Managing Heat Stress and Its Impact on Cow Behavior

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Summary

- Heat stress affects several aspects of the dairy industry including cattle behavior.
- Heat stress will increase an animal's standing time as it tries to dissipate heat over its entire body surface.
- Increasing standing time or decreasing resting time reduces milk production.
- Prolonged standing further increases the risk of lameness.
- Understanding environmental and physiological parameters that affect standing behavior will improve industry efforts to minimize heat stress in dairy cattle.
- Core body temperature is correlated standing behavior, with cattle more likely to stand above a 102.07 °F (39.2 °C) core body temperature.
- Correlation between thermal heat index and cattle behavior has also been evaluated, although predictive capacity has yet to be established. However, cattle are more likely to stand above a THI of 68.

Introduction

The issue of environmental impacts on dairy production and cattle welfare has long been of interest to the industry. One environmental stressor which has commanded considerable research attention within the past several decades has been thermal stress. Production loss due to heat stress has been estimated at $900 million annually to U.S. dairy herd (St. Pierre et al., 2003). This interest in heat stress has coincided with the spreading demographic of the United States dairy industry from the Midwest to warmer and more arid climates, such as the desert Southwest, as well as an increase to heat sensitivity due to a doubling of average production per cow. Improvements in warm weather dairy housing have provided more efficient technologies for cooling animals exposed to hot climates. However, heat stress remains an important environmental stressor on dairy cattle.

Heat stress directly and indirectly affects feed intake, cow body temperature, maintenance requirements and metabolic processes, feed efficiency, milk yield, reproductive efficiency, cow behavior, and disease incidence (Thatcher, 1974; Cook et al., 2007; Tucker et al., 2007; Rhoads et al., 2009). These effects are well documented. It is only recently that researchers have attempted to understand the correlation of one of the most understood outcomes (increased body temperature) to one of the least understood outcomes (modified cow behavior) and its possible effect on bottom line production.

Heat Stress and Dairy Cattle

Domestic animals have a core body temperature (CBT) range in which metabolism functions without modification, termed the thermoneutral zone. Typically, core body temperature is higher than ambient temperature to ensure that heat generated by metabolism flows out to the environment (Collier et al., 2006). Deviation outside of this range – which is relatively narrow – leads to increases in resting metabolism, modifications to the biochemistry and cellular physiology as well as the behavior of the animal (Shearer and Beede, 1990). The thermoneutral zone lies between 41 and 77 °F (5 and 25 °C) for dairy cattle (Roenfeldt, 1998). Above 77 °F (25 °C), the body must modify physiology and behavior to keep CBT above the environment temperature.

Heat Stress and Thermal Humidity Index

Temperature is not the only environmental factor that affects the intensity of heat stress. The temperature humidity index (THI) measures the combined effects of ambient temperature and relative humidity (RH) to ascertain heat load intensity (Berry et al., 1964). This index was later categorized into heat stress levels with an index above 72 THI [75 °F (23.9 °C) with 65% RH to 90 °F (32.2 °C) with 0% RH] established as the lower threshold of heat stress (Whittier, 1993; Armstrong, 1994). However, because of the increased milk production per cow since the development of the THI, a 22 lbs/d (10 kg/d) increase will decrease the threshold for heat stress by 9 °F (5 °C; Berman, 2005). A recent re-evaluation of the THI has suggested that due to this improvement of milk production, the THI heat stress threshold should be lowered to 68 THI [72 °F (22.2 °C) with 45% RH to 80 °F (26.7 °C) with 0% RH; Zimbelman et al., 2009].

Heat Stress and Reproduction

Elevated core body temperature (CBT) in dairy cows caused by heat stress can have detrimental effects on reproductive performance. An increase in rectal temperature of 1.8 °F (1 °C) occurring 12 h post-insemination decreased pregnancy rates by 16% (Ulberg and Burfening, 1967). Gwazdauskas et al. (1973) reported an increase in uterine temperature of 0.9 °F (0.5 °C) on the day of or the day after insemination resulted in decreased conception rates by 13% and 7%, respectively. Badinga et al. (1985) attributed decreased conception rates of lactating cows to their inability to maintain normal body temperature at high environmental temperatures [> 86 °F (30 °C)]. Ealy and colleagues (1993) further support this hypothesis by reporting that bovine embryos become more resistant to adverse effects of maternal heat stress as pregnancy progresses. Embryos are sensitive to deleterious effects on d 1 following artificial insemination but develop substantial resistance by d 3. Expression of estrous behavior is also depressed when cows become heat-stressed.

Prolonged heat stress negatively affected reproduction by increasing estrous cycle length and decreasing duration of estrus (Abilay et al., 1975). A decrease in the frequency of pulsatile release of luteinizing hormone on d 5 of the estrous cycle was observed in heat-stressed cows compared to cooled cows (Wise et al., 1988). Follicular dynamics are altered and follicular dominance is depressed by heat stress (Wolfenson et al., 1995). Furthermore, fetal growth is negatively affected due to decreased uterine blood supply and the insufficiency of the placenta to provide maternal nutrients (Collier et al., 1982).

Heat Stress and Milk Production

When cows are subjected to heat stress, feed intake decreases. Simultaneously, maintenance requirements are increased due to activation of the thermoregulatory system. There is need to expend energy to maintain homeothermy that would otherwise be available for useful production (e.g. milk; Buffington et al., 1983). Mild to severe heat stress in dairy cattle has been estimated to cause an increase in maintenance requirements by 7 to 25% (NRC, 2001). By definition, heat-stressed cows are in a state of negative energy balance (NEBAL) since feed intake is not meeting energetic demands of maintenance and lactation.

Decreased intake accounts for approximately 36% of the decrease in milk production due to shifts in postabsorptive metabolism and nutrient partitioning (Rhoads et al., 2009). Under thermoneutral conditions, cows experiencing NEBAL have increased rates of lipolysis. This is characterized by the presence of elevated plasma nonesterified fatty acid (NEFA) concentrations, while glucose is partitioned to the mammary gland for milk synthesis. However, heat-stressed cows have lower NEFA concentrations and a higher rate of peripheral glucose utilization, suggesting that glucose uptake by other tissues reduces the amount of glucose available for milk synthesis (Rhoads et al., 2009).

A reduction in feed intake precedes a decrease in milk production when cows are subjected to heat stress (Rhoads et al., 2009). Spiers et al. (2004) showed that feed intake decreased within 1 d after initiation of heat stress, while milk yield decreased after d 2 of heat stress. Collier et al. (1981) demonstrated that maximum decrease in milk yield during heat stress occurs 48 hours after the initiation of the stress.

Prolonged thermal stress negatively impacts somatotropin (growth hormone or GH) secretion from the anterior pituitary (Mitra et al., 1972). Depressed GH concentrations result in slower growth rates, reduced nitrogen retention, and contribute to decreased lactation performance in dairy cattle (Mitra et al., 1972).

Johnson et al. (1963) reported that milk yield decreased by 4 lbs/d (1.8 kg/d) per cow for every 1 °F (0.55 °C) increase above a daily rectal temperature of 101.5 °F (38.6 °C). More recently, Igono et al. (1985) reported that a cow with a mean rectal temperature of 102.4 (39.1 °C) produced 1.54 lbs/d (0.7 kg/d) less milk than a cow with a rectal temperature of 101.8 °F (38.8 °C). Zimbelman et al. (2009) also reported a negative relationship between rectal temperature and milk production. This is relationship is further complicated with higher internal heat production in high producing cows compared to low producing cows, regardless of environmental influence (Purwanto et al., 1990).

Heat Stress and Production Efficiency

There are a number of behavioural, physiological and metabolic mechanisms which are employed by the cow to keep CBT above environmental temperature. Some of these are shown in Figure 1.

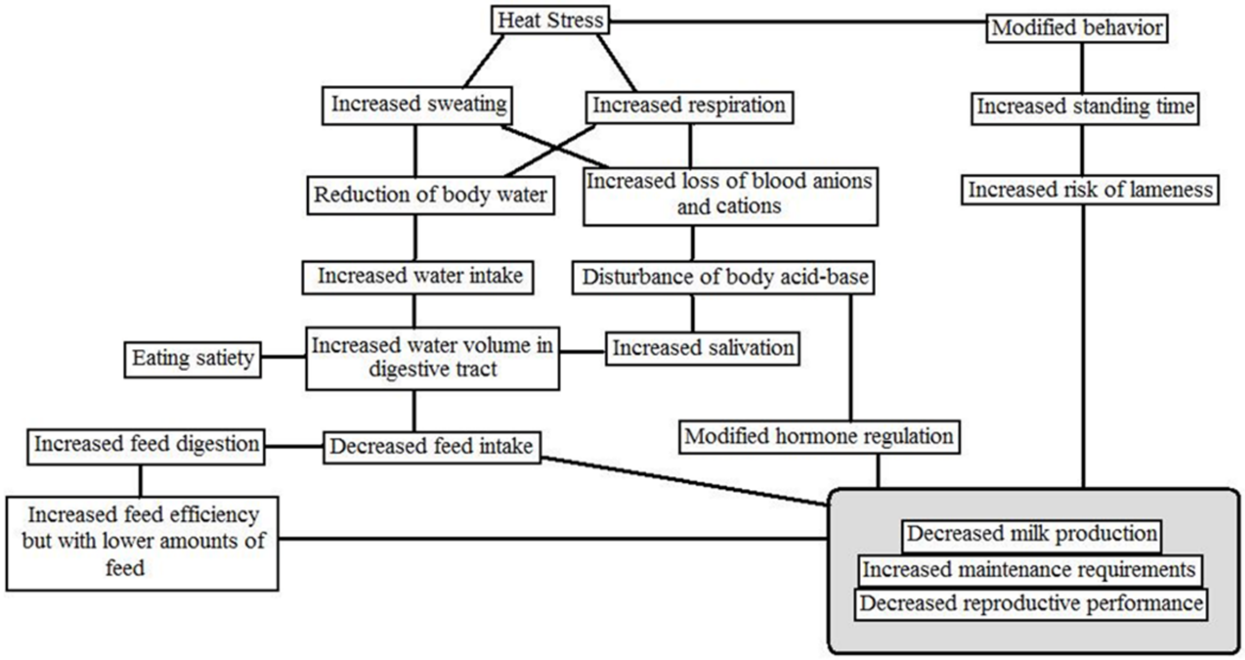

Figure 1. Schematic of the general effects of heat stress in dairy cows. (Adapted from Atrian and Shahryar, 2012).

Energy production and expenditure through cellular maintenance produces excess metabolic heat. Thus, heat exchange from the animal to environment is necessary to maintain optimal CBT (Kadzere et al., 2002). A negative correlation between metabolic hormones (thyroid hormones, somatotropin, prolactin, etc.) has been reported (Mitra et al., 1972; Johnson et al., 1988; Lu 1989; Collier et al., 2006). These hormones are responsible for energy expenditure and heat production, including gut motility and blood flow to the digestive system (Hales et al., 1984; Johnson et al., 1988). A decrease in gut motility leads to slower passage rate, decreasing feed intake. West (2003) reported a 1.9 lbs (0.85 kg) decrease in dry matter intake with every 1.8 °F (1 °C) increase in ambient temperature above a cow's thermal neutral zone. While digestion is improved, the lowered amount of feed within the digestive system is unable to meet requirements (Kadzere et al., 2002), decreasing feed efficiency.

Physiological mechanisms which improve heat dissipation also lead to an increase in maintenance requirements because of an increase in nutrient needs. Examples include increased respiration rate, increased sweating, increased heart rate, and increased salivation (Atrian and Shahryar, 2012). These in turn lead to increased body fluid loss which further increases maintenance requirements to abate dehydration and blood homeostasis (Collier et al., 2006). While these actions may seem futile, 15% of total body heat loss can be realized through normal respiration (McDowell et al., 1976), and increased respiration rate can and does increase heat loss potential (Campos Maia, et al., 2005).

Together, the cow's adaptation to minimizing heat production and maximizing heat dissipation leads to economic issues. Milk production will decrease, but energy and nutrient usage by the cow will increase. With an increase in maintenance requirements compounded by a decrease in dietary nutrients, nutrients are diverted from systems not necessary for survival. Rhoads and others (2009) reported a significant repartitioning between dietary and body nutrients utilized for milk production during heat stress, with decreased feed intake accounting for only 36% of milk production loss. Smith and others (2008) calculated that at a milk price of $18/cwt ($39.50/100 kg), a 2 to 12 lbs (0.9 to 5.5 kg) drop in milk production per cow per day due to heat stress could cost an operation between $32 [2 lbs/d (0.9kg/d) loss for 90 days] and $324 [12 lbs/d (5.5 kg/d) loss for 150 days].

Heat Stress and Health

Other than the physiological issues that arise from heat stress adaptation, there is ample research linking heat stress to particular aspects of an animal's health. Specifically, lameness incidence increases with an increase in ambient temperature (Cook et al., 2007). This coincides with the change of seasons as well; lameness prevalence is lower in cool months as compared to warm months (Sanders et al., 2009). These climatic and seasonal effects are also correlated to mastitis (Dohoo and Meek, 1982; Elvinger et al., 1991). Several trials have reported an increase of disease, particularly reproductive issues, during warmer months of the year due to the acceptable environment for pathogens and vectors (Collins and Weiner, 1968; Silanikove, 2000; Kadzere et al., 2002). Death losses also increase with an increase in THI (Vitali et al. 2009). Recent interest has also hinted at the effect of cow behavior on increased risk for locomotive diseases.

Heat Stress and Cow Behavior

Within the last decade, research efforts have turned to welfare of cattle experiencing heat stress. With an increase in ambient temperature or solar radiation, cattle are more likely to seek shades or other cooling structures (Tucker et al., 2008; Atrian and Shahryar, 2012). This change in behavior, aside from the physiological changes to decrease heat production mentioned above, suggests that dairy cows will also seek micro-environments that have a lower ambient temperature. Furthermore, cattle are more likely to seek optimum environments that have maximized cooling capacity. For instance, a recent study reported cattle were more likely to choose shade over a cooling system directed away from the shade, but were also likely to take advantage of shade that included a cooling system (Anderson et al., 2012).

To maximize heat loss regardless of environment, dairy cattle in areas with elevated temperature often stand to increase available surface for heat dissipation (Igono et al., 1987; Anderson et al., 2012, Smith et al., 2012). Even a mild increase in ambient temperature can invoke an increase in standing time (Smith et al. 2012). Highest incidence of lameness (new cases) occurs when cattle stand longer than 45% of the day (Galindo and Broom, 2000), and locomotion scores increase during summer months relative to winter months (Cook et al., 2007). A negative correlation between time spent lying and incidence of lameness as well as time spent lying and temperature humidity index has also been reported (Leonard et al., 1996; Privolo and Riva, 2009). This suggests that cattle exposed to higher temperatures are more likely to stand to improve heat dissipation but are also more likely to experience periods of lameness during the same time frame. Reducing resting time has been reported to reduce milk production (Bach et al., 2008, Grant 2007). It was estimated that for each hour of increased resting time that milk production increased 3.7 lbs (1.7 kg).

The effects of lameness on dairy production are compounded by and just as disconcerting as heat stress effects. Lameness affects resting and feeding behavior (Cook et al., 2007), decreases reproduction efficiency (Garbarino et al., 2004), and increases the likelihood for early removal from the herd (Collick et al., 1989). In hot climates, cattle are forced to risk lameness or risk overheating.

CBT and Cow Behavior

To further our understanding of behavioral conditions of heat stressed dairy cows, we combined three different data sets from heat stress trials conducted in Arizona (Anderson et al., 2012), California (S. Rungruang, unpublished), and Minnesota (Smith et al., 2012). In each trial, lactating dairy cows were fitted with 2 data loggers: one recorded CBT intra-vaginally, and one recorded angle of leg to determine lying status. All data were standardized to 5-minute intervals for CBT or 15-minute intervals for ambient conditions, and 2 hours per each milking period were removed to eliminate human interference and subsequent feeding.

While mild temperatures in the Minnesota trial resulted in higher lying CBT, the 2 other climates revealed greater incidence of heat stress and higher standing CBT compared to lying CBT (Figure 2). Table 1 shows the narrow CBT range (0.11 °F or 0.06 °C) of cattle standing compared to cattle lying. Altogether, CBT during posture shift (lying to standing or standing to lying) was equal (Table 2), suggesting that dairy cattle may be cognizent of their fluctuating CBT and are reacting preemptively to battle a dramatic shift in CBT, regardless of time of day (Figure 3).

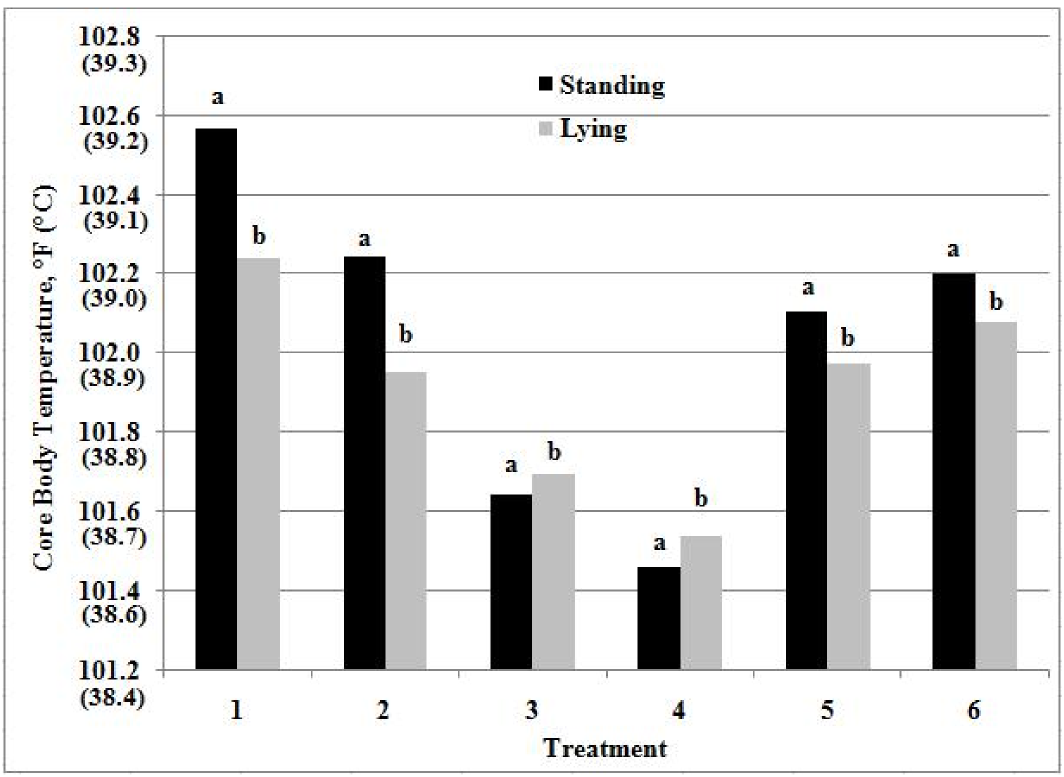

Figure 2. Cumulative core body temperature relation to posture in lactating dairy cows. Treatments are designated as follows: 1 = Arizona with fixed fans and misters under drylot shade; 2 = Arizona with adjustable fans and misters under drylot shade; 3 = Minnesota within a cross-ventilated building; 4 = Minnesota within a cross-ventilated building with evaporative pads; 5 = California with feed-line soakers and fans; and 6 = California with hydrothermally cooled freestalls without feed-line soaking or fans. A treatment effect is observed ($P < 0.0001$). Columns within treatment with different letter designations differ ($P < 0.01$).

Table 1. Core body temperature of lactating dairy cows in relation to posture[1]

Item:	Posture		SEM	*P* Value
	Standing	Lying		
Core Body Temperature, °F	103.834	101.912	0.0025	0.0001
(°C)	(39.908)	(38.840)	(0.0014)	

[1] Data is representative of cows in Arizona (n = 56), California (n = 37), and Minnesota (n = 64).

Table 2. Core body temperature of lactating dairy cows in relation to posture[1]

Item:	Posture				SEM
	Initial Stand	Continuance of Stand	Initial Lying	Continuance of Lying	
Core Body Temperature, °F	102.144[a]	101.916[b]	101.847[c]	101.917[b]	0.0085
(°C)	(38.969)	(38.842)	(38.804)	(38.843)	0.0047

[a,b,c] Letters in the same row with a different superscript differ (*P* < 0.0001).
[1] Initial lying is representative of the period in which the animal has transitioned from a standing to lying posture; continuance of lying is representative of the period after the animal has initially lied down. Data is representative of cows in Arizona (n = 56), California (n = 37), and Minnesota (n = 64).

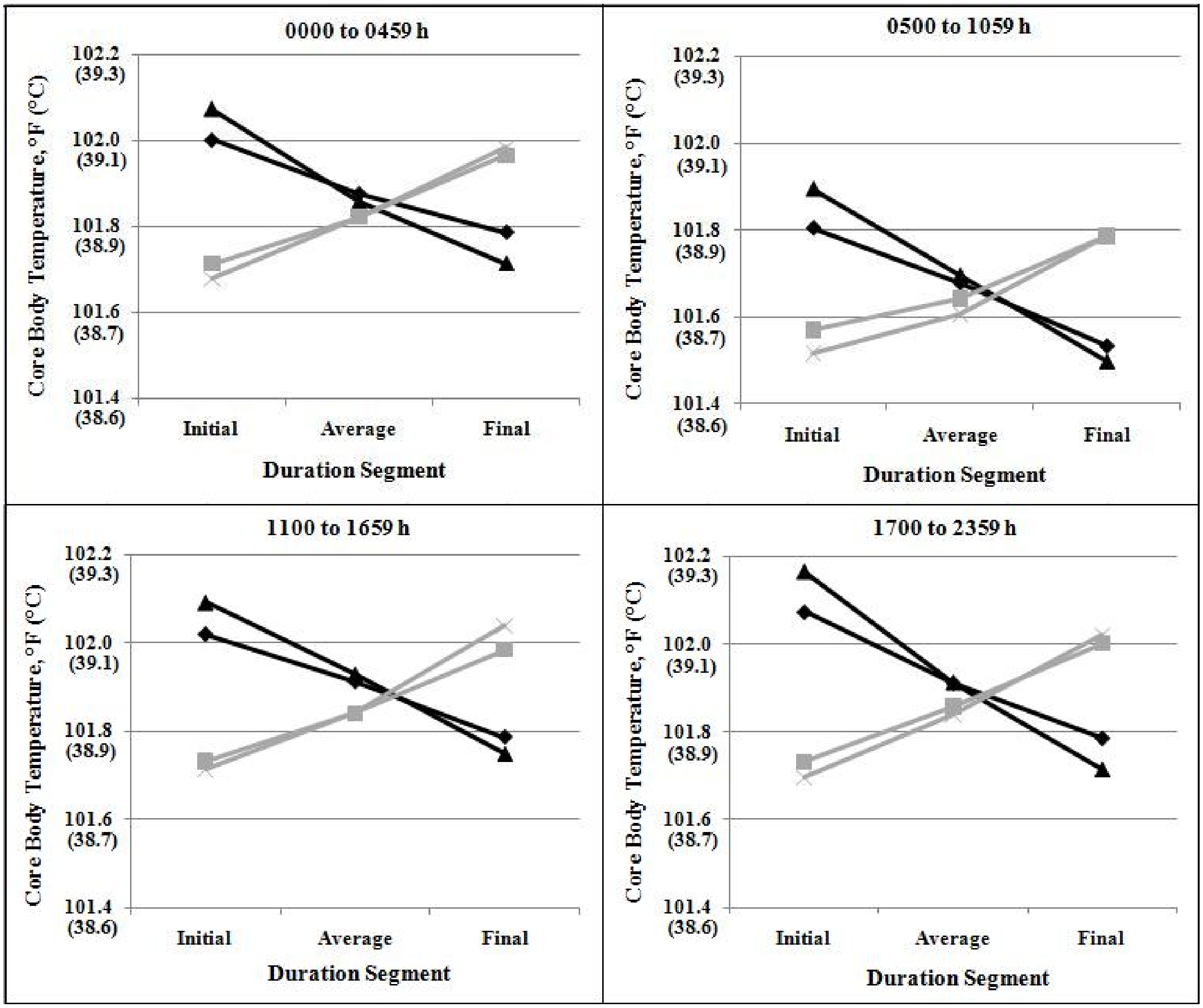

Figure 3. Effect of period of day on core body temperature of standing and lying bouts (Period effect: $P < 0.01$)

An analysis of the entire data set (> 260,000 data points) provided a correlation ($r^2 = 0.56$, $P < 0.0001$) between CBT and cow posture, giving researchers and producers a more specific CBT in which to focus their attention when managing dairy cattle for heat stress and cow comfort. In this data set cattle were more likely to be standing at a CBT greater than 38.93 °C (102.07 °F; Figure 4).

This does not suggest that cows with a CBT below this mark do not experience heat stress. However, with increased standing behavior as an indicator of heat stress, this CBT provides a point at which to improve our management efforts to alleviate the negative affects of heat stress, particularly in decreasing the amount of time a cow stands to dissipate body heat.

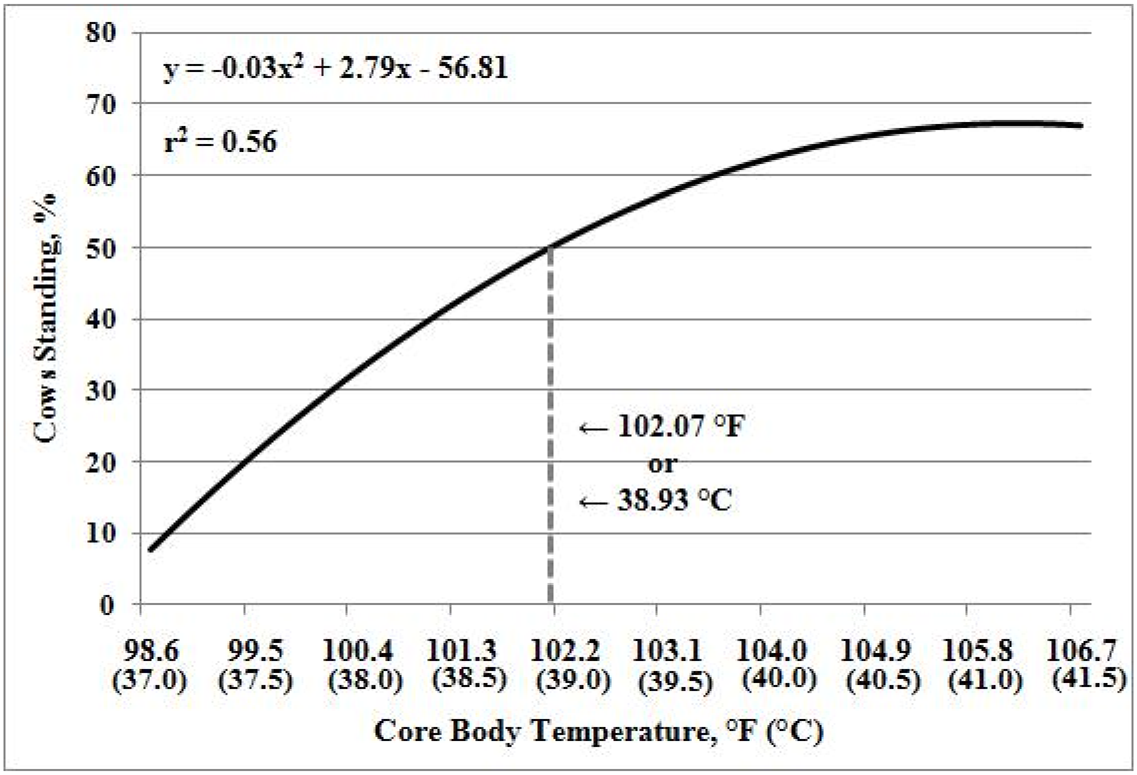

Figure 4. Percent of animals standing in relation to core body temperature. Data is representative of cows in Arizona (n = 56), California (n = 37), and Minnesota (n = 64).

Data using THI as a predictor of stance were limiting in predictive power ($r^2 < 0.20$). This may be in part to the diminished number of THI data points (< 90,000) as compared to the CBT data points (> 260,000). However, the impact of THI on cattle behavior is measurable (Table 3) and appears to follow the same pattern as CBT. Although not specified, the 50 percent mark would occur just above a THI of 71, which is just above a THI of 68, the established threshold where heat stress begins in high producing dairy cows (Zimbelman et al., 2009).

Table 3. Percent of cattle standing within THI categories[1]

	THI Category[2]						
Item:	< 68	68 to 71	72 to 79	80 to 89	90 to 98	> 100	SEM
Animals Standing, %	43.6	49.8	53.0	68.2	49.7	52.2	1.6

[1] P < 0.0001. Data is representative of cows in Arizona (n = 56), California (n = 37), and Minnesota (n = 64).
[2] Categories defined as thermal neutral (< 68), heat stress threshold (68 to 71), mild-moderate heat stress (72 to 79, moderate-severe heat stress (80 to 89), severe heat stress (90 to 98), and extremely severe heat stress (> 100).

Summary

Heat stress is a major economic issue in the dairy industry. Its effects reach beyond milk production into reproduction, health, and welfare arenas through physiological and behavioral changes. Modifications to cow behavior are linked to overall production performance and should not be overlooked. Improving the cow's comfort by reducing the amount of time it stands to dissipate heat can ultimately reduce the effect of heat stress on milk production.

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