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Temperature-Humidity Indices as Indicators of Milk Production Losses due to Heat Stress

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ABSTRACT

Meteorological data (1993 to 2004) from 2 public weather stations in Phoenix, Arizona, and Athens, Georgia, were analyzed with test day milk yield data from herds near weather stations to identify the most appropriate temperature-humidity index (THI) to measure losses in milk production due to heat stress in the semiarid climate of Arizona and the humid climate of Georgia. Seven THI with different weightings of dry bulb temperature and humidity were compared. Test-day data were analyzed using 2 models to determine threshold of heat stress and rate of decline of milk production associated with a specific THI. Differences in thresholds of heat stress were found among indices and between regions. Indices with higher weights on humidity were best in the humid climate, whereas indices with larger weights on temperature were the best indicators of heat stress in the semiarid climate. Humidity was the limiting factor of heat stress in humid climates, whereas dry bulb temperature was the limiting factor of heat stress in dry climates.
Key words: temperature-humidity index, heat stress, milk loss

INTRODUCTION

Heat stress is caused by a combination of environmental factors (temperature, relative humidity, solar radiation, air movement, and precipitation). Many indices combining different environmental factors to measure the level of heat stress have been proposed. However, their use is limited by poor availability of data. The majority of studies on heat stress in livestock have focused mainly on temperature and relative humidity (Igono et al., 1985; Igono and Johnson, 1990; Ravagnolo and Misztal, 2000; Bouraoui et al., 2002; St-Pierre et al., 2003; West, 2003; Correa-Calderon et al., 2004) because data on the amount of thermal radiation received by the animal, wind speed, and rainfall are not publicly available. On the other hand, temperature and humidity records can be usually obtained from a meteorological station located nearby.

A temperature-humidity index (**THI**) is a single value representing the combined effects of air temperature and humidity associated with the level of thermal stress. This index has been developed as a weather safety index to monitor and reduce heat-stress-related losses. Different animal species and humans have different sensitivities to ambient temperature and the amount of moisture in the air. Cattle can tolerate much higher temperatures at lower relative humidity than swine. This is due to the fact that cattle can dissipate excessive heat more effectively by sweating, whereas swine do not have sweat glands. However, during hot and humid weather the natural capability of cattle to dissipate heat load by sweating and panting is compromised, and heat stress occurs at these conditions in cattle much faster than in swine (Yousef, 1985).

The water vapor content of the air is important because it has an impact on the rate of evaporative loss through skin and lungs. When the mean daily temperature falls outside of the animal's comfort zone, the amount of moisture in the air becomes a significant element in maintaining homeostasis of the animal. Generally, meteorologists use wet bulb temperature (**T_{wb}**), relative humidity (**RH**), or dew point temperature (**T_{dp}**) to measure water vapor content. The T_{wb} represents the equilibrium temperature of a thermometer covered with a cloth that has been wetted with pure water. Relative humidity provides information about saturation of the air at a given temperature. Dew point temperature is the temperature to which the air must be cooled for saturation to occur; that is, the temperature at which RH is 100% (Jensen et al., 1990).

In humans, the effect of T_{wb} on comfort is almost 6 times as large as that of T_{dp}, whereas in cattle it is only about twice as large. This difference reflects differences in the capacity for evaporation. Humans can dissipate about 190% of their metabolic heat production by evapo-

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ration, whereas cattle can dissipate only 105% of their metabolic heat production (Bianca, 1962).

Because of the differences in sensitivity to ambient temperature and amount of moisture in the air among species, a range of equations for calculation of THI with different weightings of dry bulb temperature (**T_{db}**) and air moisture have been proposed. Some indices integrate air moisture in the index by T_{wb} (Thom, 1959; Bianca, 1962; National Research Council, 1971); others use T_{dp} (National Research Council, 1971; Yousef, 1985) or RH (National Research Council, 1971). However, none of the indices has been designed specifically for Holstein cows milking in field conditions.

The impact of heat stress on production of cows is alleviated in many dairies by some kind of heat abatement system such as shades, fans, fog misters, and sprinklers. These systems differ in efficacy of cooling and thus create variation in thermal conditions to which cows are exposed (Ryan et al., 1992). Thermal relief provided by those devices differs significantly between climatic regions. Climatic conditions in the Southeast United States are characterized by high air temperature associated with high humidity. These hot and humid conditions significantly compromise evaporative heat loss. Because of this phenomenon, evaporative cooling of cows is more successful in dry climates than in humid climates.

Wet bulb depression (**WBD**) is the difference between the dry bulb and wet bulb temperatures (Jensen et al., 1990). It indicates the maximum decrease of air temperature by evaporation. This is useful for prediction of decline of temperature due to evaporative cooling. Assuming efficiency of the evaporative cooling system (eff, in decimals) is known, the temperature of the cooled air (**T_{cool}**) can be calculated by the following equation (Bucklin et al., 2004):

$$T_{cool} = T_{db} - \text{eff} \times (T_{db} - T_{wb}).$$

A 70% efficient evaporative cooling system at T_{dp} = 28°C and T_{wb} = 22°C can cool the air to T_{cool} = 28 − 0.7 × (28 − 22) = 23.8°C. At the same environmental conditions, but with a 60% and 80% efficient evaporative cooling system, the temperature will be reduced to 24.4 and 23.2°C, respectively. At saturation, the T_{wb}, T_{db}, and T_{dp} are all equal. Otherwise the T_{dp} is less than the T_{wb}, which is less than the T_{db}.

The objective of this study was to identify among 7 temperature humidity indices the most suitable THI for assessing losses of milk production in US Holstein cows exposed to heat stress in the hot or semiarid climate of Arizona or the hot and humid climate of Georgia.

MATERIALS AND METHODS

Meteorological data were obtained from the Southern Regional Climate Center (Baton Rouge, LA) and consisted of hourly T_{db} and RH recorded between 1993 and 2004. Records from 2 weather stations were extracted. The weather station in Phoenix was selected as a representative of the semiarid climate of the southwest United States, and the weather station in Athens represented the hot and humid climate of the southeast United States.

Following is a list of temperature humidity indices compared in this study. All T-values are in degrees Celsius, and RH is a percentage.

$$THI1 = (0.15 \times T_{db} + 0.85 \times T_{wb}) \times 1.8 + 32$$
(Bianca, 1962),

$$THI2 = (0.35 \times T_{db} + 0.65 \times T_{wb}) \times 1.8 + 32$$
(Bianca, 1962),

$$THI3 = [0.4 \times (T_{db} + T_{wb})] \times 1.8 + 32 + 15$$
(Thom, 1959),

$$THI4 = (0.55 \times T_{db} + 0.2 \times T_{dp}) \times 1.8 + 32 + 17.5$$
(National Research Council, 1971),

$$THI5 = (1.8 \times T_{db} + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times T_{db} - 26) = 0.81 \times T_{db} + 0.143 \times RH) + 0.0099 \times RH \times T_{db} + 46.3$$
(National Research Council, 1971),

$$THI6 = (T_{db} + T_{wb}) \times 0.72 + 40.6$$
(National Research Council, 1971), and

$$THI7 = T_{db} + 0.36 \times T_{dp}) + 41.2$$
(Yousef, 1985).

The index THI1 is used to monitor discomfort from temperature and humidity in humans. The THI2 and THI7 have been empirically determined in cattle exposed to heat stress conditions in climatic chambers. How these indices from controlled environments relate to field conditions with diurnal fluctuation of environmental variables remains unanswered. The index THI3 is used to monitor the degree of discomfort in humans. The THI5 represents the Oklahoma Mesonet Cattle Heat Stress Index, designed to indicate level of heat stress of outdoor cattle. This index has been used in studies on heat stress by researchers from the University of Georgia (Holter et al., 1996; Ravagnolo et al.,

Table 1. Descriptive statistics of performance data (1993–2004) from herds near Athens, Georgia, and Phoenix, Arizona

	Athens				Phoenix			
Item	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
Number of records	110,480	—	—	—	683,876	—	—	—
Number of cows	12,473	—	—	—	81,889	—	—	—
Number of herds	61	—	—	—	53	—	—	—
Number of test days per cow	9	2	1	13	8	2	1	17
DIM	174	97	5	365	166	93	5	365
Milk, kg	28	7	2	59	30	7	2	79
Distance between herd and weather station, km	32	9	2	51	23	14	10	70

2000; Ravagnolo and Misztal, 2000, 2002a,b; West, 2003); and THI6 has been developed by the United States Weather Bureau to describe discomfort in humans.

Milk Yield Data

First-parity milk yield test-day records from 58 herds near Athens, Georgia, and 61 herds near Phoenix, Arizona, were used (Table 1). Only herds not farther than 70 km from the respective closest weather station were included. Data from Athens consisted of 110,333 test-day records of 12,473 cows with average milk production of 28 kg and DIM of 174 d. Data from Arizona contained 683,055 test-day records on 81,889 cows with average milk production of 30 kg and DIM of 166 d. More detailed statistical description of both data sets is given in Bohmanova (2006). Management data on presence and efficacy of heat abatement systems used in the selected herds were not available.

Statistical Models

Two linear models were fitted using program BLUPF90 (Misztal, 1999), to compare the ability of different THI to detect losses of milk production due to excessive temperature and relative humidity. First, test-day milk yield records were analyzed by a model that treated THI as a categorical variable (each degree of THI was defined as a different class) to identify the shape of the response of milk production to heat stress. The model was as follows:

$$y_{ijklmrs} = hys_i + freq_j + age_k + dim_l + thi_m + anim_r + pe_s + e_{ijklmrs},$$

where hys_i is ith herd × year season class (seasons defined from December to February, March to May, June to August, September to November), $freq_j$ is jth frequency of milking (j = 1,2), age_k is the kth age at calving class (k = 1 to 8), dim_l is the lth DIM class (l = 1 to 37), thi_m is the mth THI class, $anim_r$ is the additive genetic effect of animal r, pe_s is the permanent environmental effect of animal s, and $e_{ijklmrs}$ is the residual.

The variance covariance structure was

$$\mathrm{var}\begin{bmatrix} a \\ p \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & 0 & 0 \\ 0 & I_s\sigma_p^2 & 0 \\ 0 & 0 & I_r\sigma_e^2 \end{bmatrix},$$

where A (r × r) is an additive relationship matrix and I_s is an identity matrix of size s × s for the permanent environmental effect, I_u is an identity matrix of size u × u for the residual (u is the number of test-day records) and $\sigma_a^2 = 5.44$, $\sigma_p^2 = 9.46$, and $\sigma_e^2 = 15.74$.

The second fitted model accounted for heat stress by a linear regression on degrees of heat stress (t) as follows:

$$y_{ijklmrs} = hys_i + freq_j + age_k + dim_l + \alpha \times t + anim_r + pe_s + e_{ijklmrs},$$

where t was defined as

$$t = \begin{cases} 0 & THI \leq threshold \text{ (no heat stress)} \\ THI\text{-}threshold & THI > threshold \text{ (heat stress)} \end{cases},$$

and α represented a slope of decline of milk production per degree of THI above threshold. Different thresholds, ranging from THI 64 to 86, were tested in the model, and the one that provided the highest R^2 was selected.

The abilities of indices to detect heat stress were compared by their estimated sum of yearly milk yield losses (Δy) of milk production. Because the aim was to recognize index that identifies the most heat stress, it was assumed that the index with the largest losses in milk yield over a year was the best. The sum of yearly milk yield losses for nth THI and herds surrounding the oth weather station (Athens or Phoenix) was defined as

$$\Delta y_{no} = \alpha_{no}\sum_{p=1}^{365} t_{pn},$$

Table 2. Descriptive statistics of weather data from Athens, Georgia, and Phoenix, Arizona

	Athens				Phoenix			
Daily minimum	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum
RH[1] (%)	50	17	16	96	19	8	5	48
T_{db}[2] (°C)	12	7	–4	23	18	8	3	33
T_{wb}[3] (°C)	11	7	–6	23	12	6	1	23
T_{dp}[4] (°C)	9	9	–12	22	1	7	–14	18
THI1[5]	52	13	22	73	55	11	33	76
THI2	52	13	23	74	57	12	34	79
THI3	63	11	40	80	68	10	50	87
THI4	65	10	42	81	69	10	50	88
THI5	54	12	28	74	61	10	39	80
THI6	57	11	33	74	62	10	43	80
THI7	57	10	34	73	61	10	42	80
Daily average								
RH (%)	72	13	39	99	32	13	11	74
T_{db} (°C)	17	7	1	29	24	8	9	38
T_{wb} (°C)	14	7	–1	24	15	5	4	24
T_{dp} (°C)	11	8	–8	23	4	7	–9	20
THI1	58	12	31	76	61	10	42	79
THI2	59	12	31	78	64	11	43	83
THI3	69	10	47	85	75	10	56	91
THI4	70	10	48	86	74	10	56	92
THI5	61	11	36	79	67	9	50	83
THI6	63	10	40	78	68	9	50	85
THI7	62	10	40	78	66	10	48	84
Daily maximum								
RH (%)	93	8	60	100	50	18	19	100
T_{db} (°C)	23	7	6	36	30	8	13	45
T_{wb} (°C)	17	6	3	27	18	5	8	27
T_{dp} (°C)	14	7	–6	26	8	6	–6	23
THI1	64	11	38	81	68	10	47	86
THI2	66	11	39	85	72	11	49	92
THI3	76	9	53	91	82	9	62	99
THI4	77	9	54	93	81	10	61	98
THI5	69	10	45	85	73	8	57	88
THI6	69	9	47	85	75	9	56	93
THI7	69	10	45	85	73	10	53	90

[1]Relative humidity.
[2]Dry bulb temperature.
[3]Wet bulb temperature.
[4]Dew point temperature.
[5]THI = temperature-humidity index.

where α_{no} is the rate of decline in milk production identified by the nth THI in the oth weather station, and $\sum_{p=1}^{365} t_{pn}$ is the sum of degrees of heat stress per year for the nth THI and oth weather station.

RESULTS AND DISCUSSION

Temperature humidity index is usually classified into classes that indicate level of heat stress. However, definitions of those levels vary between indices and authors. For instance, Armstrong (1994) identified index below 71 as comfort zone, values ranging from 72 to 79 as mild stress, 80 to 89 moderate stress, and values above 90 as severe stress. Huhnke et al. (2001) divided THI7 into 2 categories: $79 \le$ THI7 ≤ 83 dangerous situation, and THI7 ≥ 84 emergency situation. Thom (1959) categorized THI as $70 \le$ THI3 ≤ 74 uncomfortable, $75 \le$ THI3 ≤ 79 very uncomfortable, and THI3 ≥ 80 serious discomfort.

The ratio of T_{wb} to T_{db} can provide a useful perspective on weighting placed on humidity and ambient temperature (Bianca, 1962). The highest ratio of T_{wb} to T_{db} was for THI1 and THI2, and it was 5.7 and 1.9, respectively. The ratio of 1 was for THI3 and THI6. For THI4, THI5, and THI7, the ratio between T_{wb} and T_{db} was determined numerically and is 1.2, 0.3, and 1.2, respectively.

Climatic Profile of Phoenix, Arizona

Climatic conditions in Phoenix can be characterized as dry and hot, with average temperature of 24°C (75.2°F) and relative humidity of 32% (Table 2). As shown in Figure 1, the average January RH of 47% is

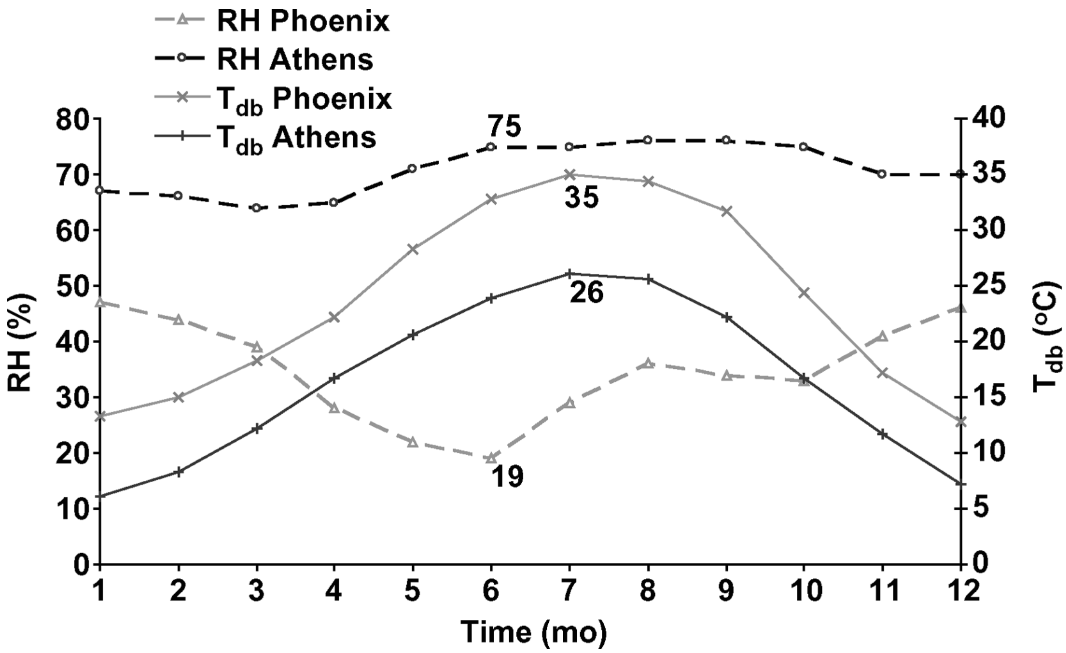

Figure 1. Average monthly pattern of dry bulb temperature (T_{db}) and relative humidity (RH) in Athens, Georgia, and Phoenix, Arizona.

the highest among all months. From March to June, average daily RH declines from 39 to 19%. Mean T_{db} gradually increases from January to July, crosses a borderline of 30°C (86°F) in May, and reaches 35°C (95°F) in July. Heat stress in Arizona is observed during the months of July and August (Igono et al., 1992). During May and June, cows are exposed to hot air, but because the air is dry (RH is between 22 and 28%) cows can be evaporatively cooled and thus are less affected by heat stress. The local monsoon season, occurring from June to September, is associated with a rise in RH. Because of the higher RH in these months, the ability to cool cows by heat abatement devices is compromised.

Figure 2 has the monthly patterns of wet bulb depression (WBD = $T_{db} - T_{wb}$) for both locations. As mentioned earlier, WBD indicates the potential for lowering T_{db} by evaporative cooling. In Phoenix, WBD differs among months. The highest WBD occurs in June, when RH is low and when air has high capacity for evaporation of water. The lowest values are observed from December to March, but evaporative cooling is not used during these months.

Climatic Profile of Athens, Georgia

The climate in Athens is warm and humid with average temperature of 17°C (62.6°F) and RH of 72% (Table 2). Monthly mean temperatures are lowest in January (6°C ≈ 42.8°F) and peak in July and August (26°C ≈ 78.8°F). Relative humidity stays >70% for 67% of all days of the year. Summer months (June, July, August, September) are characterized by hot weather with high humidity of 75% (Figure 1). As shown in Figure 2, WBD is very low (around 3°C ≈ 37.4°F) in these months. Because of the high humidity, evaporative cooling doesn't provide any significant relief to the heat stressed cows, and consequently a decline in milk production is observed. In general, efficacy of evaporative cooling systems in Georgia is low because of high humidity, which is present the whole year. In contrast, Phoenix in summer is much warmer, but because the air is dry it can be cooled by up to 13°C.

Wet bulb and dew point temperatures were derived from RH and T_{db}. Detailed formulas are provided in Bohmanova (2006). Temperature and amount of moisture in the air (RH, T_{wb}, or T_{dp}) were integrated into 7 temperature-humidity indices (THI1 to THI7). Figures 3 and 4 illustrate yearly patterns of THI1 to THI7 in Phoenix and Athens, respectively. All indices follow a similar trend, with minima in January and December and maxima in June; however, they differ in scale. The largest differences between indices are observed in summer months.

Seasonal Differences in Milk Yield

Seasonal differences in milk production are caused by periodic changes of environment over the year, which has 1) a direct effect on animal's milk production

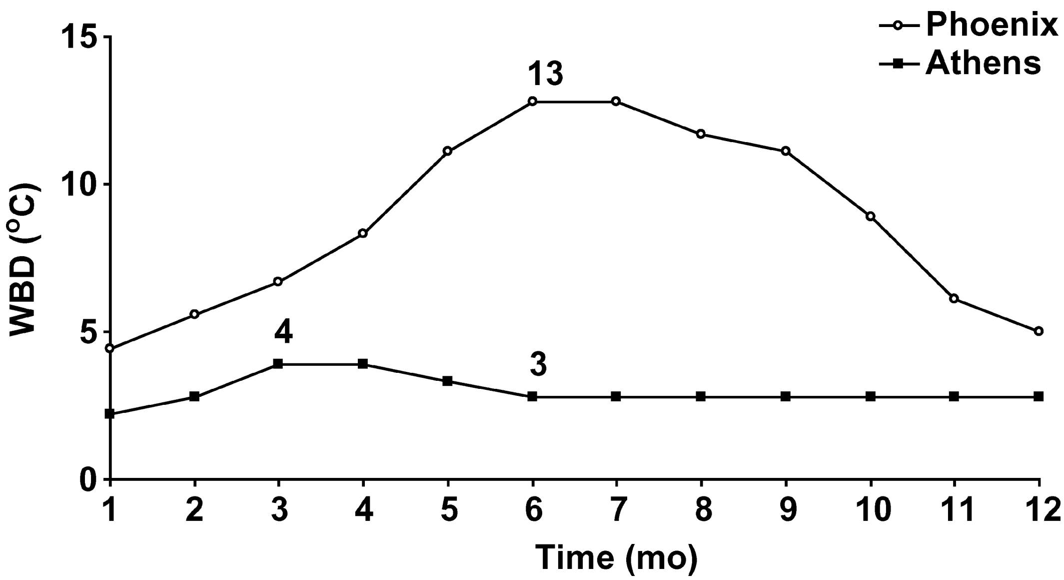

Figure 2. Average monthly pattern of wet bulb depression (WBD) in Athens, Georgia, and Phoeniz, Arizona.

through decreased DMI and 2) an indirect effect through fluctuation in quantity and quality of feed.

March, April, and May are months of maximal milk production in Phoenix (Figure 5). Considering THI5 as an indicator of heat stress and assuming heat stress is induced at THI5 ≥ 72, decline of milk production due to heat stress should be detected already in May (Figure 6). Evaporative coolers are usually set to turn on when $T_{db} \geq 30°C$ (86°F), which usually occurs in late April to early May in Phoenix (Igono et al., 1992). Considering this fact and assuming that an evaporative cooling system with efficiency of 60% is used, THI5 in May is reduced to 67, which is below the threshold of heat stress. This may explain the absence of decline of milk

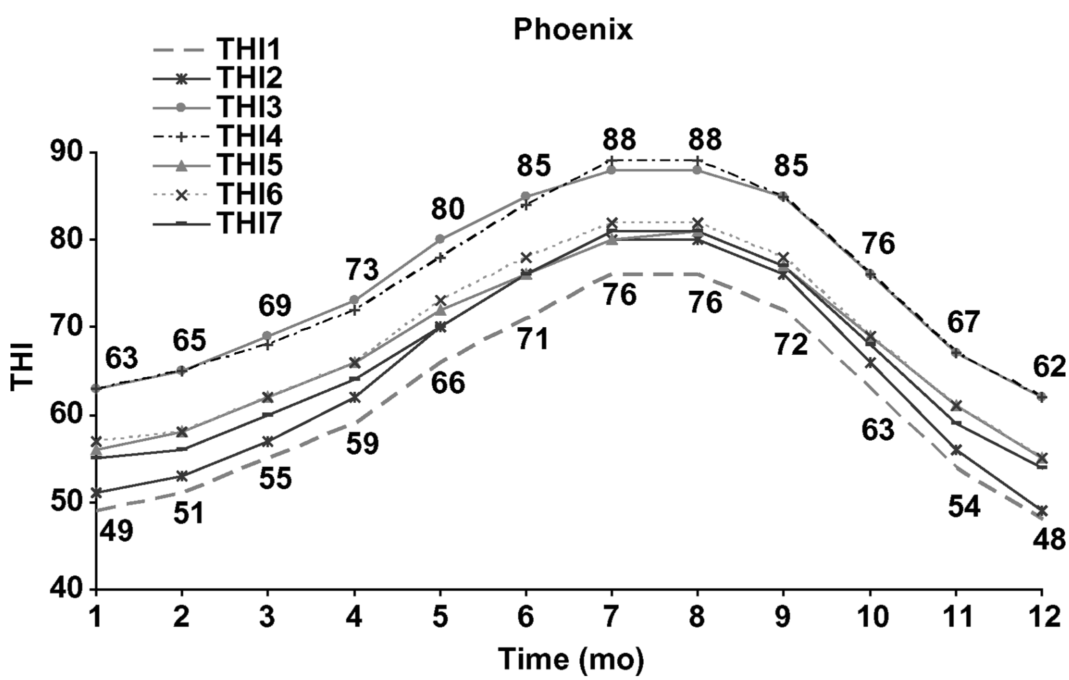

Figure 3. Average monthly pattern of temperature-humidity index (THI) 1 to THI7 in Phoenix, Arizona.

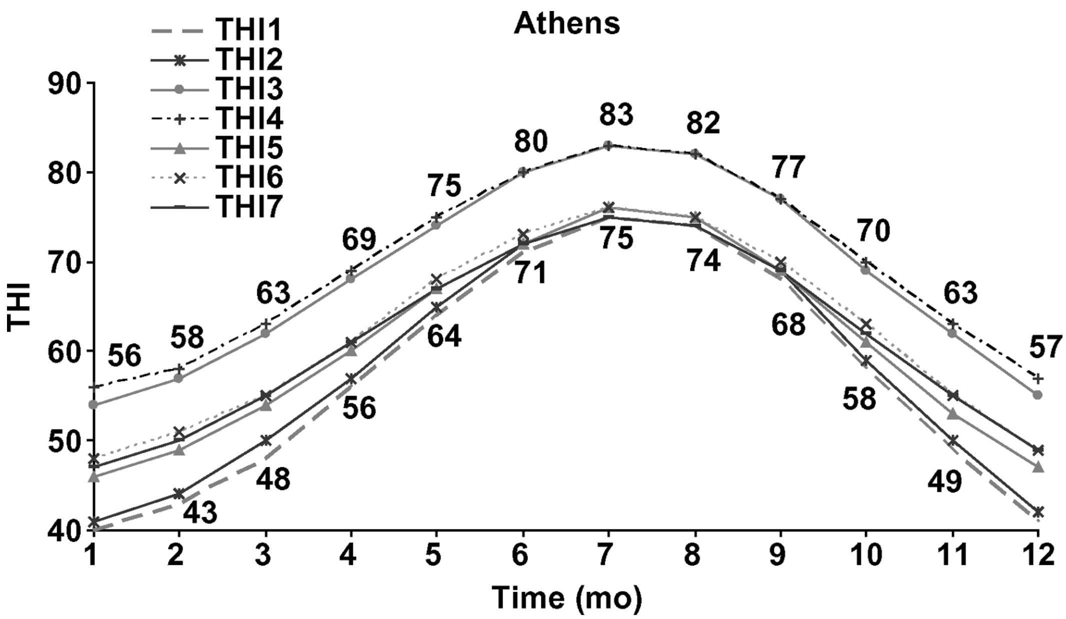

Figure 4. Average monthly pattern of temperature-humidity index (THI) 1 to THI7 in Athens, Georgia.

production in April. However, from June to August, THI climbs from 76 to 81. In these months, even with use of evaporative cooling, THI5 cannot drop below 72 (Figure 6). This may explain the sharp decline of milk production from June to August. Milk production begins to recover from heat stress in October when THI5 is <72.

In Athens, milk production is at its maximum in April and starts to decline in May. However, in May THI5 is 67, and therefore no loss of milk production is expected. This decline could be explained by effects other than heat stress or by the fact that THI5 is not a good indicator of heat stress in this humid region. Milk production in June, July, and August is significantly compromised by heat stress. Despite that THI5 is much higher in June and July in Phoenix than in Athens, when the effect of cooling is considered, THI5 declines to the same degree. As mentioned earlier, WBD and therefore possible decline of temperature with evaporative cooling are low in Athens due to high humidity. In September, environmental conditions in Phoenix are worse than in Athens, even with use of cooling. This is in agreement

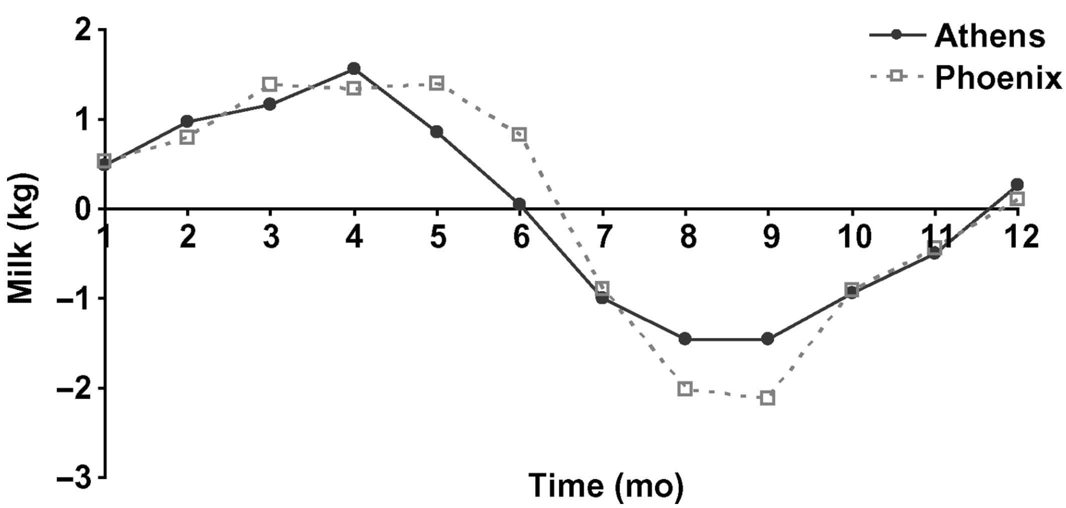

Figure 5. Seasonal differences in milk production in herds near Athens, Georgia, and Phoenix, Arizona.

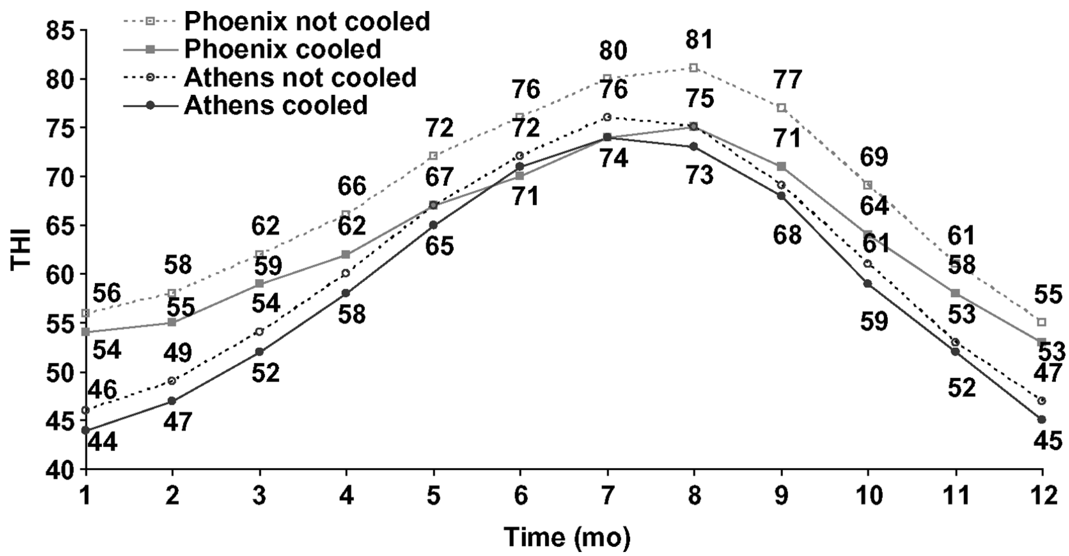

Figure 6. Temperature-humidity index (THI5) with (cooled) and without (not cooled) accounting for use of evaporative cooling.

with Figure 5, showing much steeper decline of milk production in Phoenix than in Athens. It indicates that the level of heat stress is much higher in Phoenix than in Athens.

Mayer et al. (1999) reported relationships between THI and milk production losses as being linear, broken-stick, or exponential. Igono et al. (1992) found a linear and curvilinear relationship between THI and milk on farms with and without cooling, respectively. Ravagnolo et al. (2000) described decline of milk production due to heat stress by a broken-stick function.

Results of the first model found that the response to heat stress in milk production followed a broken-stick function (Figure 7). This means that milk yield stayed constant until a certain point (threshold) and then linearly declined with increasing degree of THI. This pattern was observed for all indices.

As shown in Table 3, the second model revealed large differences in thresholds of heat stress among indices and between regions, ranging from 68 for THI1 in Athens to 83 for THI4 in Phoenix. The indices THI1 and THI2 had the lowest and THI3 and THI4 the highest

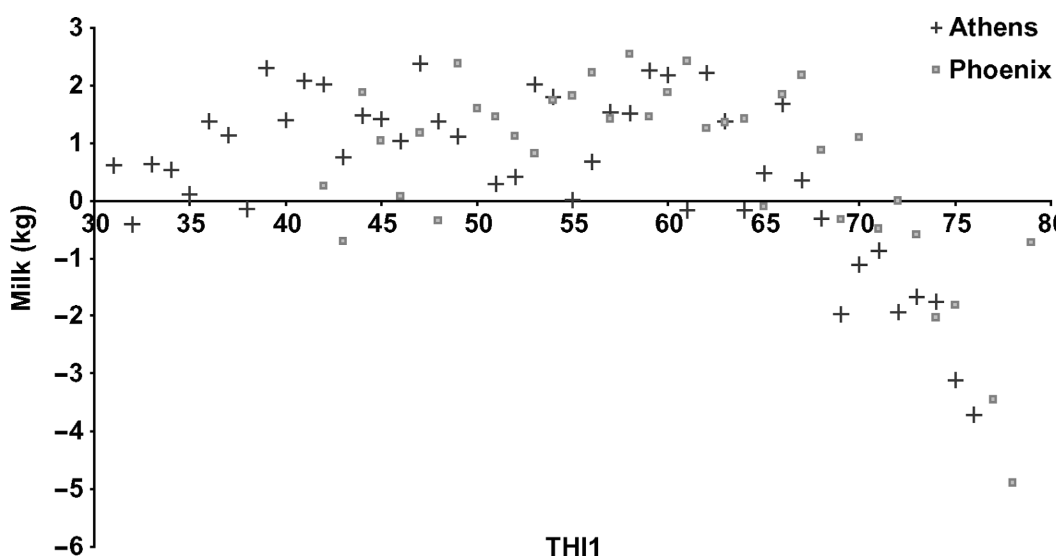

Figure 7. Least squares estimates of decline of milk production with THI1 in Athens, Georgia, and Phoenix, Arizona.

Table 3. Threshold of heat stress and rate of decline (α) of milk production (in kg) due to heat stress for 7 temperature-humidity indices (THI)

	Athens		Phoenix	
	Threshold	α (kg)	Threshold	α (kg)
THI1	68	–0.29	73	–0.57
THI2	69	–0.27	74	–0.26
THI3	78	–0.37	83	–0.28
THI4	79	–0.37	82	–0.27
THI5	72	–0.39	74	–0.30
THI6	72	–0.39	75	–0.22
THI7	71	–0.37	74	–0.27

threshold from all indices in both regions. Thresholds in Athens were on average 3 degrees lower than in Phoenix. This is probably due to more efficient use of cooling devices in Phoenix.

Indices differed in rate of decline (α) of milk production per degree of THI, ranging from –0.40 (THI5) to –0.27 (THI2) in Athens and from –0.59 (THI1) to –0.23 (THI6) in Phoenix. However, because of different scaling (one degree increase in THI doesn't represent the same increase in T_{db} and RH in all indices) and thresholds, direct comparison of indices using α was not possible. Table 4 has losses in milk production per year ($\boldsymbol{\Delta}\mathbf{y}$) detected by THI1 to THI7 in Athens and Phoenix. In Athens, the largest declines of 127 and 125 kg have been identified by THI2 and THI1, respectively. Those indices are characterized by high T_{wb} to T_{db} ratio. In contrast, the lowest decline in Athens (101 kg) has been detected by THI5, an index with the lowest T_{wb} to T_{db} ratio. On the other hand, THI5 was the best index for detection of heat stress in Phoenix, with Δy of 168 kg. The worst indicator of heat stress was THI1 with Δy of 124 kg. This implies that different indices should be used in humid and in semiarid climates. Indices with higher weightings of humidity are more appropriate for humid climates, and indices with the most emphasis on ambient temperature are more suitable for semiarid climates.

Disintegration of estimated THI thresholds of heat stress into corresponding T_{db} and RH revealed that heat stress occurred in Athens at temperatures ≥23°C and RH of 75% and in Phoenix at ≥30°C and RH of 25%. Assuming that cows in both regions have on average similar heat tolerance, the fact that decline of milk production due to heat stress occurs in Phoenix at much higher temperature suggests that the causes of heat stress differ between environments. In hot, humid environments evaporative cooling is compromised, and performance is adversely affected at temperatures lower than cows can accommodate comfortably in other parts of the country. In a semiarid climate, cows can be exposed to higher absolute temperatures before they show similar decreases in comfort and productivity. Evaporative cooling is effective as a heat-abatement tool for much of the year in the southwest, but is much less so in the southeast, where temperatures are lower but humidity is much higher (Figure 6).

Considering that the average milk production per cow per lactation increased by 3,500 kg during the last 20 yr (Shook, 2006) and that all available THI have been designed more than 20 yr ago, it may be necessary to develop new indices that will be more suitable for the current cow and environment.

CONCLUSIONS

Temperature-humidity indices differ in their ability to detect heat stress. Indices with larger weights on humidity seem to be more suitable for humid climates. On the other hand, in climates where humidity does not reach levels that could compromise evaporative cooling, indices with the most emphasis on ambient temperature are preferable.

ACKNOWLEDGMENT

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Table 4. Ratio of wet bulb and dry bulb temperature (T_{wb}:T_{db}) in temperature-humidity index (THI) 1 to THI7, percentage of variability explained by each model (R^2), sum of degrees of heat stress per year (Σt) and yearly losses (Δy) in milk production due to heat stress detected by THI1 to THI7 in Athens, Georgia, and Phoenix, Arizona

		Athens			Phoenix		
Item	T_{wb}:T_{db}	R^2 (%)	Σt	Δy (kg)	R^2 (%)	Σt	Δy (kg)
THI1	5.7	73.61	436	–126	64.82	211	–124
THI2	1.9	73.61	471	–127	64.80	536	–142
THI3	1.0	73.56	302	–113	64.72	447	–131
THI4	1.2	73.53	291	–108	64.99	580	–163
THI5	0.3	73.51	255	–100	64.99	542	–168
THI6	1.0	73.51	264	–104	64.76	634	–147
THI7	1.2	73.51	285	–105	64.99	585	–162

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