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WIND SPEED AND SOLAR RADIATION CORRECTIONS FOR THE TEMPERATURE-HUMIDITY INDEX

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1. ABSTRACT

Wind speed (WSPD) and solar radiation (RAD) are known factors contributing to the degree of heat stress cattle are subjected to. However, the most commonly used indicator of heat stress for cattle (Livestock Weather Safety Index) uses only the temperature-humidity index (THI) and does not account for WSPD or RAD. Accurate adjustment to the THI equation based on WSPD and RAD are essential in determining level of heat stress. Therefore, visual assessments of heat stress based on panting scores (0 = no panting, 4 = severe panting) were collected at 1700 h during three summer studies. The 1700 h time was selected, since it is typically near or at the hottest portion of the day and was shown to be the time cattle displayed the greatest level of heat stress. These data were combined into one data set and included 5520 observations. A weather station, located in the facility where cattle were confined, recorded THI and WSPD (m/s). Solar radiation (W/m^2) was recorded .7 km west and 1.7 km north of the facility. Temperature-humidity index averaged 79.7 ± 5.2 (range 63.9 to 86.2) at the time panting scores were assigned. A regression equation (RE) was developed using hourly values for THI, WSPD, and RAD to predict panting score (panting score = -6.317 + (0.097 * THI) – (0.233 * WSPD) + (0.0026 * RAD)) at 1700 h. The ratio of WSPD to THI and RAD to THI(-2.400 and 0.027 for WSPD and RAD, respectively) represent the adjustments to the THI for WSPD and RAD. For instance, for each 1 m/s (2.24 mph) increase in WSPD THI is reduced 2.4 units, and for each 100 W/m^2 decrease in RAD THI is reduced 2.7 units. These corrections would be most appropriate to use, within a day, to predict THI during the day using hourly data or current conditions. As real-time conditions change immediate adjustments in THI can be made using these corrections. To predict THI for a future weather event or day then daily averages could and may be more appropriate to use, whereby adjustments to THI would be based on projected average daily conditions. Adjustments in THI based on daily averages were for each 1 m/s increase in WSPD, THI would be reduced 3.14 units, and for each 100 W/m^2 decrease in RAD, THI would be reduced 1.49 units. Although, knowledge of THI alone is beneficial in determining the potential for heat stress, accurate adjustments for WSPD and RAD are essential to more accurately represent and predict the degree of animal comfort.

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2. INTRODUCTION

Feedlot cattle finished in the summer months are often affected by periods of adverse climatic conditions (Hahn and Mader, 1997; Mader et al., 1999b; Hahn et al., 2001). These conditions consisting of elevated ambient temperature, relative humidity, and high solar radiation coupled with low wind speed can produce an increased heat load on the animal resulting in reduced performance, decreased animal comfort , and(or) death (Mader et al., 1997a; Mader et al., 1999a; Hubbard et al., 1999). The ability of feedlot managers and consultants to assess climatic effects on cattle is of utmost importance, not only to ensure that the animal's welfare is maintained, but also to ensure animal performance and profitability (Mader, 1986; NRC, 1987; Mader 1996). Performance is largely dependent by daily dry matter intake. Dry matter intake is often driven by internal factors. One principle factor driving intake is body temperature (Hahn, 1995; Frank et al., 2001). Also, core body temperature is the best indicator of an animal's susceptibility to heat stress, however, devices used to monitor core body temperature are not feasible for large numbers of animals in commercial settings. A viable alternative would be to monitor degree of panting and/or respiration rate (Silanikove, 2000; Gaughan et al. 2000).

The Livestock Weather Safety Index (LWSI; LCI,1970) is commonly used as a benchmark to determine the susceptibility of cattle to heat stress, by assigning potentially heat stressed animals into normal, alert, danger and emergency categories. The LWSI quantitates environmental conditions using a combination of temperature(Ta) and percent relative humidity (RH) and is based on the temperature-humidity index (Thom, 1959; NOAA, 1976). The THI = .8*Ta + ((RH/100)*(Ta - 14.3)) + 46.4. Although THI has been effectively used as a heat stress indicator, correction for wind speed and solar radiation would be useful. Solar radiation can greatly influence heat load, while changes in wind speed result in altered convective cooling. Both solar radiation and wind speed alter the ability of the animal to maintain thermal balance. Therefore, the objectives of this study were to identify environmental variables that correspond to a visual assessment of heat stress (i.e. panting). Accounting for these two environmental variables in the temperature-humidity index would enhance the applicability of the LWSI under varying environmental conditions.

3. PROCEDURE

Three hundred sixty feedlot steers were used as the database for this analysis. These steers originated from three studies previously reported by Davis et al. (2001a and b) and Davis and Mader (2002) involving management strategies designed to reduce the effect of heat stress on summertime feedlot performance of cattle. Experiments 1 (84 head) and 2 (96 head) were conducted from June 23, 1999 to September 13, 1999 (82 days), while Exp. 3 (192 head) was conducted from June 8, 2000 to August 30, 2000 (83 days). Panting scores were assigned to individual animals at 1700 hour by visual observation using the scoring system presented in Table 1. These observations were made on days 9 to 15, 20 to 22, 29 to 31 of Exp. 1 and 2, and additionally on days 36 to 37 of Exp. 1 and days 54 to 55, and 68 to 69 of Exp. 2. During Exp. 3, observations were made on days 18 to 19, 29 to 33, 40 to 41, 54 to 55, 58, 61 to 62, and 78 to 79. The combination of these observation times resulted in a total of 5,520 individual panting score assessments.

Table 1. Panting scores assigned to steers.

Score	Description
0	Normal respiration, ~60 or less breaths/min (bpm)
1	Slightly elevated respiration, ~ 60 - 90 bpm
2	Moderate panting and/or presence of drool or small amount of saliva, ~ 90 - 120 bpm
3	Heavy open-mouthed panting; saliva usually present ~ 120 - 150 bpm
4	Severe open-mouthed panting accompanied by protruding tongue and excessive salivation

Weather variables and pattern used for this analysis are shown in Table 2. All variables (except solar radiation) were collected continuously and compiled hourly using a weather station located in the center of the feedlot facility. Solar radiation was obtained from the High Plains Climate Center automated weather station located .7 km west and 1.7 km north of the feedlot facilities. A regression equation was developed to determine the relationship between panting score and weather variables at the time of panting score assignment. To develop correction factors for THI based on wind speed (WSPD) and radiation (RAD), mean climatological data were used to predict a panting score. The ratio of WSPD and RAD parameter estimates to the THI parameter estimate were used to determine correction factors.

Table 2. Mean, maximum and minimum values for temperature (Ta), relative humidity (RH), temperature-humidity index (THI), wind speed and solar radiation daily averages and at 1700 hours on the days panting scores were assigned.

Item	Mean ± SE	Max	Min
1700			
Temperature, °C	30.3 ± 4.0	36.5	18.4
Relative humidity, %	58.3 ± 12.4	92.0	37.5
Wind speed, m/s	3.7 ± 1.5	7.2	1.1
Radiation, W/m^2	347.3 ± 110.7	493.6	15.1
THI[a]	79.7 ± 5.2	86.2	63.9
Daily average			
Temperature, °C	25.4 ± 3.2	29.3	15.8
Relative humidity, %	75.3 ± 6.4	91.8	62.2
Wind speed, m/s	3.2 ± 1.5	6.3	1.4
Radiation, W/m^2	226.2 ± 50.8	311.0	48.8
THI[a]	72.8 ± 5.1	80.2	59.7

[a]Temperature-humidity index = .8*Ta + ((RH/100)*(Ta-14.3)) + 46.4.

4. RESULTS

Mean, maximum, and minimum values for THI, wind speed, and solar radiation for the days that panting scores were assigned are presented in Table 2. Temperature during panting score assessment averaged 30.3 ± 4.0 °C, while relative humidity averaged 58.3 ± 12.4 %. This resulted in average THI being 79.7 ± 5.2 units. The LWSI classifications for heat stress are as follows: Normal (≤ 74), Alert (74 < THI < 79), Danger (79 ≤ THI < 84), and Emergency (THI ≥ 84). The range of THI for the days in which panting score was determined on the animals represented all categories of the LWSI. Measurements of wind speed and solar radiation were also comprised of a wide range of conditions (1.1 to 7.2 m/s and 15.1 to 493.62 W/m^2, respectively). Inferences made regarding application of this model must remain within the bounds of the ranges of environmental variables measured.

The parameter estimates for the effects of THI, WSPD, and RAD on panting score of the steers are presented in Table 3. The regression equation developed using hourly values predicts panting score to be equal to -6.317 + (0.097 * THI) – (0.233 * WSPD) + (0.0026 * RAD)) at 1700 h. The ratio of WSPD to THI and RAD to THI(-2.400 and 0.027 for WSPD and RAD, respectively) represent the adjustments to the THI for WSPD and RAD. For instance, for each 1 m/s (2.24 mph) increase in WSPD THI is reduced 2.4 units to maintain the same degree of panting. For each 100 W/m^2 decrease in RAD THI is reduced 2.7 units to maintain the same degree of panting. These corrections would be most appropriate to use, within a day, to predict THI during the day using hourly data or current conditions. As real-time conditions change immediate adjustments in THI can be made using these corrections.

Table 3. Parameter estimates for the regression equation predicting panting score from temperature-humidity index (THI), wind speed, and solar radiation at 1700 hours (R^2 = .47) and using daily averages (R^2 = .51).

Variable	Parameter estimate ± SE
1700 hour	
Intercept	-6.3173 ± .2876
THI	.0972 ± .0040
Wind speed, m/s	-.2331 ± .0121
Solar radiation, W/m^2	.0026 ± .0002
Daily averages	
Intercept	-7.2190 ± .2704
THI	.1275 ± .0042
Wind speed, m/s	-.4002 ± .0153
Solar radiation, W/m^2	.0019 ± .0003

Current conditions are important in assessing acute effects of heat stress, however, a better assessment of overall heat balance may be average daily conditions, which partially accounts for both nighttime and daytime conditions (NRC, 1996; Fox and Tylutki, 1998). For instance, nighttime temperature has been shown to have an effect on production of lactating dairy cows (Fuquay et al., 1974). Also, nighttime THI has been suggested as a critical factor in the ability of feedlot cattle to survive during severe heat stress (Hahn and Mader, 1997; Hahn et al., 2001). Thus, to predict THI for a future weather event or day then daily averages would be more appropriate to use versus hourly data. Adjustments in THI based on daily averages were for each 1 m/s increase in WSPD, THI is reduced 3.14 units, and for each 100 W/m^2 decrease in RAD, THI is reduced 1.49 units.

The negative relationship between WSPD and panting score in both models illustrates the ability of the animals to utilize convective heat exchange. Increased air movement over the body surface results in a disruption of the boundary layer of air near the skin surface. Disruption of this airspace allows for the removal of warm air being replaced of this cooler air. Although, this would only hold true as long as ambient temperatures are below body temperatures. Body heat of the animal is then transferred to the cool air and removed via continuous air movement (Robertshaw, 1985). Additionally, Arkin et al. (1991) showed that thermal conductivity of the boundary layer of air adjacent to the fur increases linearly with wind velocity. Although, the increased ability of the animal to dissipate heat has been suggested to reach a maximum when wind speed approaches 2 m/s (NRC, 1981). For the models developed in this study, benefits of wind speed above 2 m/s were apparent, since no quadratic or curvilinear response to wind speed was found.

A significant impact of RAD on panting score at the time of assessment is not surprising given the benefit shade structures have shown in reducing heat stress of animals (Mader et al., 1997b; Brosh et al., 1998; Mitlohner et al., 2001). Solar radiation can contribute 1000 W/m^2 to the overall heat load of the animal (Walsberg, 1992). This amount of RAD can be further exacerbated by the hair color of the animal. In these studies approximately 75% of the steers were black-haired. Arp et al. (1983) found that black-haired steers in commercial feedlots had body surface temperatures as much as 21 °C greater than white-haired contemporaries. The emissivity of black-haired steers approaches 1, while white-haired contemporaries have an emissivity < .40 (Robertshaw, 1985; Cena and Monteith, 1975). Thus, large numbers of black-haired steers in the current data set may have allowed for a more drastic effect of solar radiation. Nevertheless, substitution of average 1700 hour values for WSPD and RAD (Table 3) into the regression equation and solving the equation to determine the THI value at which PS equals 1 (100% of steers elevated respiration rate) results in THI equal to 74.9. This value is consistent with the LWSI threshold value of 75 to signify an "alert" environmental situation. Lemerle and Goddard (1986) reported that respiration increases when THI exceeds 73.

Close monitoring of weather variables is essential in determining the potential for environmental stress related complications in livestock operations (Mader and Davis, 2002). The LWSI has long been used as an indicator for potential heat stress related losses, however its precision is questioned under conditions of varying wind speed and radiative heat load. Adjustments proposed in this report should allow producers to more accurately predict the potential for heat stress within the bounds of the environmental variables measured.

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