Heat stress detection and mitigation in feedlot cattle

by

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Abstract

Feedlot cattle frequently endure high environmental temperature-humidity index conditions in the summer months within cattle feeding regions of North America. Heat stress develops when the total heat gain (combined effects of environmental and metabolic factors) exceeds an animal's heat loss capabilities. The objective of my research was evaluating heat mitigation strategies and developing a practical method to identify animals that are of greatest risk of heat stress; thus improving animal welfare and performance.

A number of heat abatement strategies have been utilized in US feedlots including shade, sprinklers, nutritional modifications, and misters. A literature review was performed using published journal articles demonstrated significant benefits of providing shade to feedlot cattle. Sprinkling the pen surface may be just as beneficial as sprinkling or misting cattle. Sprinkling the ground not only cooled the ground which increased the thermal gradient between lying cattle and the ground, but also provided increased thermal conductivity and better heat flow down that gradient.

A study was performed to develop a noninvasive, remotely applied, practical method to identify animals at risk for heat stress. Infrared thermography images were obtained during the morning hours and pant scores obtained in the afternoon hours. Data mining techniques were employed to evaluate accuracy of potential classification methods to identify heat stress events in the afternoon based on the known morning data. Using infrared technology as a diagnostic test was not accurate for predicting heat stress events in the study presented.

Finally a retrospective study of Kansas feedlot performance, medical and weather data was performed. Findings indicate that diagnostic counts of bovine respiratory disease are associated with elevated ambient temperature two days prior. In conclusion, heat stress in beef

feedlot animals is an important area of research. Heat mitigation methods such as shade have been proven to be effective at reducing heat stress in beef feeder cattle. Further research is needed to evaluate the use of infrared technology to predict heat stress events in the feedlot setting.

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Dedication

I dedicate this project to my husband, Daniel, and Grandpa Don.

Chapter 1 - Literature Review

A review of objective outcomes of non-nutritional heat abatement strategies in beef feedlot cattle.

Feedlot cattle frequently endure high environmental temperature-humidity index conditions in the summer months within cattle feeding regions of North America. Heat stress develops when the total heat gain (combined effects of environmental and metabolic factors) exceeds an animal's heat loss capabilities.

Cattle performance is adversely affected when heat stress causes decreased feed intake, growth rate, and efficiency.[1] A coping strategy of cattle during heat stress is to decrease metabolic heat production by lowering feed intake, which adversely affects productivity.[2] Mader estimated average economic losses due to adverse weather, including heat waves and severe winter weather, within the range of US $10-20 million / year for the US beef feedlot cattle industry.[3] These economic losses in extreme cases may be due to cattle deaths and in less severe cases due to production loss. Furthermore, ensuring cattle welfare will continue to be of upmost importance as producers strive to produce a wholesome product for consumers.

Management strategies to reduce and alleviate heat-stress-related production losses, economic losses, and stress are warranted. A number of heat abatement strategies have been utilized in US feedlots including shade, sprinklers, nutritional modifications, and misters. The objective of this literature review is to review quantitative outcomes of non-nutritional heat abatement strategies in beef feedlot cattle.

Materials and Methods

Articles for this review were identified by searching PubMed, AGRICOLA, and CABI utilizing the keywords: feedlot (feedyard, confined feeding operation), beef, heat, stress, shade, sprinkle, and mist. Articles were sorted based on title relevance. Abstracts were then utilized to determine further relevance. Additional relevant articles were identified by reviewing literature cited in the originally identified articles. Studies had to be published in a journal and have a control beef cattle population with no heat mitigation. Heat mitigation strategies reviewed in this paper are shade, misting, and sprinkling (ground and cattle). Articles investigating dairy animal populations and nutritional mitigation strategies were excluded.

Results

Shade versus no shade

Shade has been extensively studied in feedlot settings. In this review, effects of shade on dry matter intake (DMI), gain:feed, average daily gain, body weight, water intake, body temperature, carcass traits, panting score, and respiration rate will be summarized.

Effect of shade on dry matter intake

Mitlohner et al. reported increased feed consumption in *Bos Taurus* feedlot cattle provided shade in the Texas Panhandle. [2,4] In 2002, DMI over a 121 day feeding period was 2.9 % greater for the shaded versus unshaded heifers.[4] In 2001, daily DMI was 7% greater for shaded vs unshaded heifers.[2] These findings mimic the finding of Gaughan et al.[5] investigating Angus steers in Queensland Australia over a 120-day study duration and Hagenmaier et al.[6] investigating steers and heifers in a Kansas commercial feedlot in 2013 being fed Zilpaterol hydrocholirde.

Boyd et al. reported DMI in feedlot cattle is unaffected by shade in Nebraska.[7] This is contradictory to Hagenmaier[6], Mitlohner[2,4], and Gaughan[5]. This suggests the snow fence used as shade in the Boyd study was inadequate at mitigating heat stress or the heat stress was insufficient to hinder performance. Furthermore, the hide color distribution in the Boyd et al.[7]

study was 78 % red and 22% black. The other studies in comparison had predominately black hided cattle.

Sullivan et al. found during periods of increased heat load, daily dry matter intake of unshaded cattle decreased approximately 50%, whereas shaded cattle decreased approximately 10 %.[8] After the conditions leading to increased heat load had passed, a period of compensatory intake in the unshaded cattle surpassed the pre-heat-load intake by approximately 33%. The finding of differences in compensatory gain after a heat load between shaded and unshaded cattle are contrary to those in studies by Mitlohner[2] and Gaughan[5] in which no compensatory gain was noted. These studies reported that unshaded cattle exposed to heat stress did not show compensatory body weight gain when hot conditions abated. These differences may be due to the method of feeding. In the Sullivan et al. study[9], animals were fed ad libitum with self-feeders.

Brown Bandle et al. found that steers with access to shade had significantly higher accumulative feed intake starting at 1400 hour and continuing through the rest of the day when the maximum daily temperature humidity index was equal or above 84. No significant differences were found in when maximum daily temperature humidity index was less than 84. Although not significant, the no-shade steers had a slightly higher accumulative feed intake in the normal category. This indicates that animals in the no-shade treatment were compensating for the decrease in feed intake at higher temperatures. [10] Clarke et al. found no differences in DMI between shaded (75 % sunlight exclusion knitted cloth) and unshaded Hereford steers weighing 358 +/- 28 kg over a three month feeding period in Australia.[11] However during a heat wave, a reduction in dry matter intake was noticed in all steers, with unshaded steers affected worse. Following the heat wave, compensatory intakes were observed in both shaded and unshaded cattle. The study did not run statistics on the effect of the heat wave on DMI in the steers and if a statistically significant difference in compensatory gain was noted. Some researchers have speculated shade did not benefit growth performance of cattle due to the ability to acclimate to heat and compensate to the point in which the benefits of shade provision are diminished. I do not agree with this statement based on the studies reviewed. Shade does improve dry matter intake and compensatory gain by unshaded cattle does not surpass that of shaded cattle to negate the effect of shade.

Effect of shade on gain:feed ratio

Sullivan et al. found G:F for shaded cattle was greater than cattle denied shade in Angus yearling heifers.[8] Gaughan et al. had similar results; shaded cattle had a G:F ratio of 1.65 kg/d versus unshaded cattle at 1.51 kg/d.[5] Mitlohner et al. found no significant differences in shaded verses unshaded heifers (P = 0.086) in West Texas, numerically, shaded cattle had a 6% increase in G:F[2]. This agrees with another study Mitlohner et al. performed the following year (2002) where no difference was found in G:F ratio between shaded and unshaded cattle (P = 0.26)[4]. Clarke et al. found no differences in feed efficiency between shaded and unshaded Hereford steers in Australia.[11] In studies performed in Nebraska, Bond et al. found no difference in feed conversion in young bulls being fed high forage diets, although breed x treatment (shade) interactions were prevalent.[12] However high roughage diets are not typical of those fed to feedlot animals. Metabolic heat load from feeding high energy diets can make a significant contribution to overall heat stress.[13] Hagenmaier et al. found that unshaded cattle had a greater G:F; however, shaded cattle had greater DMI resulting in no difference in ADG and final BW. [6] G:F ratio is not consistently improved by the addition of shade structures in feedlots.

Effect of shade on average daily gain and body weight

ADG was 6.1 % greater for shaded than unshaded cattle in the study that Mitlohner et al. conducted in Texas in 2000.[4] Mitlohner et al. found ADG was 11.8% higher for shaded vs unshaded heifers. [2] Gaughan et al. found similar results in Angus steers in Queensland, Australia. [5] Blaine et al. found that ADG was numerically higher but not significant, for shaded cattle versus unshaded cattle.[14] White et al. studied the effects of shade and pen surface on steers receiving high forage diets. When fed 80% forage, steers with access to shade had higher average daily gain than steers denied shade regardless of pen surface (concrete or dirt). In the second experiment, steers fed high forage diets on concrete with shade had higher average daily gain than those fed on concrete without shade and those on dirt with or without shade.[15]

Bond et al. performed a study in Nebraska in the summers of 1972 and 1973 on young bulls. They found no difference in daily weight gain between shaded and unshaded bulls in either year. Hagenmaier et al. found no difference in ADG between shaded and unshaded cattle being fed Zilpaterol hydrochloride. Shaded cattle had greater DMI however unshaded cattle had a greater G:F resulting in no difference in ADG and final BW.[6]

The final body weight at 121 days on feed was 11.3 kg/heifer greater in shaded than unshaded heifers in the study Mitlohner et al. performed. [4] Blaine et al. performed a study in South Africa in which they found that final live weight of shaded cattle was 6 kg heavier than non-shaded animals. [14] The final body weight on day 131 as 27 kg/heifer greater for shaded verses unshaded heifers in the study Mitlohner et al. performed.[2] Thus, these heifers reached their target body weight 19.4 days earlier than for heifers without shade. Shade improves ADG when environmental conditions provide sufficient stress on beef cattle. Because ADG is higher, shaded animals can reach target body weight with less days on feed, resulting in economic benefits.

Effect of shade on water intake

Sullivan et al. found no statistical differences in water usage between shaded and unshaded cattle.[8] When the days were categorized as moderate and hot, water usage was greater (P = 0.02) for unshaded heifers. When the day was categorized as very hot, water usage was slightly less for unshaded cattle (P = 0.09). Gaughan et al. found no treatment differences over a 120-day feeding period for water consumption. During a 21 day period of high ambient temperature, there was a significant difference in water consumption between shaded and unshaded steers. [5] Mitlohner et al. reported that access to shade did not affect water intake.[2] However, this could be due to greater DMI intake of shaded cattle in the Mitloher et al. study. The impact of shade on water intake does not have a clear conclusion. More studies would need to be performed to justify reduced water intake as a driving factor for adding shade to a feedlot.

Effect of shade on body temperature

Gaughan et al. found no body temperature differences between shaded and unshaded steers over an entire 120 day study measuring body temperature via a surgically implanted device between the internal oblique and the peritoneum in the flank.[5] However, a difference in mean body temperature between treatment groups was identified during a 21 day period of high THI within the 120 study.[5] Gaughan et al. reported that during a severe heat event, shade decreased cattle body temperature by 2.3%. [5] Boyd et al. found that in shaded cattle not fed zilpaterol hydrochloride, there was a slight decrease in average and maximum body temperature compared to unshaded cattle, but only by approximately 0.1%.[7] During this study, the majority of days fell in the Alert THI category as described by Mader.[16] This finding is similar to that reported by Gaughan et al. [5] found in 2010, with no differences in body temperature for shaded versus unshaded cattle in average temperature conditions. It was only when cattle were exposed to high THI that Guaghan et al. reported a benefit of shade to reduce body temperature.[5]

Brown-Bandle et al. found that shade reduced cattle's core body temperature during daytime hours, using a telemetry system transmitter that was implanted into the abdominal cavity of each steer.[10] Eight animals were housed in individual concrete surfaced pens for the study and shade significantly lowered body temperature in the afternoon for cattle when the THI was categorized in the Danger and Emergency categories.[10] In all categories but the danger category, animals in the shade group had a higher core body temperature during the nighttime hours than unshaded animals.[10] This response may be due to radiation losses due to the night sky being impaired by the shade structure. A similar event was seen with respiration rate of unshaded cattle being lower than shaded cattle in a study performed by Eigenberg et al.[17] The benefit of shade on core body temperature is not consistent during the diurnal period. The average body temperature throughout the entire day did not differ between shade and unshaded cattle. However, this nighttime effect of the shaded cattle did not totally negate the effects of the added value of shade during the day. The shaded cattle had less fluctuation in body temperature over the 24 hour period; the magnitude of improvement during the day for shaded cattle was greater than the detriment of shade in the nighttime hours in degrees Celsius difference.

Clarke et al. found that unshaded Hereford steers had a significantly higher rectal temperature than shaded Hereford steers in a feedlot in Australia.[11] Temperatures were recorded weekly when steers were quietly moved to the cattle handling facility.[11] Gaughan et al. found that mean rectal temperatures that were obtained by continuous data loggers were greater for unshaded heifers than shaded heifers; however, access to shade did not always result in a lower rectal temperature.[18] An effect of time of day on rectal temperature was evident in that during the afternoon hours, (1201-1700), shaded heifers had higher rectal temperatures than unshaded heifers.[18] The rest of the hours in the day, the shaded heifers had lower rectal temperatures.[18] The lower body temperature of the unshaded heifers during the afternoon hours is a function of the relationship between respiration rate and body temperature. The unshaded heifers had a significantly higher respiration rates than shaded heifers and the highest respiration rate of the day measured on the unshaded cattle. Other, unmeasured factors such as amount of air movement may have influenced the observed results.

Gebremedhin et al. studied the effects of shade on body temperature of different breeds and hide colors of cattle. The four breeds used were black Angus, MARCIII (dark red), MARC I (tan), and Charolais (White). Vaginal temperatures were recorded every minute with a commercial temperature logger for four days. It was found that the average body temperature of the heifers with access to shade was lower than that with no access to shade.[19] Providing shade especially lowered the vaginal temperature for black and dark red-colored heifers. The data presented suggests that body temperature is well controlled under a wide range of conditional, and shade is only beneficial in reducing body temperature associated with severe heat episodes. Dark colored cattle may see greater benefits.

Effect of shade on carcass traits

Shaded cattle were found to have a higher hot carcass weight than unshaded cattle by Mitlohner et al.[2,4], Gaughan et al.[5] and Blaine et al.[14]. This finding is likely due to a higher finishing weight before harvest. This finding coincides with the findings stated above referring to higher ADG and total body weight observed with shaded cattle.

Mitlohner et al. found that shaded heifers had a higher quality grade than their unshaded counterparts. This difference could likely be attributed in the large percentage of dark cutting carcasses in the unshaded heifers (19.8 % unshaded vs. 8.3 % in shaded) because marbling score did not differ. Within a group of cattle being harvested, dark cutters will bring down the overall quality grade of the group. This increase in quality grade had not been seen in previous studies. [4] Marbling score also did not differ between shaded and unshaded cattle in studies by Gaughan et al.[5], Mitlohner et al.[2], Hagenmaier et al.[6], Blaine et al.[14], Boyd et al.[7], Mader et al. [13], and Clarke et al.[11].

Mitlohner et al. reported that shade increased actual and adjusted fat thickness in Charolais heifers.[2] This differs from the findings by Mitlohner et al.[4] using Angus and Charolais heifers as study subjects, Gaughan et al.[5] using Angus steers, Mader et al. [13] using Angus x Hereford steers, and Clarke et al.[11] using Hereford steers.

Hagenmaier et al. found that shaded cattle had greater dressing percentage than unshaded cattle[6]. These findings are contradictory to Gaughan et al.[5] who reported the dressing percentage of shaded steers was less than the unshaded steers. Other studies have found no difference in dressing percentage.[11,13] Many have reported that shade has no effect on lean muscle area and kidney, pelvic, heart fat.[2,4-6,11] Carcass characteristics, except higher hot carcass weight, are not a justification to add shade to a feedlot operation.

Effect of shade on physiological responses

Higher respiration rate associated with cattle classified as suffering from heat stress compared to non-heat stressed cattle may mean an animal that is more heat stressed responds by increasing respiratory rate or may mean that an animal with a higher respiratory rate may be more sensitive to heat stress. Boyd et al. found no difference in respiration rate between shaded and unshaded cattle, suggesting shade was not effective at mitigating heat stress.[7] This finding is inconsistent with other research. Mitlohner et al.[2] found a 29% decrease in respiration rate of shaded versus unshaded cattle and Brown-Brandle[10] et al. found that shade access reduced respiration rate during some portions of the day across all weather categories studied. The shades in the Boyd et al. study were composed of layered snow fence.[7] Eigenburg et al.[20] found snow fence to reduce respiratory rate, but was the least effective of the materials observed, potentially resulting in the lack of shade response noted in the Boyd study. In a study performed by Mitlohner et al., respiration rates fluctuated and were lower for the shaded verses unshaded heifers. [2] This large impact of shade on respiration rate has been previously documented.[4,10,11,18]

Mitlohner et al. found that in unshaded treatments, the respiration rate between Charolais and Angus were similar, but under shade respiration rate was lower in Charolais than in Angus heifers. [2] Brown-Bandle et al. found contradictory results when breeds were studied in that their data showed an interaction between hide color and THI category.[21] There was a significant reduction in respiration rate in black hided cattle in all THI categories while white heifers showed a significant respiration rate reduction only at the Emergency THI category.[21] Brown-Bandle et al. determined that while all animals benefited from access to shade, Black Angus heifers had the largest benefit between shaded and unshaded pens.

Eigenberg et al. studied the effects of shade on respiration rate on 8 individually housed bos tarus feedlot steers. Daytime mean respiration rates were significantly lower for shaded versus unshaded steers. However, nighttime respiration rates were significantly lower for non-shaded steers, possibly due to reduced nighttime radiation in shaded cattle.[17] These daytime effects of reduced respiration rate were not annulled as the overall respiratory rate throughout the entire day were much less for shaded versus unshaded steers. These findings are similar to those found by Brown-Bandle et al. studying nighttime body temperature differences between shaded and unshaded cattle.[10] Data presented shows a consistent decrease in respiration rate, allowing cattle to utilize less energy on physiologic cooling.

Effect of shade on panting score

Cattle begin open mouth breathing during heat stress to increase tidal volume to more efficiently dissipate heat loads that exceed the ability of primary evaporative cooling mechanisms such as sweating and increased respiratory rate.[6,8]

Guaghan et al. found that the mean panting score (MPS) was greater ($P<0.05$) for the unshaded cattle compared with shaded cattle at three daily observation times; 0600, 1200, 1600h. [5] Panting score was assigned by visual observation with 0 being no panting and 4 being excessive drooling, high respiration rate, open mouth with tongue out. The study was performed in Central Queensland with Angus steers that were not adapted to the subtropical climate. The largest differences were seen at the 1200 hour. Extreme heat load category was defined as MPS >1.2 and high category defined as MPS 0.8-1.2. The MPS of unshaded cattle at the 1200 hour were in the extreme heat category for all periods during the study (d 0-30, d 31-60, d 61-90, d91-120). The MPS of shaded cattle was in the extreme category during only one period and in the high category the remaining periods.[5] Sullivan et al. found similar results as access to shade and an increased allocation of shade area reduced but did not fully eliminate the effects of high THI on panting score.[9] Hagenmaier et al. found a shade treatment X THI category interaction for open mouth breathing. Open mouth breathing was determined between 1500-1700 h. Days classified as Danger (maximum THI >79) [16] increased prevalence of open mouth breathing compared to Alert days (maximum THI <79) [16] in unshaded cattle but not in shaded cattle.[6] Boyd et al. found no difference in panting score between shaded and unshaded cattle, suggesting the shade generated by layered snow fence was not effective at mitigating heat stress.[7] The effects of shade on respiration rate and panting score are positive, improving cattle comfort and decreasing the energy designated for physiologic efforts.

When discussing literature cited above, shade area provided per animal and the type of shade material utilized could result in different outcomes. Sullivan et al. found that provision of a shade area greater than 2.0 m^2/animal does not appear to provide any additional production benefits such as gain:feed ratio or average daily gain in cattle nearing slaughter weight. However during periods of high THI , mean pant scores and behavioral data from Sullivan et al. suggest that 2.0 m^2 shade / animal did not produce the same welfare improvements as the 3.3 and 4.7 m^2 shade/ animal.[9] If the goal of the producer is strictly based on finances and is production based, greater than 2.0 m^2 shade / animal is not indicated. However, welfare may be enhanced if more shade is allocated per animal. The studies cited above, in which shade area was not being studied, ranged in shade area per animal from 1.5 m^2 shade / animal to 3 m^2 shade / animal. Not all studies specified shade allotted per animal. Another study would be helpful to determine at what shade area between no shade and 2.0 m^2/animal does production benefits begin to occur.

Type of shade also impacts production benefits. No improvement of dry matter intake was noticed by Boyd et al. by providing shade to feedlot cattle in Nebraska.[7] This findings are contradictory to Hagenmaier[6], Mitlohner[2,4], and Gaughan[5]; however, Boyd et al. utilized snow fence as the means of shade. Brown-Bandl et al. performed a study to evaluate different shade materials (no shade, snow fence, 60% aluminet shade cloth, 100% shade cloth) which found that while each shade treatment reduced black globe temperature compared to no shade, 100% shade cloth resulted in maximum reduction.[10] While the 100% shade cloth offered the greatest environmental advantage, the animal responses didn’t always correspond with the environmental measures. The study found that the manual respiratory rate (RRm) increased as the conditions became more stressful however the RRm response when the THI resulted in the environmental conditions being classified in the Alert category showed no difference between cattle in the no shade and snow fence treatments; however those with access to 60% aluminet and 100% shade cloth had a positive response, with 100% shade cloth having the lowest RRm.[10] However in the danger and emergency category, no significant differences in RRm were found between different shade types.[10]

The electronically measured respiratory rate was recorded throughout the day instead of a single time point. In the emergency conditions, all shade provided relief to cattle in the afternoon versus no shade.[10] The 60% aluminet proved the most effective shade in the emergency category, as these cattle had significantly lower RRe than other treatments.[10] This may be due to the 60% aluminet being more permeable allowing air to move through the material. Brown-Bandl et al. found that the maximum body temperature steadily increases as THI became more stressful. In the danger and emergency THI categories, the type of shade provided was important.[10] The shade provided by snow fence did not provide much protection.[10] To reduce body temperature in hot temperatures there is a minimum quality of shade needed.[22] Eigenburg et al.[20] found similar results in that snow fence would reduce respiratory rate, but was the least effective of the materials observed. Potentially the contradictory results in the Boyd et al. study[7] were due to the material utilized as a shade structure. These findings indicate 60% aluminet to be the best shade structure to alleviate heat stress during extreme heat conditions however 100% shade cloth may be just as good of option in heat conditions not reaching the extreme category.

Gebremedhin et al. studied the solar absorptivity coefficients of four breeds of heifers during periods of high temperatures.[19] Their findings indicate that black heifers absorbed the highest solar load followed by dark red heifers. The white hair coat heifers absorbed the least and the tan heifers were between white and dark colored heifers.[19] Boyd et al. reported DMI in feedlot cattle is unaffected by shade in Nebraska.[7] This is contradictory to Hagenmaier[6], Mitlohner[2,4], and Gaughan[5]. The hide color distribute in the Boyd et al.[7] study was 78 % red and 22% black. The other studies in comparison had predominately black hided cattle. This may indicate that shade provided to black cattle is more beneficial than to other coat colors as the solar load experienced by black cattle is the greatest.

Misting cattle versus not misting

Mitlohner et al. studied the effects of shade and misting on animal performance. The water misters delivered 0.5 L of water/minute and the droplet diameter was 50 um. Mitlohner et al. found that rectal temperatures were lower for misted heifers than non-misted heifers in experiment 1 that lasted 28 days but there was no difference found across treatments in experiment two that lasted 131 days.[2] The rectal temperatures were collected by handling the cattle in a working facility. This process may have affected the rectal temperature and confounded results. It was also found that heifers that were misted without shade had a higher respiratory rate than those that were not misted with no shade.[2] Sprinkling may be more effective than misting cattle at ameliorating the effects of heat stress because misting results in fine water droplets clinging to the outer hair of the cattle's coat without reaching the skin to enhance evaporative cooling. Presence of water droplets on the hair, but not on penetrating to the skin might result in an insulation later (air between skin and wet outer hair), which could act as evaporation barrier.

Sprinkling cattle versus not sprinkling

Sprinkling cattle to alleviate heat stress is beneficial because latent heat of vaporization associated with a change of water from a liquid to gas state could act to dissipate heat on the hide surface.[23] Sprinkling is different from misting is relation to droplet size of the water particle. The following articles on sprinkling did not specify the water particle size but one can assume misting is characterized as droplet size less than 100 um and sprinkling would be characterized as droplet size greater than 100 um. Because the transfer of heat by evaporation happens despite equal or reversed thermal gradients between an animal its surrounds, evaporative cooling may be the only means of heat dissipation in extreme environmental conditions when the environmental temperature is higher than the temperature of the animal. Evaporative cooling also depends on the degree of water saturation of the air (relative humidity).[24] As water is evaporated from the animal, it cools the air surrounding the animal. This lower ambient air temperature increases the heat gradient and allows greater heat flow away from the animal. [25]

Sprinkling cattle effect on dry matter intake

Morrison et al. performed a study in 1970 on Angus and Angus x Hereford steers on slotted floor pens with aluminum shade. Animals were sprinkled for 1 minute every 30 minutes when temperature was 80°F or higher. Cattle that were sprinkled ate significantly more feed than the unsprinkled cattle. [26] However, Davis et al. found that dry matter intake did not differ between cattle that were sprinkled and those that were not in a study performed in Nebraska when sprinklers were placed 1.7 m above the pen surface and applied water when THI at 0900 h was >=68. The sprinklers came on every 1.5 hours for 20 minutes from 1000-1750 h. [24]

Sprinkling cattle effect on body temperature

Davis et al. reported that steers in pens that were sprinkled tended to have lower tympanic temperature than the control steers from 1400-1600 h and tympanic temperatures that were significantly lower between 1700-1900 h.[24] Feeding in the morning and evening was also evaluated in this study and a sprinkling by feeding time interaction was apparent. The elevated tympanic temperature of dry steers over time was due to the greater mean daily temperature of steers fed in the AM that were not sprinkled which differed from all other treatment groups.[24] This suggests than sprinkling enhanced cattle comfort.

Gaughan et al. studied the effects of water application on rectal temperature, respiration rate, and dry matter intake of heifers exposed to heat stress conditions, and the effect of continued or intermittent water application once it was initiated.[27] *Bos taurus* heifers were housed in controlled environmental chambers. They reported water applied directly to beef cattle exposed to environmental conditions that are likely to cause heat stress can rapidly lower body temperature and respiration rate. However, once the decision to wet cattle as a heat stress relief strategy has been made, the procedure should be continued for as long as heat stress conditions prevail. Failure to do so may result in increased susceptibility of cattle to hyperthermia.[27]

Sprinkling pen surface versus not sprinkling pen surface

Dry soils thermal conductivity is very low, thus the ability of animals to dissipate heat to the soil is poor. Thermal conductivity of soil is not consistent and may be improved by the addition of water. It has be indicated that thermal conductivity of clay-type soils commonly found in feedlots may be enhanced by increasing water content, increasing heat transfer from the animals.[23,24] Wetting the ground not only cools the ground which increases the thermal gradient between lying cattle and the ground, but also provided increased thermal conductivity and better heat flow down that gradient.[24,25]

Mader et al. performed a study with 96 Angus x Charolais cross steers to evaluate the effect of sprinkling pen surface. Cattle in the control group received no pen sprinkling, and there were two treatment groups, AM pen was sprinkled from 1000-1200 h and PM sprinkled from 1400-1600 h when THI was predicted to be >= 77 to eliminate mud accumulation. Sprinklers were placed at ground level.[23] Davis et al. performed a similar study with ninety-six angus crossbred steers in which steers were in a control group (no sprinkling), AM mound sprinkling, or PM ground sprinkling. [24] Neither study found a significant difference in cattle dry matter intake between treatments. Mader et al. found that sprinkled cattle has a 2.5% numerically greater DMI than control cattle. [23] Mader et al. also reported that AM sprinkled cattle tended to have greater ($P = 0.06$) G:F than PM sprinkled cattle.[23] Davis et al. reported that steers in pens that had the mound wetted between 1000-1200 h had lower tympanic temperatures between 2300-0800 h than those that the mound was wetted between 1400-1600 h but no difference to the control animals. [24] This suggests that benefits of sprinkling seem to be enhanced if sprinkling is started in the morning, prior to cattle getting becoming heat stressed.[24] Another study performed by Mader et al. found cattle that were sprinkled had significantly lower panting scores at 1100, 1400 and 2000 hours and numerically less at 1700 h[25]

When sprinkling is used in a feedlot setting, one can speculate that the sprinkling may cause increases in humidity and could potentially add to heat stress. Mader et al. studied the effect of sprinkling on the feedlot microclimate when the pen surface was sprinkled. Soil temperatures in the sprinkled pens were lower ($P<0.05$) than dry pens at all measured times. Also, sprinkled pens had soil temperatures that were consistently lower than ambient temperatures.[25] Relative humidity above the sprinkled mound averaged 72.4 % and dry mounds averaged 68.9%. This indicates that sprinkling does increase humidity. However, the average THI was lowered by sprinkling in that the average THI above sprinkled mounds was 0.5 units lower than THI above dry mounds.[25] The data presented suggested the microclimate was altered by sprinkling and animal comfort was improved. Lowering ambient temperature via the sprinkling process offset any adverse effects of increased relative humidity, indicating sprinkling has an overall positive effect on cattle production in the feedlot settling.

Conclusion

This data shows significant benefits of providing shade to feedlot cattle. The overall economic benefit of using shade depends not only on location, but also on cost of building and maintaining shade structures. Benefits of using shade would most likely be found in areas with greater ambient temperature and/or solar radiation. More consistent benefits of using shade would likely occur the further south cattle are in the United States. Multiple studies have shown increases in dry matter intake, average daily gain and body weight. Less data suggests improvement in gain to feed ratios. The main carcass improvement was increased hot carcass weight due to a higher end body weight. When welfare is considered, shade consistently lowers panting scores and respiratory rate.

In addition to adding shade structures, sprinkling can be effective in minimizing heat stress. Sprinkling the pen surface may be just as beneficial as sprinkling or misting cattle. During misting, fine water droplets cling to the outer hair of the cattle’s coat with minimal wetting of the skin which can cause increased insulation acting as an evaporation barrier and worsening heat stress risk. Sprinkling the ground not only cooled the ground which increased the thermal gradient between lying cattle and the ground, but also provided increased thermal conductivity and better heat flow down that gradient. Benefits of sprinkling tend to be enhanced if sprinkling is started in the morning, prior to cattle getting hot. Wetting or sprinkling can have adverse effects, particularly when the cattle become acclimated to being wet and failed or incomplete sprinkling occurs during subsequent hot days.

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Chapter 2 - Infrared thermography as a diagnostic tool to predict heat stress events in feedlot cattle

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Introduction

Feedlot cattle frequently endure high environmental temperature-humidity index conditions in the summer months within cattle feeding regions of North America. Cattle performance is adversely affected by high temperatures; unshaded cattle have poor dry matter intake, high feed to gain ratio, poor average daily gain, and therefor weigh less at harvest than their shaded counterparts.[1] It has been shown that adequate heat abatement overnight is necessary to reduce heat stress events the following day.[2]

Body temperature of an animal can be used to diagnose heat stress;[3,4] however, there are few methods to accurately and efficiently record body temperature of cattle in a feedyard setting. A noninvasive, remotely applied, practical method to identify animals that did not adequately cool overnight is needed to improve animal welfare and performance. Infrared thermography has been identified as a potential means to identify bovine respiratory disease[5,6] and foot lesions in dairy cattle before manifestation of clinical signs,[6,7] as well as inflammation associated with the subcutaneous placement of growth promoting implant placement on the convex surface of the ear of feedlot cattle.[8] Furthermore, infrared thermography has been recognized as a possible indicator of heat production in beef cattle.[9]

Predicting which animals in a feedlot are predisposed to heat stress would allow precautionary measures to be established for calves at risk for hyperthermal events, thereby improving animal welfare. The objective of this study was to determine if infrared thermographic camera images taken in the morning after overnight heat abatement could be used as the basis for diagnostic tests to predict subsequent heat stress events in feedlot cattle exposed to elevated ambient temperatures. The hypothesis was that infrared images capturing profile surface temperature during the 0600 hour could be used as a diagnostic tool to predict predisposition to heat stress events during the 1500 hour.

Materials and Methods

Animals

Sixty beef heifers with a mean ± SD body weight of 385.8 ± 20.3 kg were used in the study. All study procedures were approved by the Institutional Animal Care and Use Committee (IACUC number 3334). Calves were housed in three pens with twenty animals per pen. All cattle had free access to water and were fed a corn-based step up ration. Pens were 45.7 m x 18.3 m, with earthen surface and no shade. A remote weather station[a] at a nearby location recorded ambient temperatures and humidity readings every hour on study days. Using recorded ambient temperature and humidity, temperature humidity index (THI) was calculated using the following equation[10,11]: THI = (0.81 X ambient temperature) + (relative humidity X [ambient temperature – 14.4]) + 46.4.

Procedure

Profile digital thermal images[b] of individual animals were captured from immediately outside the pen via convenience sampling during the 0600 hour and 1500 hour for ten days over a fourteen-day period. Monitoring was performed on days for which temperature was forecasted to exceed 29.4°C. Pant scores were assigned to individual animals during the 0600 hour and 1500 hour by a trained observer blinded to body surface temperature (EU) readings obtained from the thermal images. The scoring system was modified from Mader et al [12] and was as follows: 0 for normal respiration, 1 for elevated respiration, 2 for moderate panting and / or presence of saliva, 3 for open-mouth breathing, and 4 for severe open mouth breathing with tongue protruding. Afternoon monitoring periods were selected to occur in the middle of the afternoon when rectal temperature was greatest.[10] Calf coat colors were categorized as one of three coat colors (black, white, or red) and were recorded for each animal. Digital thermal images were imported into a thermographic imaging software program[c] for analysis. An area extending from the tail head along the dorsal aspect of the top line to between the shoulder blades, along the angle of the shoulder, along the ventral aspect of the abdomen to the caudal portion of the thigh and back to the tail head was selected (**Figure 2.1)** and analyzed to calculate an average body surface temperature for the animal.

Morning images (0600 h) were analyzed using a standard color scale between 21.1°C to 48.8°C, in that the color scheme and temperatures assigned to each color were uniform between all images. Images were then converted to greyscale, uploaded to an image analysis software program[d,] and the area defined above was selected. Each greyscale pixel in the selected area corresponded to a specific temperature and was assigned to a number between 0 and 255. For example, a black pixel would equal 0 and ≤ 21.1°C, a white pixel would equal 255 and ≥ 48.8°C, and all variations of grey would represent temperatures between 21.1°C and 48.8°C and thus were assigned values between 0 and 255. A color histogram was created to represent the number of pixels at each color. The total number of pixels in the selected area was recorded and the percent of pixels at each assigned number (0 to 255) was calculated. A cumulative percent was calculated for the percentage of pixels above each assigned number (0 to 255).

Statistical Analysis

Data were imported into a statistical software program for analysis[e]. A linear mixed model was generated to determine relationships between average surface temperature and pant scores from morning and afternoon. The 3-way interaction model included fixed effects of pant score, coat color, am/pm with random effect of day and repeated effects for calf within a pen. Backward elimination was used to select the appropriate model. Coat color was left in the model as a main effect even if not significant ($P > 0.05$) because it has been shown that cattle with dark hides have higher tympanic temperatures compared to light coat-colored cattle.[13]

A separate linear mixed model was generated to evaluate relationships between morning body surface temperature and afternoon pant score. Only observations that included both a morning image and an afternoon pant score for an individual calf were used in the model. The two way interaction model included afternoon pant score and coat color with random effects for day and repeated effects for calf within a pen. Backward elimination was used to select the appropriate model. For main effects and interaction comparisons, values of $P \leq 0.05$ were considered significant. For comparisons within morning and afternoon $P < 0.01$ were considered significant.

Algorithm Development

In additional to traditional statistical analysis, data mining techniques were employed to evaluate accuracy of potential classification methods to identify heat stress events in the afternoon based on the known morning data. Cumulative percentages of morning pixel data were matched with afternoon pant scores for a particular animal and imported into a commercial data mining software[f] package for analysis in similar methodology to previous research using training, testing, and validation datasets.[14] Calf coat color, predicted high ambient temperature, predicted humidity, ambient temperature at 0600 h of trial day, and relative humidity at 0600 h for each study day were imported. Pant scores were divided into two categories, < 3 and ≥ 3. Data were partitioned into training (50%), testing (25%), and validation (25%) datasets. The training partitioned data were then used to build automatically generated Decision Trees, Decision Stumps, Random Trees, Random Forests, Logistic Model Trees, Naïve Bayes Classifiers, Naïve Bayes Trees, Logistic Bases, Base First Trees, Bayesian Logistic Regressions, and Artificial Neural Networks to predict a pant score category ($<$ or ≥ 3) based on known pant score category from the training data set. The test data were then placed in each model to generate a predicted pant score. Predicted pant score category and actual pant score category were then compared to evaluate overall predictive accuracy for each model. Correlation between all inputs were calculated and overall accuracy of each model was assessed. To begin, variables with a correlation of 1 were dropped from the model and accuracy was assessed. Next variables with a correlation of > 0.95 were dropped from the model and accuracy was assessed. The process continued with > 0.90 and > 0.85 correlations being dropped. Based on the kappa results, the correlation setting with highest kappa was selected for each learning model. By changing linear correlations and number of breaks, models were able to learn and increase pruning ability. After generation of final classification models, validation data were evaluated and used to generate diagnostic sensitivity, specificity, overall accuracy, and kappa statistics for each model type. Finally, thermographic data were removed from algorithms to assess if accuracy was higher with or without thermographic data.

Results

Ambient temperature did not reach 29.4°C for all data monitoring days. For days 7 and 8 the maximum ambient temperatures were 28.0 and 29.1°C, respectively. Sunrise was 0600 and sunset was 2100 throughout the study. All calves remained in the study throughout its duration. Environmental conditions by day were recorded in **Table 2.1**. Numbers of observations per pant score by time of day are summarized in **Table 2.2**.

The final statistical model for evaluating relationships between average body surface temperature and pant scores in the morning and afternoon included main effects of pant score, coat color, time of day, interaction between pant score and time of day, and random effects for day and repeated measures for calf within a pen. The model showed a significant ($P = 0.01$) interaction between pant score and am/pm reading (**Figure 2.2**). Afternoon body surface temperatures were greater than morning body surface temperatures, and the effect of temperature on pant score was detected in the afternoon surface temperature recordings. The coat color of the calf was not significant ($P = 0.45$), but was retained in the final statistical model. For morning pant scores, there was no significant temperature difference between the pant score 0 and 1. There were no recordings of pant scores 2, 3 or 4 in the morning. There was an interaction ($P < 0.05$) between pant score and afternoon body surface temperature. Pant score 1 had a greater ($P < 0.01$) surface temperature compared to pant score 0 in the afternoon, and pant score 2 had a greater surface temperature than pant score 0 and 1 ($P < 0.01$). Cattle with pant scores 3 and 4 both had a greater (*P* < 0.01*)* body surface temperature compared to those with pant scores 0, 1, and 2 in the afternoon, but there were no differences detected between pant score 3 and 4 (*P* > 0.01).

The final statistical model for evaluating the relationship between morning body surface temperature and afternoon pant score included fixed effects of morning average surface temperature and coat color, with random effect of day, and repeated measure for calf within a pen. The model failed to show a significant association between morning average surface temperature and afternoon pant score (*P* = 0.57) or coat color (*P* = 0.40). **(Figure 2.3)**.

The predictive classification algorithm results are summarized in **Table 2.3**. The Decision Tree had the highest overall accuracy (95% CI) at 80.2% (71.1, 87.1) and highest kappa value (95% CI) of 0.55 (0.38, 0.72). The Decision Tree resulted in three branches (**Figure 2.4**). The first cut point was based on 0600 h ambient temperature of 24.6°C. When 0600 h ambient temperature was equal to or below 24.6°C a pant score of < 3 was assigned, when 0600 h ambient temperature was above 24.6°C the data moved on to the next learning step. There were sixteen misclassifications at this step. 0600 h percent humidity of 76% was used as the next cut point. If 0600 h percent humidity was below 76 % a pant score of < 3 was assigned. If 0600 h percent humidity was above 76 % the data moved on to the next learning step. There were six misclassifications at this step. Infrared data were then used in the learning model. The cut point of 98.58 % of cells being greater than 30.5°C was the final learning factor. If less than 98.58% of the pixels were above 30.5°C, a pant score of < 3 was assigned and if 98.58% or more of the pixels were above 30.5°C, a pant score of ≥ 3 was assigned There was one misclassification for <3 and sixteen misclassifications for ≥3 on this final step. The Decision Stump, Neural Network and Bayesian Logistic Regression models had kappa values of 0 and sensitivity values (95% CI) of 0.0 (0.0, 15.0), 0.0 (0.0, 13.7), 0.0 (0.0, 13.7), respectively. When the thermographic data were removed from the Decision Tree, accuracy (95% CI) dropped from 80.2 (71.1, 87.1) to 78.3 (69.0, 85.5).

Discussion

In the present study, infrared technology was identified as a potential means to objectively measure heat stress events in calves in a research setting. To determine if cattle are experiencing heat stress, it is common to use a subjective pant score system. Pant scores have been used to evaluate heat-related animal discomfort, as well as having a direct relationship with environmental heat load.[12] Gaughan and Mader[15] demonstrated that as body temperature increased within a time of day, pant score also increased; however, pant scores have the limitation of being subjective. Our study demonstrated that afternoon body surface temperatures captured by infrared technology are statistically different among different pant score categories. By capturing infrared thermal images of cattle, an objective measurement of heat load could be described.

Infrared thermal imaging could be an asset in future heat stress trials. Observers would no longer have to assign subjective pant scores to cattle, rather could utilize thermography and average body surface temperatures to assign a value that would not be based on a subjective observation. By using an objective surface temperature measurement to assign heat load, heat load could be more uniformly described between research trials and observer bias and error could be decreased. The practicality of thermographic screening in research settings is constrained by time and expertise required to upload images and calculate average surface temperatures compared to the relatively quick and simple method of assigning pant scores. Using available technology, it does not appear that infrared thermal imaging captured several hours before a heat stress event (after overnight heat abatement and before peak temperature humidity index) would have application for predicting heat stress risk in a commercial feedlot setting unless heat stress screening was being done on a regular basis.

In this study, average morning surface temperature captured by infrared technology had less than a 2°C range and provided little additional value to weather information to determine risk of an afternoon heat stress event. Morning infrared images were poor predictors of afternoon heat stress events using artificial learning models. The Decision Tree model had the highest kappa value between predicted pant score category and actual pant score. If the goal was to select cattle that were most likely to experience heat stress, the Naïve Bayes Tree algorithm generated the model with the highest sensitivity. However, the wide confidence interval associated with this model could be costly to a feedlot if intervention was expensive, as false positives would be fairly common. If identifying calves that would not show the clinical sign of panting when exposed to a heat stress event was the objectve, the Decision Stump, Neural Network, and Bayesian Logistic Regression had 100% specificity; however, these three algorithms had 0% sensitivity, thus precluding their utility. The Decision Stump, Neural Network, and Bayesian Logistic Regression classified all animals as having a pant score < 3 resulting in the 0% diagnostic sensitivity value. The test with the most helpful specificity was the Random Forest. High specificity for all of the algorithm datasets may be misleading, as data were composed of more calves that did not experience a heat stress event than those that exhibited pant scores associated with heat stress.

Even though the Decision Tree model for predicting heat stress events had the highest kappa value and was tied for the highest overall accuracy (95% CI) at 80.2 (71.1, 87.1), the model does not necessarily meet the goal of this study to find a practical method to predict high risk of heat stress several hours prior to indications by visual observation of pant score. It was interesting to note that when the Decision Tree model learned to predict values, three levels were needed in the learning process but the first two branches were morning weather conditions and not thermographic information. By analyzing the order by which the model learned, we realize that the model would be fairly accurate with the morning weather data alone and the thermographic data provided minimal additional information for prediction. When thermographic data were excluded, the overall accuracy dropped 1.9%. Without thermographic data, the Decision Tree made cutpoints based on ambient temperature, humidity, and predicted high ambient temperature. In a larger setting, these finding could help detect heat stress and make cutpoints for an entire group, rather than distinguish individuals that would experience a heat stress event.

Limitations of this study include not having a means to collect a measurement of solar radiation or wind speed that calves were exposed to on a daily basis. It has been shown that wind speed and radiation are influential factors in assessing heat load in cattle.[12] During this study we captured only body surface temperature of calves, no internal body temperature measurements were utilized. Therefore, we were unable to determine whether or not cattle effectively lowered their body temperatures overnight. We observed a narrow range of morning body surface temperatures, not allowing assessment of differential overnight cooling. We observed no significant impact of coat color on body surface temperatures. Davis et al. reported that black cattle had a greater overall tympanic temperature than their white counterparts and a coat color by time of day interaction was significant.[3] Further data would need to be collected to determine if average body surface temperatures and core body temperatures are related in cattle. Another variable that would be interesting to assess would be amount of mud on the haircoat and its potential association with surface temperature and heat stress. During this study, higher than usual rainfall occurred and many cattle were coated in mud. The calves used in this study had a mean body weight of 385 kg, being on the lighter end of calves at high risk to experience a heat stress event in the feedlot. Typically, cattle in feedlots at greatest risk are those which are closest to harvest, weighing 600 kg or more. A study with more high temperature days would be helpful to have more calves experiencing a heat stress event to train the artificial learning systems.

In the present study, infrared technology was identified as a potential means to objectively measure calves experiencing a heat stress event in a research setting. Using infrared technology as a diagnostic test was not an accurate assessment for predicting heat stress events in this study. More data need to be collected and analyzed to determine if infrared technology could be used as a diagnostic tool.

[a] WS-2812, La Crosse Technology, La Crosse, Wis.

[b] Ti110 camera, FLUKE Corporation, Everett, Wash.

[c] SmartView Software, FLUKE Corporation, Everett, Wash.

[d] Image J, National Institute of Health, Bethesda, Maryland.

[e] RStudio Team (2015). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA

[f] Knime, KNIME.com AG, Zurich, Switzerland.

Figure 2.1: The shaded area of the calf was selected and utilized for infrared pixel analysis to determine average temperature.

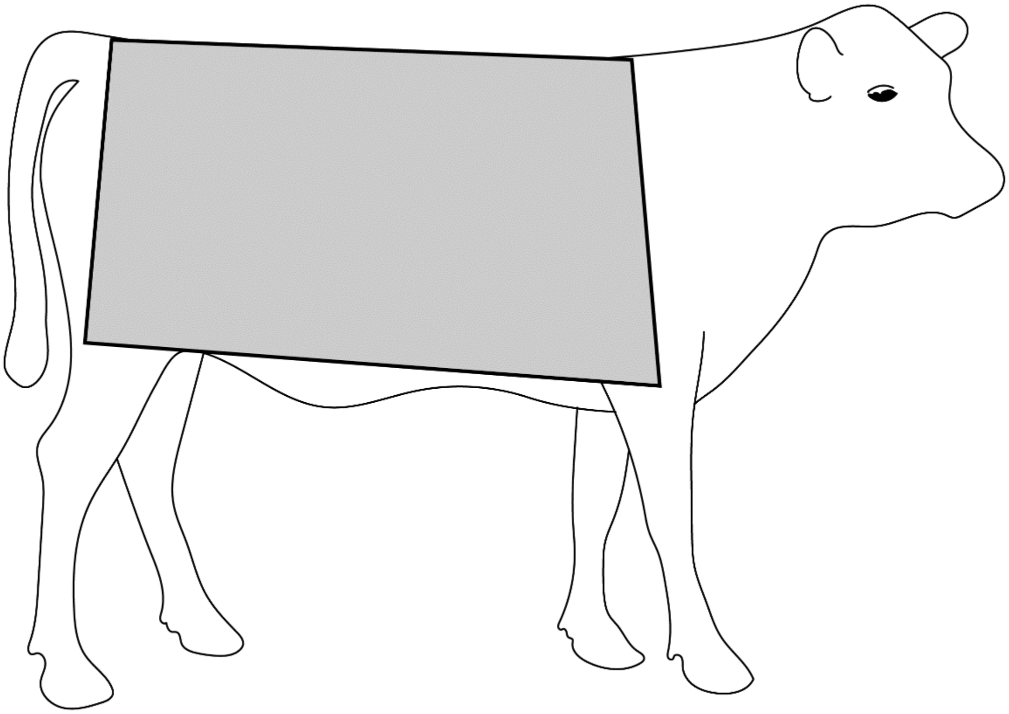

Figure 2.2: Mean ± SE surface temperature by AM / PM reading and pant score. The model included main effects of pant score, color, am/pm, interaction between pant score and am/pm reading with random effects for day and repeated effects for calf within pen. There was a significant interaction (*P* = 0.01) between pant score and am/pm reading. Within AM or PM readings, pant scores (pant score 0, white bar; pant score 1, grey bar; pant score 2, striped bar; pant score 3, dotted bar; pant score 4, black bar) not connected by a common letter were significantly (*P* <0.01) different.

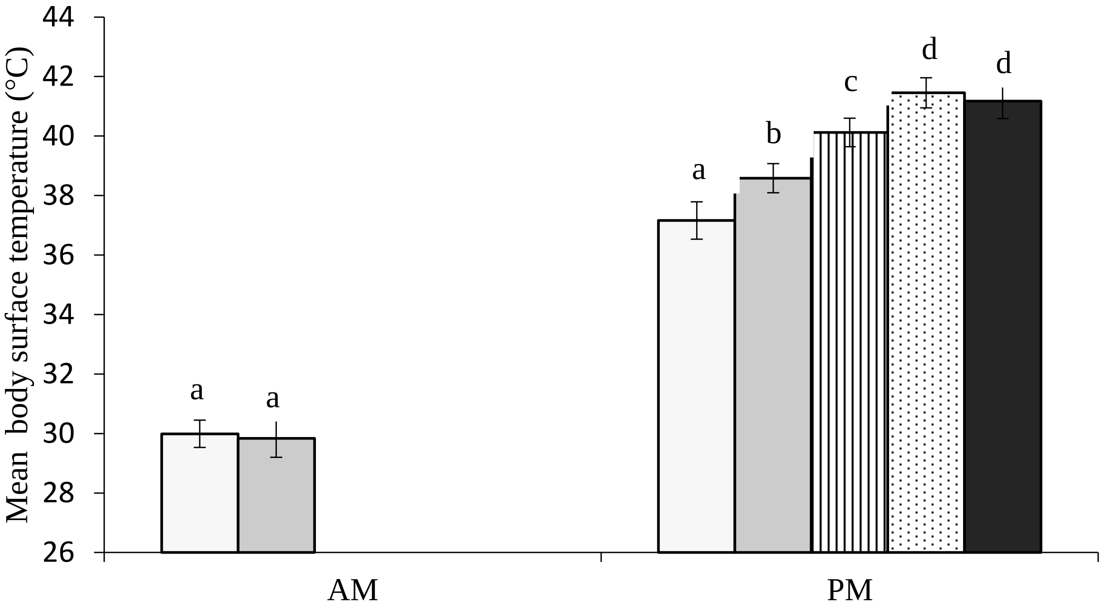

Figure 2.3: Mean ± SE temperature humidity index (THI) by pant score (A; pant score 0, white bar; pant score 1, grey bar; pant score 2, striped bar; pant score 3, dotted bar; pant score 4, black bar) and average surface temperature (B). Model included random effects for day and repeated effects for calf within pen. Pant score and average surface temperature were significantly (*P* <0.01) associated with THI. Within panel A, pant scores not connected by a common letter were significantly (*P* <0.01) different.

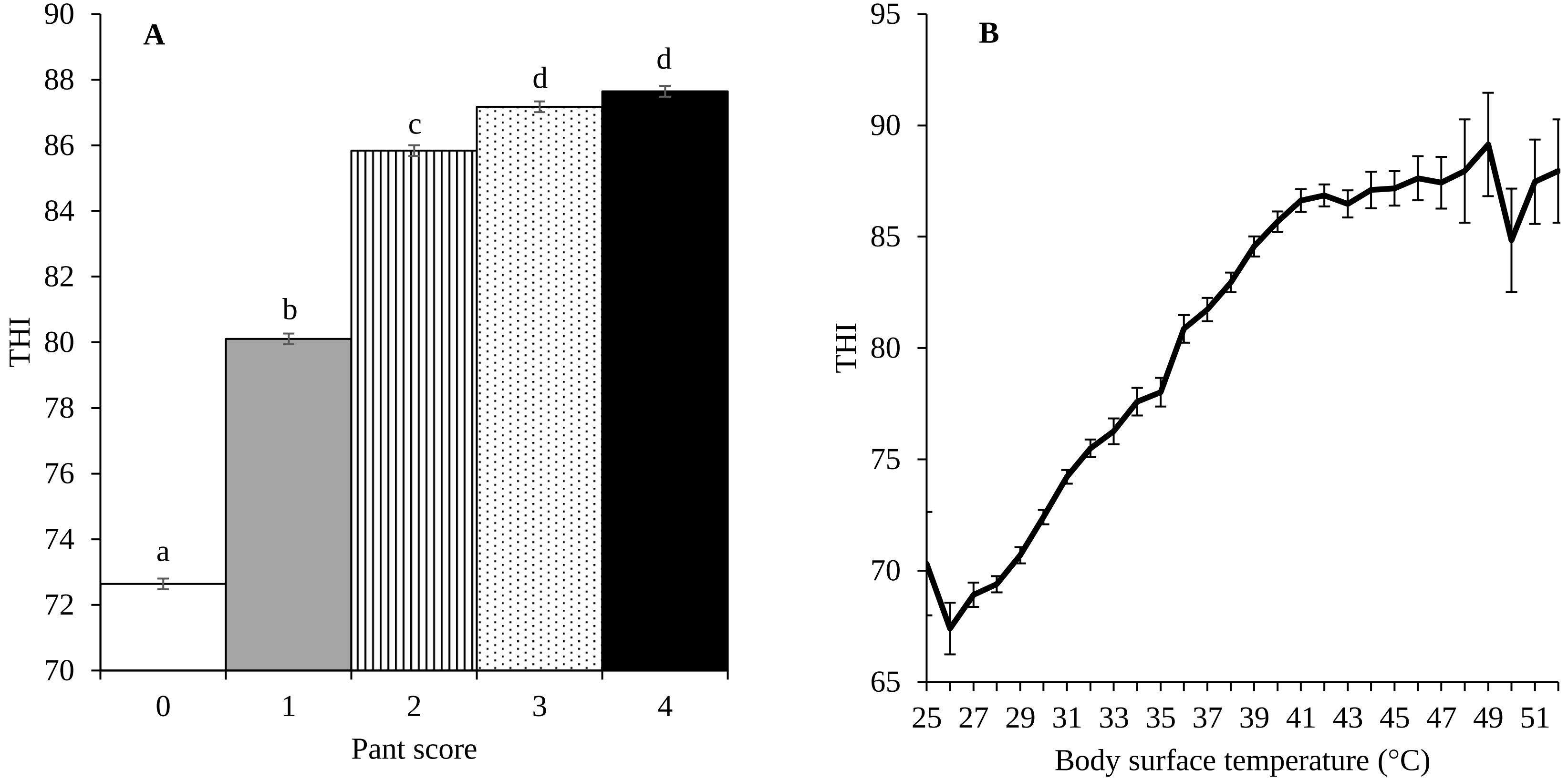

Figure 2.4: Decision Tree branches of variables included in final algorithm model in which the Decision Tree used to predict the afternoon panting score. Values in parenthesis are misclassified at each step. There were 39 misclassifications out of a total of 211.

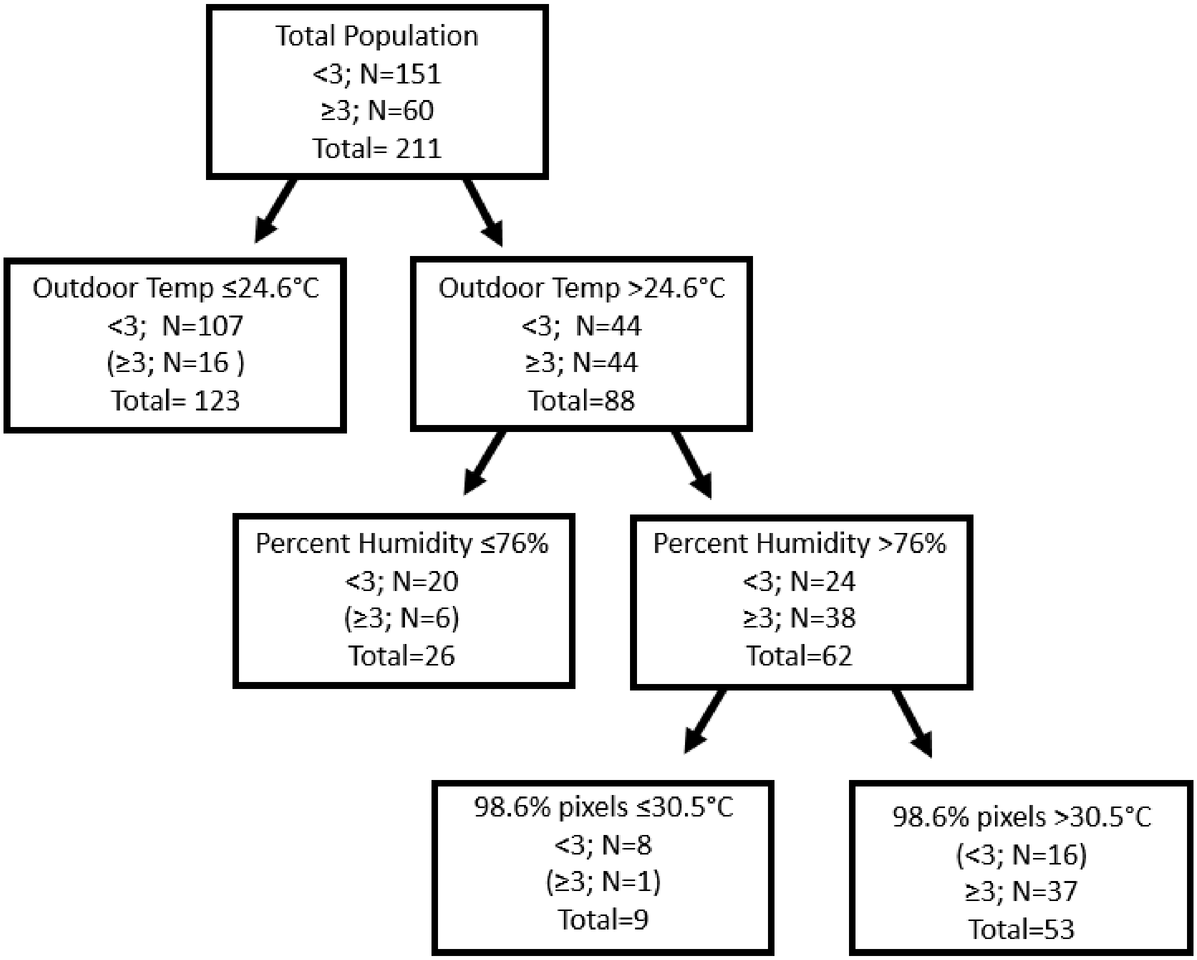

Table 2.1: Environmental conditions by trial day.

Day	Average temperature (°C)	Minimum temperature (°C)	Maximum temperature (°C)	Average humidity (%)	Minimum humidity (%)	Maximum humidity (%)	Average THI	Minimum THI	Maximum THI
1	28.38	22.5	33.4	73.67	59	91	79.24	72.00	84.66
2	30.01	24.4	34.8	68.21	57	80	81.08	74.16	86.62
3	31.53	24.4	38.3	70.08	53	86	83.45	74.76	90.09
4	30.44	24.4	37.3	70.29	43	92	81.59	75.36	88.26
5	30.20	23.7	35.8	67.75	48	90	81.10	73.97	86.13
6	27.19	21.6	32.9	78.25	60	94	77.93	70.66	84.33
7	23.48	17.7	28.0	72.46	53	91	71.58	63.74	76.83
8	23.57	16.8	29.1	76.71	60	94	71.95	62.26	78.94
9	26.55	20.2	32.6	80.46	62	94	77.16	68.10	84.70
10	31.37	24.9	38.4	69.13	47	91	82.81	74.76	89.85

Table 2.2: Number of observations per pant score by time of day. Pant scores were assigned in the following manner: 0 for normal respiration, 1 for elevated respiration, 2 for moderate panting and / or presence of saliva, 3 for open mouthed breathing, and 4 for severe open mouth breathing with tongue protruding.

	Pant Score				
Time	**0**	**1**	**2**	**3**	**4**
AM	520	24	0	0	0
PM	25	121	177	85	31

Table 2.3: Sensitivity, specificity, accuracy, and kappa values by algorithm type for predicting afternoon heat stress events in cattle using morning infrared surface temperature data, calf coat color, predicted high ambient temperature, predicted humidity, ambient temperature at 0600 h of trial day, and relative humidity at 0600 h of trial day.

Algorithm	**Sensitivity (95% CI)**	**Specificity (95% CI)**	**Accuracy (95% CI)**	**Kappa (95% CI)**
Decision Tree	63.2 (46.0, 77.7)	89.7 (79.3, 95.4)	80.2 (71.1, 87.1)	0.55 (0.38, 0.72)
Random Tree	50.0 (32.6, 67.3)	91.0 (81.8, 96.0)	80.2 (71.1, 87.1)	0.45 (0.25, 0.64)
Logistic Model Trees	67.7 (48.5, 82.7)	84.0 (73.3, 91.1)	79.2 (70.1, 86.2)	0.51 (0.33, 0.69)
Naïve Bayes	74.2 (55.1, 87.5)	80.0 (68.9, 88.0)	78.3 (69.0, 85.4)	0.51 (0.34, 0.68)
Naïve Bayes Tree	80.6 (61.9, 91.9)	77.3 (65.9, 85.9)	78.3 (69.0, 85.5)	0.53 (0.36, 0.69)
Logistic Base	61.3 (42.3, 77.6)	81.3 (70.3, 89.1)	75.5 (66.0, 83.1)	0.42 (0.23, 0.61)
Random Forest	25.0 (11.4, 45.2)	93.6 (85.0, 97.6)	75.4 (66.0, 83.1)	0.23 (0.03, 0.43)
Base First Tree	29.0 (14.9, 48.2)	93.3 (84.5, 97.5)	74.5 (65.0, 82.3)	0.27 (0.07, 0.46)
Decision Stump	0.0 (0.0, 15.0)	100.0 (94.2, 100.0)	73.6 (64.0, 81.5)	0.00 (NA, NA)
Neural Network	0.0 (0.0, 13.7)	100.0 (93.9, 100.0)	70.8 (61.0, 79.0)	0.00 (NA, NA)
Bayesian Logistic Regression	0.0 (0.0, 13.7)	100.0 (93.9, 100.0)	70.8 (61.0, 79.0)	0.00 (NA, NA)

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Chapter 3 - Associations between ambient summer temperature and daily respiratory disease diagnosis count in beef feeder animals

Introduction

Bovine respiratory disease (BRD) is the most common disease in commercial feedlots. A review published in 1997 estimated that $4 billion annually was associated to the detrimental effects of bovine respiratory disease in the United States.[1] Predisposing causes of BRD are typically synergistic and include age, stress and immunologic status of the animal.[2] Factors that contribute to stress include shipping, processing, nutritional changes, comingling, and extreme weather conditions.

Evidence has shown that ambient temperature affects feedlot cattle health, including BRD.[3] Peak incidence of BRD generally occurs in the fall and early winter.[3,4] This may be in part to the temperature changes but is also confounded by the highest number of cattle being on feed during this time. Associations between weather conditions (minimum temperature, wind speed, wind chill, etc) during the first forty five days after feedlot arrival and BRD found that several weather factors were significantly associated with BRD risk in the feedlot cattle populations.[5]

Feedlot cattle frequently endure extreme heat within cattle feeding regions of North America in the summer months, contributing to physiological stress. Theurer et al. found that cattle with Mannheimia haemolytica induced pneumonia had significantly more changes in behavior and increased biomarkers of stress and pain during high ambient temperatures (maximum temperature greater than 32°C.[6] However, there is little research showing the effects of heat waves on BRD morbidity. An enhanced understanding of how elevated environmental temperature affect BRD morbidity may allow more focused detection methods with the result being more effective management. Therefore, the objective of this retrospective study is to determine if the number of feedlot cattle treated for BRD is associated with summer weather variables in different lag periods from the day elevated environmental temperature occurred, and then to evaluate if there is a temperature threshold at which the risk for BRD treatment increases.

Data and statistical methods

Data source

This retrospective analysis used data from cattle in a south central Kansas feedlot from June to August 2006. The number of animals in the study varied daily during this period due to animals arriving and leaving the yard with the average daily animal count being 19,929. Animals were a mixture of steers (40%), heifers (46%), and bulls (<1%), some pens were a mixture of steers and heifers; therefore, the exact percentages of each are not available. Mean arrival weight was 335.5 kg. No data was recorded regarding the weight of the animals at the time of treatment.

The weather data were downloaded from R using an R package “weatherData”, which included average daily temperature on a daily basis. In this study, a count of cattle diagnosed and treated for BRD (cattle pulled and treated for respiratory disease) for every day during the summer period (June-August 2006) was available and was combined with the corresponding daily weather information. BRD risk was not able to obtained from the data set due to the daily number of cattle at risk not being available.

Statistical Methods

A Pearson correlation was performed to indicate the association between the weather data and diagnosis count. A significance test for every Pearson correlation was conducted to test whether the correlation was statistically significant at 0.05 significance level.

Considering there might be a delayed (or lagged) association between weather and the diagnosis count; for instance, yesterday's temperature might be a more important predictor of cattle being diagnosed with BRD today than today's temperature (i.e. the 1-day lagged association), a time lag analysis was conducted by shifting the weather factors forward in time and re-fitting the previous model. For every fitted model, an auto-correlation value was generated which indicates the association between weather and daily diagnosis count.

To determine the temperature threshold for increasing BRD diagnosis count during the summer period, a segmented linear regression was applied. The segmented linear regression, also known as piecewise regression, is a method to detect a threshold or a breaking point to partition the linear regression into several segments. In this study, regarding to the threshold temperature, we would compare the p values and regression coefficients of segmented regression models below and above the estimated threshold temperature.

Results

Time lags and correlation map

The auto-correlation value reached the peak with two days lag of average daily temperature and daily diagnosis counts (**Table 3.1**); indicating BRD diagnostic counts in the summer period were more associated with elevated temperatures two days prior than other lag periods tested. Association between diagnosis count and average ambient temperature two days prior are statistically significant at 0.05 significance level. Although not evidence of causation, elevated average ambient temperature is associated with increase in BRD diagnostic count two days later.

Break points for threshold temperature

Using the segmented linear regression approach, the estimated threshold daily average temperature for increasing diagnosis counts is 28.3° C. This result indicates that when the average daily temperature is above 28.3° C, cattle may be more likely to be diagnosed with BRD. When average temperature was greater than 28.3 C, each additional degree in temperature increased BRD diagnostic count approximately 3 head, with an coefficient of determination of 0.1242

From the p-value and coefficient of the linear model below and above the threshold temperature, there is a significant linear association between average daily temperature and the daily diagnosis count when the temperature was above 28.3° C whereas there is no significant association when the temperature was below 28.3° C. **Figure 3.1** shows the graphical representation of the association between BRD daily diagnostic count and average daily temperature. **Table 3.2** summarizes the effect of ambient temperature two days prior on BRD diagnostic count.

Discussion

BRD diagnosis counts are associated with daily temperature when average daily temperature is greater than or equal to 28.3° C. Knowing that extreme summer heat leads to increased diagnosis of BRD, heat mitigation strategies may be of benefit. The effects of heat mitigation strategies on performance have been extensively studied, but how these strategies affect respiratory health have not been researched. Shade and other heat mitigation strategies have been found to increase average daily gain and dry matter intake.[7,8] Since shade has been shown to lower ground surface temperature where cattle are housed, use of this heat mitigation strategy may be helpful to decrease the number of cattle treated for BRD in the summer mouths.[9]

More research would need to be done to see how heat mitigation strategies effect BRD diagnosis counts during extreme summer heat.

A two day lag exists between elevated average daily temperature and increased BRD diagnosis counts in one Kansas feedlot during the 2006 summer. Also a daily average threshold temperature of 28.3° C was identified. Enhanced detection methods for respiratory disease could be aimed for two days following any day that averaged or exceeded 28.3° C. If feedlot cowboys knew when the greatest impact of the extreme heat could be expected, increased personnel and resources could be allocated to help address the detrimental effects. By being better prepared, cattle welfare may be improved and disease could be addressed more efficiently.

Although an association, day delay and threshold temperature have been identified in this retrospective study, one limitation is only one Kansas feedlot and one summer were utilized in this study. Weather patterns in different regions of the country are different and these findings cannot be extrapolated to feedlots in different areas of the country. Furthermore, weather patterns change from year to year; utilizing multiple years would be helpful. Future studies of multiple feedlots, different demographic regions, and over multiple years would provide valuable additional information and would improve external validity. Another limitation of this study is only average daily temperature was studied. Further research could be done to see the effects of other temperature variables such as humidity, minimum temperature and temperature-humidity index on BRD diagnosis and time delay.

Conclusion

Our study showed that elevated average daily temperature is associated with an increase in Bovine Respiratory Disease diagnosis counts in one Kansas feedlot in one summer studied. The number of cattle diagnosed with BRD was highest two days following the elevated temperature. A threshold temperature was discovered in which the BRD diagnosis counts would increase. When average daily temperature was greater than or equal to 28.3° C, BRD diagnosis counts increased two days following the day with elevated temperature. These findings are important to help feedlot cowboys focus their timing of locating diseased cattle in the summer months. Being able to identify diseased animals early in the disease process increases chances for cure and improves animal welfare. Further research is needed in more locations over multiple years and including multiple weather variables.

Figure 3.1: Average daily temperature two days prior versus BRD diagnosis count. There is a significant linear association between average daily temperature and the daily diagnosis count when the temperature was above 28.3° C whereas there is no significant association when the temperature was below 28.3° C. When average temperature was greater than 28.3 C, each additional degree in temperature increased BRD diagnostic count approximately 3 head, with a coefficient of determination of 0.1242.

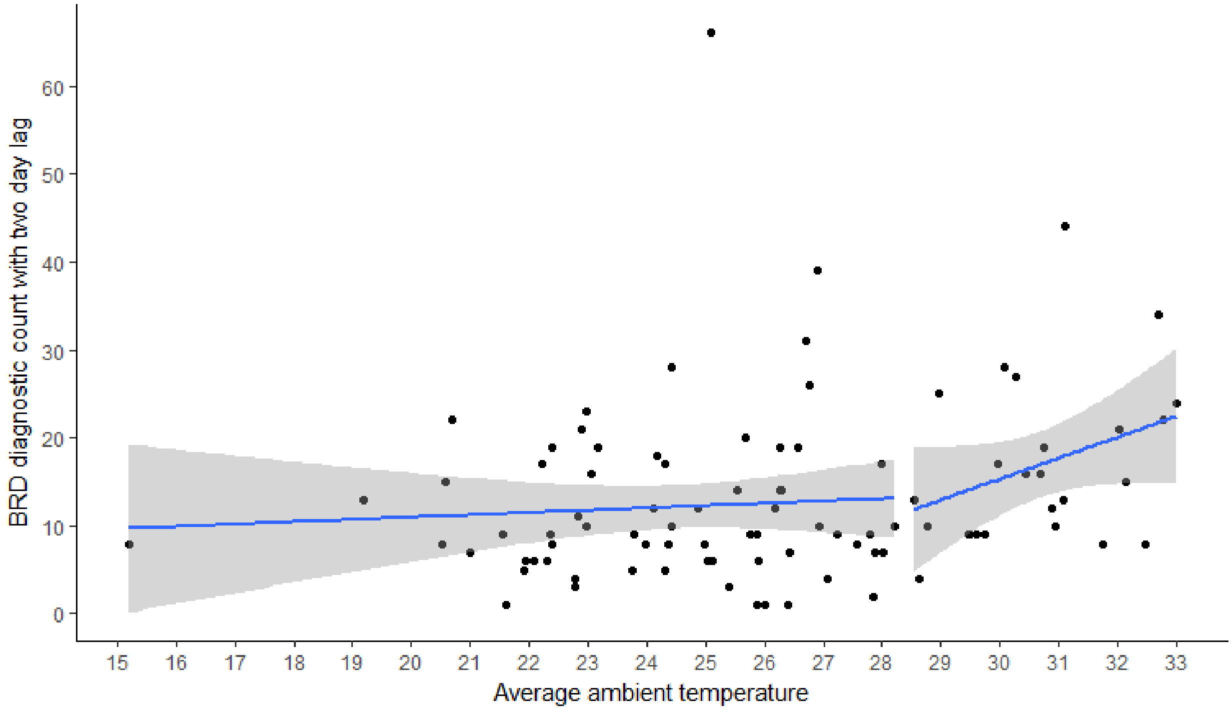

Table 3.1 Daily BRD diagnostic counts were compared with daily average temperature in various day delays. For example, today's average ambient temperature was compared with today's BRD diagnosis count (0 day lag), tomorrow's BRD diagnosis count (1 day lag), and so on. Correlation values were calculated in each day delay. The greatest correlation between average ambient temperature and BRD diagnostic count was with a two day lag.

Days Lag	Correlation Value
0	0.04
1	0.06
2	0.29
3	0.25
4	0.18
5	0.18
6	0.20
7	0.21
8	0.16

Table 3.2: Effect of ambient temperature two days prior on BRD diagnostic count. 90 days total were utilized in the study. *P* values less than 0.05 are considered significant.

Environmental temperature category	**Number of days**	**Slope of line**	**R-squared**
<28.3 °C	62	-0.3385	0.005047
≥28.3 °C	28	3.025*	0.1242

Note: * significance at 0.05 level

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