Quantifying Heat Stress and Its Impact on Metabolism and Performance

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Quantifying Heat Stress and Its Impact on Metabolism and Performance

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Introduction

Pronounced seasonal patterns of milk yield and composition are evident in cattle. These seasonal patterns are largely induced by climatological variables, breed effects and management factors, such as feed quality and reproductive management. Month of parturition is known to have a pronounced impact on subsequent milk yield and composition. Highest yields occur following January and February parturition while lowest yields occur following August and September calvings (see Figure 1). The seasonal pattern in milk yield is related to the direct and indirect effects of environment on milk production. Direct effects are related to the effects of elevated temperature on milk yield; indirect effects are due to photoperiod effects and the negative impact of heat stress, during late pregnancy on maternal and fetal metabolism and circulating plasma endocrine patterns which are altered by the stress (Collier et al. 1982). As is apparent from Figure 1, there is also a seasonal pattern in milk protein which parallels the seasonal pattern in milk yield. Interestingly, the milk protein yield pattern appears to be more directly affected by temperature as the nadir occurs during the hottest part of the summer. This may reflect the need for production of heat shock proteins by mammary epithelial cells during periods of heat stress which would reduce milk protein synthesis rates while the milk yield curve displays both direct and carry-over effects related to indirect effects on pregnancy and metabolic state of the cow.

The majority of studies published on climatic effects on milk composition and yield have evaluated effects of temperature. Dairy cattle are sensitive to heat stress because of the high metabolic heat production and feed intake associated with rumen fermentation and milk yield. Likewise, for the same reasons, dairy cattle are relatively resistant to cold stress. Heat stress in cattle is characterized by increased rectal temperature, elevated respiration rates and decreased feed intake which contributes to the decreased milk yield. The environmental temperature range from -5 to 23.9ºC has little impact on milk yield and composition and is referred to as the thermoneutral zone for the lactating dairy cow. However, temperatures above 23.9ºC are known to decrease solids-not-fat (**SNF**), protein, lactose and fat percentage of milk. Due to its involvement in osmotic regulation of milk, the impact of temperature on lactose and mineral content of milk is much smaller than the impact of temperature on protein and fat yields. Generally, in temperate regions, the fat content may average 0.4% lower and the protein content 0.2% lower in summer as compared to winter months. An alternative approach to evaluating cooling needs in cattle is to use the Temperature Humidity Index (**THI**). This combined measure of both ambient temperature and relative

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humidity has been shown to be more effective in evaluating environmental effects on lactating cattle than temperature alone.

Reevaluation of Temperature Humidity Index

The THI was originally developed by Thom (1958) and extended to cattle by Berry et al (1964). It is currently used to estimate cooling requirements of dairy cattle in order to improve the efficiency of management strategies to alleviate heat stress. The Livestock Conservation Institute evaluated the biological responses to varying THI values and categorized them into mild, moderate and severe stress levels for cattle (Whittier, 1993; Armstrong, 1994). However, as pointed out by Berman (2005), the supporting data for these designations are not published. In addition, the index is based on a retrospective analysis of studies carried out at The University of Missouri in the 1950's and early 1960's on a total of 56 cows averaging 15.5 kg of milk/d, (range of 2.7-31.8 kg/d). In contrast, average production per cow in the United States is presently over 30 kg/d with many cows producing above 50 kg/d at peak lactation. The sensitivity of cattle to thermal stress is increased when milk production is increased thus reducing the "threshold temperature" when milk loss begins to occur (Berman, 2005). This is due to the fact that metabolic heat output is increased as production levels of the animal increase. For example, the heat production of cows producing 18.5 and 31.6 kg/d of milk has been shown to be 27.3 and 48.5% higher than non-lactating cows (Purwanto et al., 1990). Research has shown that when milk production is increased from 35 to 45 kg/d the threshold temperature for heat stress is reduced by 5°C (Berman, 2005). The physiological effects based on THI predictions on milk yield are currently underestimating the severity of heat stress on Holstein cattle. Radiant heat load and/or convection effects were not evaluated by Berry et al., (1964) and the majority of dairy cows are currently housed under a shade structure during heat stress months. Although shade structures alleviate some of the radiant heat load, there is still a conductive effect coming from the metal shade structure. In Israel, a typical shade structure is estimated to add 3°C to the effective ambient temperature surrounding the animals (Berman, 2005). The use of fans for cooling management systems causes varying convection levels under shade structures as well.

An additional factor in utilizing THI values is the management time interval. In past research, the milk yield response to a given THI was the average yield in the second week at a given environmental heat load therefore milk yield measurements were not recorded until two weeks after experiencing the environment (Berry et al., 1964). In order to avoid economic production losses dairy producers need to be informed of the level of cooling to be implemented immediately when heat stress occurs. Research has indicated that the effects of a given temperature on milk production are maximal between 24 and 48 hours following heat stress (Collier et al., 1981; Spiers et al., 2004). It has also been reported that ambient weather conditions two days prior to milk yield measurement had the greatest correlation to decreases in milk production and dry matter intake (West et al., 2003). Research has shown that the total number of hours when THI is greater than 72 or 80 over a 4-day interval had the highest correlation with milk yield (Linville and Pardue, 1992). Collectively, these findings indicate that current THI values for lactating dairy cows underestimate the impact of a given thermal load on animal productivity and have an inappropriate time interval associated with cooling management decisions. Avoiding a decline in milk production over a 48-hour period will automatically prevent a decrease in lactation persistency two weeks later. Utilizing the THI in order to reduce milk production losses has been effective; however the current THI is in need of updating on an appropriate time scale with data from higher producing animals. The pattern of stress application is a final component of the THI to be considered. In the research conducted using the current THI system, animals were exposed to given THI conditions continuously; that iswithout daily circadian environmental fluctuations for the entire two week period (Berry et al., 1964). Under natural dairy management conditions temperatures do not remain constant rather they follow a circadian pattern which rises and falls during a normal 24 hour day. It is important to establish responses to THI under conditions normally experienced by lactating dairy cows. In addition, the most appropriate parameters need to be identified. For example, average, minimum, maximum, and hours above a certain THI all need to be examined. Research has reported that minimum THI is more highly correlated with a reduction in feed intake compared to maximum THI (Holter et al., 1996). When evaluating test day milk yields results showed a decrease of 0.2 kg per unit of THI increase above 72 when THI was composed of maximum temperature and minimum humidity (Ravagnolo and Miztal., 2000).

The effects of radiant heat load can be evaluated using the black globe heat index (**BGHI** = $t_{bg} + .36t_{dp} + 41.5$ where t_{bg} = black globe temperature in $^{\circ}$C and t_{dp} = dew point temperaturein $^{\circ}$C), developed by Buffington et al. (1981). Research has demonstrated that BGHI had increased correlations to rectal temperature increases and milk yield decreases compared to THI (Buffington et al., 1981). It has also been shown that the correlation of BGHI to milk yield is greater (r^2 = .36) under conditions of high solar radiation (no shade) than under a shade structure (r^2= .23; Buffington et al., 1981). However, milk production in this study was considered to be low (average of 15 kg/cow). Therefore, correlations of BGHI to milk yield under shade structures might be higher with higher producing dairy cows (which are more sensitive to increased heat loads). It is also apparent that a great deal of variation is not explained by BGHI. This might be improved by determining the impact of an additional factor like skin temperature.

Therefore, THI was reevaluated in controlled environment facilities utilizing high producing dairy cows and including radiant energy impacts on animal performance. Specific objectives were to determine the effects of minimum, maximum, and average THI and the number of hours at a given THI on milk production of high producing dairy cows. The data analyzed in this study was taken from 8 different studies over the course of three years. One hundred multiparous Holstein cows were housed in individual tie stalls in one of two environmentally controlled chambers in the William Parker Agricultural Research Center at the University of Arizona. The University of Arizona's Institute of Animal Care and Use Committee approved all protocols and use of animals in the current study. Temperature humidity Index was calculated using dry bulb temperature ($T_{db,}$ °F) and relative humidity (RH), (T_{db}-(0.55-(0.55*RH/100)*(T_{db}-58);

Buffington et al., 1977). Black globe humidity index was calculated by using black globe temperature (T_{bg}, °C) and RH (Buffington et al., 1981). Milk yields, feed intake, water intake, skin temperature, rectal temperature, respiration rate, and sweating rate were measured in all cows daily.

Although current cooling standards utilize a THI threshhold of 72 before initiation of cooling, our research indicates that physiological parameters and milk yields were affected at THI values well below 72. Between a THI of 64 and 72 there were large reductions in milk yield and we therefore chose to analyze hours above a given THI between 65 and 72 to get a more precise estimate of the threshold and subsequently arrived at a threshold of 68.

Evaluation of data on minimum THI indicates that milk yield losses become significant when minimum THI on any given day is 65 or greater, Table 1. Average losses in milk yield per day were 2.2 kg per day between a minimum THI of 65 and 73. This suggests that cooling of dairy cows should be initiated anytime minimum THI is 65 or above or when daily average THI is 68. We also investigated the time interval required at an average THI of 68 before milk yield losses became significant. This data indicated that milk yield losses became significant after 17 hours of exposure to an average THI of 68 and equated to a 2.2 kg per day loss in milk yield. Thus, our data indicates that dairy cows producing more than 35 kg/day need additional cooling when minimum THI is 65 or greater or when average THI is 68 for more than 17 hours per day.

When researchers analyzed data from on-farm studies they also concluded that milk production began to decline at an average THI of 68. However, based on entire analysis of the data, they still summarized that a THI of ≥ 72 was when adverse effects are seen (Ravagnolo et al., 2000, Freitas et al 2006). Our results indicate that a daily THI equal to 68 results in a milk loss of 2.2 kg/day for each 24 hours. Another study utilizing over a million lactation records of Italian Holstein cows indicated that milk yield losses are detectable above a THI of 68 (Bernabucci et al., 2010, Figure 3.)

These studies are summarized in a new THI chart shown in Figure 2. In addition to identifying the threshold for milk yield losses, the chart matches specific THI values with rectal temperatures and respiration rates found in the studies conducted as well as THI values associated with increased death rates as reported by Bernabucci et al. (2010).

Conclusions

The THI threshold for lactating dairy cows producing more than 35 kg of milk per day is 68. Therefore, cooling methods on commercial dairy farms should be implemented earlier to prevent these effects. Parameters indicative of heat stress were also shown to be correlated with THI and therefore are measurements that can be obtained to evaluate the degree of heat stress in the animal. Further research should be conducted to evaluate the relationship between BGHI and physiological parameters. For example, the addition of solar radiation effects may increase the correlations.

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Table 1. Effect of minimum temperature humidity index (THI) on milk yield in lactating Holstein Cows producing greater than 35 Kg milk per day

Minimum THI	Slope	P-value
49	-1.01	0.26
50	0.55	0.72
51	0.21	0.52
55	-0.28	0.76
63	-0.09	0.86
64	-0.04	0.91
65	-2.63	0.0007
66	-2.04	<0.0001
70	-3.250	0.006
73	-1.08	0.015

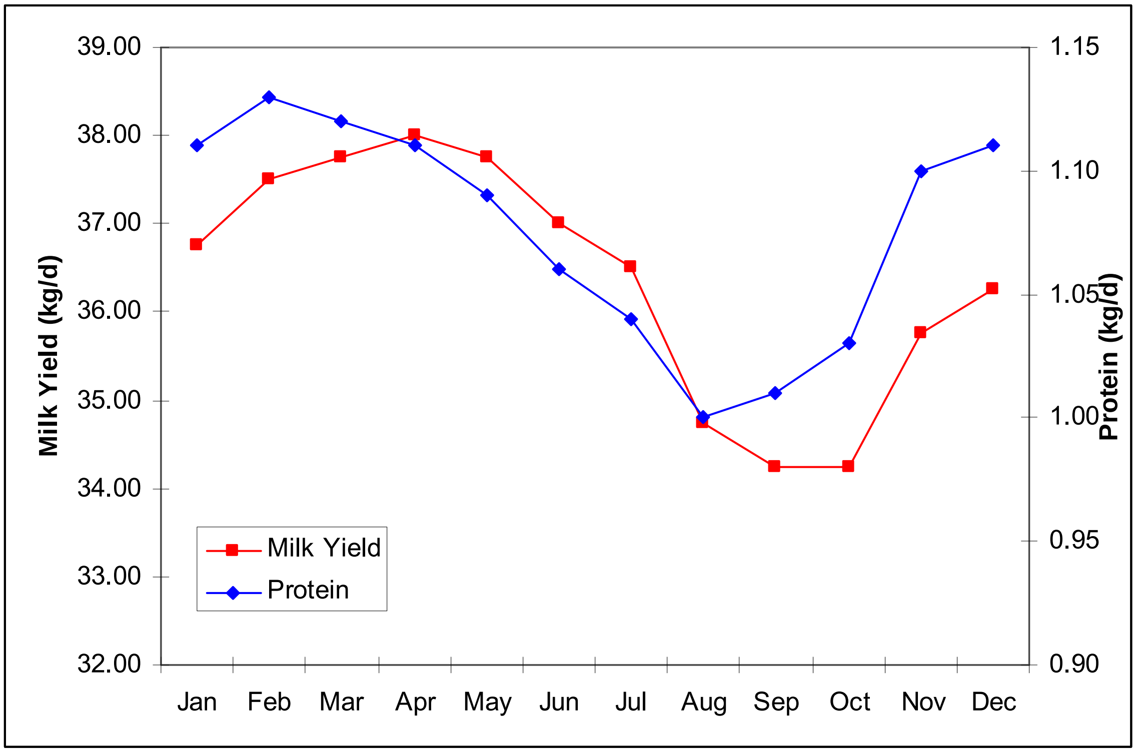

Figure 1 Effect of month of year of calving on milk and protein yield of lactating dairy cows.(Adapted from Barash et al. J. Dairy Sci. 84:2314)

Themperature		% Relative Humidity																				
°F	°C	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
72	22.0	64	65	65	65	66	66	67	67	67	68	68	69	69	69	70	70	70	71	71	72	72
73	23.0	65	65	66	66	66	67	67	68	68	68	69	69	70	70	71	71	71	72	72	73	73
74	23.5	65	66	66	67	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73	74	74
75	24.0	66	66	67	67	68	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75
76	24.5	66	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76
77	25.0	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76	77
78	25.5	67	68	68	69	69	70	70	71	71	72	73	73	74	74	75	75	76	76	77	77	78
79	26.0	67	68	69	69	70	70	71	71	72	73	73	74	74	75	76	76	77	77	78	78	79
80	26.5	68	69	69	70	70	71	72	72	73	73	74	75	75	76	76	77	78	78	79	79	80
81	27.0	68	69	70	70	71	72	72	73	73	74	75	75	76	77	77	78	78	79	80	80	81
82	28.0	69	69	70	71	71	72	73	73	74	75	75	76	77	77	78	79	79	80	81	81	82
83	28.5	69	70	71	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	82	83
84	29.0	70	70	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83	83	84
85	29.5	70	71	72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
86	30.0	71	71	72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84	85	86
87	30.5	71	72	73	73	74	75	76	77	77	78	79	80	81	81	82	83	84	85	85	86	87
88	31.0	72	72	73	74	75	76	76	77	78	79	80	81	81	82	83	84	85	86	86	87	88
89	31.5	72	73	74	75	75	76	77	78	79	80	80	81	82	83	84	85	86	86	87	88	89
90	32.0	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
91	33.0	73	74	75	76	76	77	78	79	80	81	82	83	84	85	86	86	87	88	89	90	91
92	33.5	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90	91	92
93	34.0	74	75	76	77	78	79	80	80	81	82	83	85	85	86	87	88	89	90	91	92	93
94	34.5	74	75	76	77	78	79	80	81	82	83	84	86	86	87	88	89	90	91	92	93	94
95	35.0	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
96	35.5	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94	95	96
97	36.0	76	77	78	79	80	81	82	83	84	85	86	87	88	89	91	92	93	94	95	96	97
98	36.5	76	77	78	80	80	82	83	83	85	86	87	88	89	90	91	92	93	94	95	96	98
99	37.0	76	78	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	95	96	98	99
100	38.0	77	78	79	81	82	83	84	85	86	87	88	90	91	92	93	94	95	96	98	99	100
101	38.5	77	79	80	81	82	83	84	86	87	88	89	90	92	93	94	95	96	98	99	100	101
102	39.0	78	79	80	82	83	84	85	86	87	89	90	91	92	94	95	96	97	98	100	101	102
103	39.5	78	79	81	82	83	84	86	87	88	89	91	92	93	94	96	97	98	99	101	102	103
104	40.0	79	80	81	83	84	85	86	88	89	90	91	93	94	95	96	98	99	100	101	103	104
105	40.5	79	80	82	83	84	86	87	88	89	91	92	93	95	96	97	99	100	101	102	103	105
106	41.0	80	81	82	84	85	87	88	89	90	91	93	94	95	97	98	99	101	102	103	104	106
107	41.5	80	81	83	84	85	87	88	89	91	92	94	95	96	98	99	100	102	103	104	106	107
108	42.0	81	82	83	85	86	88	89	90	92	93	94	96	97	98	100	101	103	104	105	107	108
109	43.0	81	82	84	85	87	89	89	91	92	94	95	96	98	99	101	102	103	105	106	108	109
110	43.5	81	83	84	86	87	89	90	91	93	94	96	97	99	100	101	103	104	106	107	109	110
111	44.0	82	83	85	86	88	90	91	92	94	95	96	98	99	101	102	104	105	107	108	110	111
112	44.5	82	84	85	87	88	90	91	93	94	96	97	99	100	102	103	105	106	108	109	111	112
113	45.0	83	84	86	87	89	91	92	93	95	96	98	99	101	102	104	105	107	108	110	111	113
114	45.5	83	85	86	88	89	92	92	94	96	97	99	100	102	103	105	106	108	109	111	112	114
115	46.0	84	85	87	88	90	92	93	95	96	98	99	101	102	104	106	107	109	110	112	113	115
116	46.5	84	86	87	89	90	93	94	95	97	98	100	102	103	105	106	108	110	111	113	114	116
117	47.0	85	86	88	89	91	93	94	96	98	99	101	102	104	106	107	109	111	112	114	115	117
118	48.0	85	87	88	90	92	94	95	97	98	100	102	103	105	106	108	110	111	113	115	116	118
119	48.5	85	87	89	90	92	94	96	87	99	101	102	104	106	107	109	111	112	114	116	117	119
120	49.0	86	88	89	91	93	95	96	98	100	101	103	105	106	108	110	111	113	115	117	118	120

- **Stress Threshold** Respiration rate exceeds 60 BPM. Milk yield losses begin. Repro losses detectable. Rectal Temperature exceeds 38.5°C (101.3°F)
- **Mild-Moderate Stress** Respiration Rate Exceeds 75 BPM. Rectal Temperature exceeds 39°C (102.2°F)
- **Moderate-Severe Stress** Respiration Rate Exceeds 85 BPM Rectal Temperature exceeds 40 °C (104°F)
- **Severe Stress**. Respiration Rate 120-140 BPM. Rectal Temperature exceeds 41 °C (106°F)

Figure 2. Revised Temperature Humidity Index for Lactating Dairy Cows.

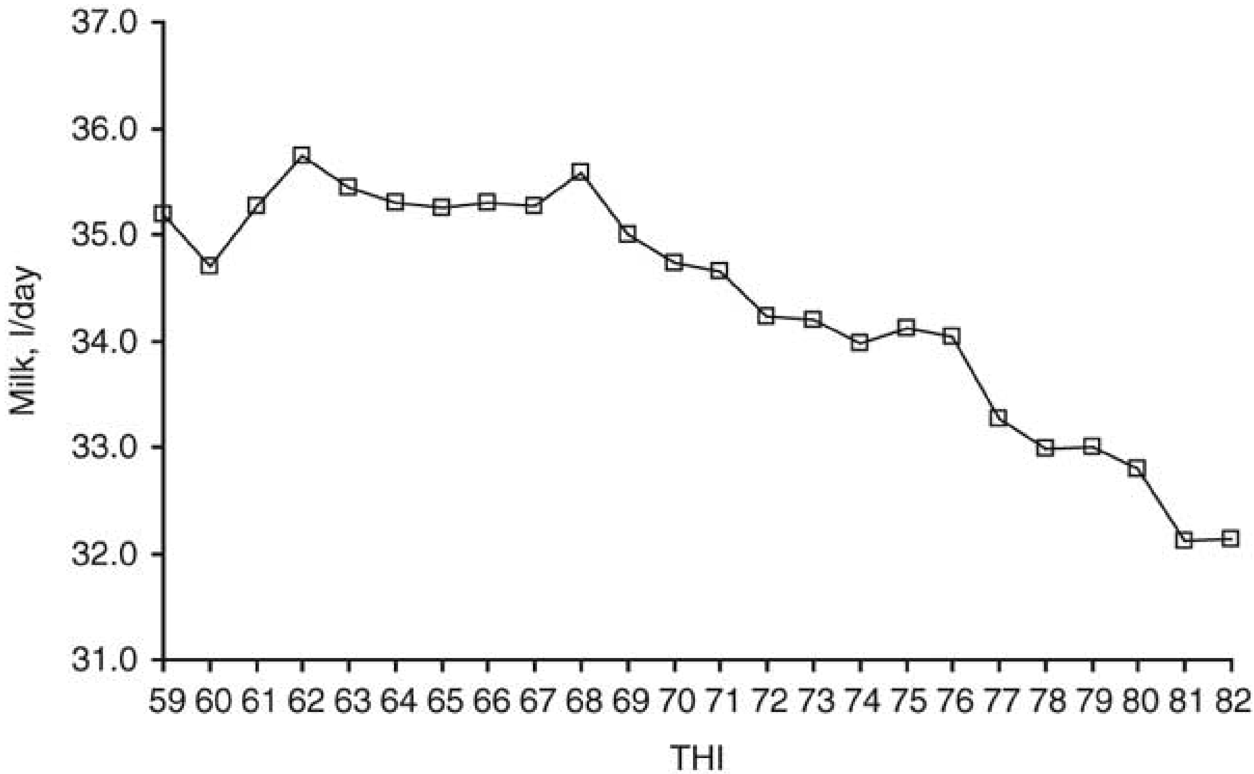

Figure 3. Effect of daily average THI on milk yield by Italian Holstein cows. From Bernabucci et al.(2010).

SESSION NOTES