by 32%, compared to highly saline water. The original saline water contained 4,387 ppm of TDS, of which 2,400 ppm was SO₄ and 520 ppm was Cl. Desalinated water contained 441 ppm of TDS. When highly saline water was reintroduced, milk yield dropped by 6 kg/day during the first week and by 4 kg/day in the second week. This study shows that a combination of high TDS and high concentrations of SO₄ and possibly Cl in drinking water during hot weather may be harmful for lactating cows.

**NUTRIENT DENSITY AND ADJUSTMENT**

The DMI generally falls during hot weather. This means that cows may not be eating adequate amounts of nutrients (energy, protein, ADF, NDF, and effective NDF). Digestion and metabolism of feed create heat, and this heat production should be cut down as much as possible. Heat increment (HI) is defined as energy expenditure associated with the digestion and assimilation of food. Each kind of feed has its own HI value. A diet with a higher nutrient density and low HI (higher energy conversion efficiency) for lactating cows under heat stress is desirable. Conversion efficiencies of intermediate products, such as acetate and glucose, to end products, such as fatty acids, are 68 - 72% and 82 - 85%, respectively. Partial efficiencies for the conversion of acetate and dietary fat to milk fat are in the ranges of 70 - 75% and 94 - 97%, respectively (Baldwin et al. 1985).

**Fiber**

Because there is greater heat production associated with metabolism of acetate compared with propionate, it is logical that low-fiber rations should be fed during hot weather. Feeding more concentrates at the expense of fibrous ingredients increases the energy density of rations, and should reduce HI (West 1999). Although increasing the level of grain feed is widely practiced in summer, any drop in fiber levels should be approached cautiously. Experiments have indicated that the highest percentage of grain diets (61.8, 51.8 and 31.8% in diet DM for early, mid and late lactation) resulted in lower milk yield, depressed milk fat, lower DMI and feed efficiency for multiparous cows (Tessmann et al. 1991). Giving cows more grain in their feed leads to a lower rumen pH, especially in hot summer (Mishra et al. 1970), and sorting the feed to remove fiber
could make the rumen pH even lower. The maximum benefit from grain appears to be when it is approximately 60 - 65% of the diet (Coppock 1985).

Feeding very high-quality forage to lactating cows in hot summer is recommended, because it reduces heat build-up and supplies necessary long fibers. Another option is high-fiber, easily fermented feed by-products. Soybean hull, brewers' grain and beet pulp pellets are all rapidly degraded in the rumen. One and a half kilograms per day per cow of beet pulp pellets were a good substitute for corn and Pangola grass. They maintained DMI, the same milk yield, milk fat and chewing activity, but cost less, thus giving a higher net income of US$ 0.93 per day per cow (Lee et al. 1999). The level of effective dietary fiber should be adequate to avoid rumen acidosis and metabolic difficulties. The ADF level should be maintained at a minimum of 18 - 19%, or alternatively the NDF should be at least 25 - 28% of diet DM.

**Fat**

Adding fat to the diets of lactating dairy cows is a common practice. The greater energy density and high energy conversion efficiency of high-fat diets may be particularly beneficial during hot weather. However, research on the effects of dietary fat during hot weather gives inconsistent results (Huber et al. 1994). It has been reported that cows fed a diet supplemented with fat could improve their fat-corrected milk yield by 22% compared with the control group (33.2 kg vs. 40.5 kg) during warm weather but not during cool weather (Skaar et al. 1989). However in one experiment, diets containing 5% added fat fed to cows in either thermoneutral or hot environment conditions did not improve milk yield (Knapp and Grummer 1991). In a recent study, diets supplemented with 3% prilled fatty acids were offered to cows, kept either in the shade or the shade plus evaporative cooling. Again, milk yield was improved only by the cooling not the fat treatment, supplementation (Chan et al. 1997).

Although the results seem contradictory, biological principles argue in favor of fat supplementation under conditions of heat stress. Extension nutritionists still suggest fat supplements to give a final fat content of 6 - 7% of diet DM, especially for high-producing cows. Sources of fat supplements include whole oilseed, tallow and protected fat products.

**Protein**

Cattle suffering from heat stress often have a negative nitrogen (N) balance, because of reduced feed intake. Both the quantity and quality of protein in the diet need to be considered when feed is being provided for heat-stressed cows. Simply increasing the level of crude protein (CP) may increase energy requirements and cause problems of environmental pollution. Excess dietary protein is converted into urea and excreted. It is estimated that for each gram of urea synthesis, 7.3 kcal of energy is expended.

Researchers in Arizona USA conducted 2 x 2 dietary protein experiments with high (18.5%) or low (16.1%) CP and high (65%) or low protein degradability (59% of CP) in both hot and moderate environments. Results showed that cows under heat stress fed a diet with high CP and high degradability (18.5% and 65%) showed a decrease in milk yield of 11% (3.1 kg/day) compared with the other three groups. In hot environments, a high CP (18.5%) diet caused DMI to fall by 1.5 kg per day, compared to the 16.1% group (Higginbotham et al. 1989b). Cows in a temperate environment did not respond to dietary protein treatments. Milk yields were similar for all treatments (Higginbotham et al. 1989a). Based on this research, it was suggested that during heat stress, the level of crude protein (CP) in the diet should not exceed 18%, while the level of rumen-degradable protein should not exceed 61% of CP or 100 grams of N/day (Huber et al. 1994).

Protein quality was also studied. High-quality protein sources (soybean, fish meal, and blood meal) with a 1% lysine content, were compared with a low-quality protein source (corn gluten meal), containing 0.6% lysine. Cows fed the 1.0% lysine diet increased their milk yield by 3.2 kg/day (Huber et al. 1994).

Studies in Taiwan of dietary protein level and quality gave results consistent with those from Arizona. In the hot summer months, cows fed diets with a high CP level (16.5% vs. 15.0%) and high degradability (63% vs. 58% of
CP) reduced their milk yield by 11.3% (2.2 kg/day). Cows fed diets with a low level of degradable protein had a higher percentage of milk fat and milk lactose, and a lower level of urea nitrogen in their blood. Fish meal and blood meal were fed as supplements to study protein quality. Cows fed blood meal increased their milk yield 1.6 kg and 1.0 kg/day, compared to the control. It may be that the first limiting amino acid in a diet of Pangola grass is lysine rather than methionine (Lee et al. 1998).

Minerals

Electrolyte minerals, sodium (Na) and potassium (K) are important in the maintenance of water balance, ion balance and the acid-base status of heat-stressed cows. The mineral requirements recommended by the National Research Council (NRC), United States, in 1989 do not seem high enough for cows suffering from heat stress. When heat-stressed cows sweat, they lose a considerable amount of K. Increasing the concentration of dietary K to 1.2% or more resulted in a 3 - 9% increase in milk yield, and also an increased DMI. Increasing the concentration of sodium in the diet from the NRC recommended level of 0.18% to 0.45% or more improved milk yield by 7 - 18% (Sanchez et al. 1994). If magnesium oxide (MgO) was added, thus increasing the Mg concentration from 0.25% to 0.44%, the milk yield of heat-stressed cows increased by 9.8% (Teh et al. 1985).

The dietary cation-anion balance (DCAB, Na + K – Cl or Na + K – Cl – S) contributes to maintain the acid-base status of cows in hot weather. For heat-stressed cows, alkaline diets are preferable. DMI increased linearly with increasing cation content from 120 to 464 mEq/kg DM, while Na or K was equally effective as a cation source (West et al. 1992). In hot weather, the level of milk fat is usually lower. Supplementation with buffers such as sodium bicarbonate (NaHCO₃) and magnesium oxide (MgO) is common. Adding sodium bicarbonate to the diet may help to maintain the pH of the rumen, and also contribute to a more cationic DCAB value to increase DMI and milk yield.

A diet with a high chloride content, with a DCAB value of -144 mEq/kg DM, depressed DMI and was associated with low blood pH and reduced blood buffering (Escobosa et al. 1984). Diets high in chloride also resulted in a lower milk protein percentage (Sanchez et al. 1997). [Thus, it is recommended that the level of dietary chloride does not exceed 0.35% of DM (Sanchez et al. 1994)]. A mixture of potassium sulfate (K₂SO₄) and magnesium oxide (MgO) were blended to increase dietary concentrations of K, S, and Mg from 1.02, 0.23 and 0.21% to 1.46, 0.41, and 0.45%, respectively. There was no improvement in milk yield or DMI of the cows under heat stress which received this supplement. In fact, the percentage of total solids in the milk fell, and the milk fat percentage was also lower (Lee et al. 2000). The reasons for this adverse effect are not yet clear. The DCAB values for both diets were similar, 288 and 281 mEq/kg DM. A simultaneous increase in the anionic S concentration may partially explain this result.

Feed additives

As well as the nutrients fed in large quantities, some minor nutrients were studied in terms of their ability to relieve cows suffering from heat stress. Generally speaking, the results were inconsistent. An improvement in performance was more likely to occur in high-producing cows fed a high-energy diet.

Niacin can prevent ketosis, and is involved with lipid metabolism. Cattle fed with 6 g niacin per day in summer increased their milk yield by only 0.9 kg/day. However, with cows yielding more than 34 kg a day, there is a clear improvement in milk yield (2.4 kg/day) (Muller et al. 1986). Under moderate to severe heat stress conditions, niacin at a rate of 12 - 36 grams a day did not improve milk yield, but lowered skin temperature by about 0.3°C (Di Costanzo et al. 1997). Similarly, there was no response in milk yield from cows receiving 10 - 20 grams of niacin per day. A group given 10 grams of niacin had a slower respiration rate in the afternoon. Both groups given niacin supplements had a higher molar percentage of the butyrate in the rumen (Lee et al. 2001).

Most research with lactating cows concerned with microbial or “probiotic” products deals with either Aspergillus oryzae (a mold classified as a fungus) or Saccharomyces cervisiae (a yeast). The effect of A. oryzae on cows under heat stress was reviewed. Results indicated that three grams of A. oryzae supplementation had little effect
on rectal temperature, respiration rate, or milk composition, but gave a 4% increase in milk yield (1 kg/day) (Huber et al. 1994). Both A. oryzae and S. cervisiae may influence the fermentation pattern and microbial population in the rumen (Yoon and Stern 1996).

**TIME OF FEEDING AND FEEDING FREQUENCY**

The feeding behavior of animals changes when it is hot. Animals will consume more feed during cooler evening hours (West 1999). The quantity of feed and the feeding schedule should be adjusted to accommodate this behavior. Having fresh feed in the mangers after milking is a good way to encourage DMI. When the weather is very hot, at least 70% of the daily feed should be given fresh at night.

Steers ate more frequent but smaller meals in a hot environment, with the result that less feed was consumed overall (7.39 vs. 8.12 kg/day), than in cool conditions (Hahn 1999). More frequent feeding could keep feed fresher, and encourage cows to eat more frequently, thus stimulating DMI. Theoretically, more frequent feeding might decrease the diurnal fluctuations in metabolites and increase feed utilization efficiency in the rumen (Robinson 1989). A fixed amount of high grain offered 12 times a day did not increase milk yield, but raised the milk fat percentage from 2.21 to 2.60%. It also increased the mean rumen pH value from 5.7 to 6.2, and shortened the period during which the rumen pH was less than 6.0 from 14 hrs a day to 4 hrs, compared to cows fed twice a day (French and Kennelly 1990).

Commercial dairy producers usually believe that frequent feeding is crucial in achieving and maintaining high productivity. This practice may be even more important during hot weather, because feed is fermented faster after preparation when air temperatures are high. However, research studies conclude that the effect of more frequent feeding on milk yield is moderate, and of little economic importance to producers (Gibson 1984). Robinson (1989) suggested that the different results from research stations and dairy farms in this respect may be the result of the high ratio of forage in the diet, the low milk yield of cows in the paper reviewed, the actual quantity of feed offered, and the environmental differences between a practical dairy farm and an ideal research center.

**REFERENCES**


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