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Effectiveness of Different Shade Materials

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Abstract. *Cattle produced in open feedlots are vulnerable to a variety of weather events; under certain conditions heat events can be especially detrimental. Shade structures are often considered as one method of reducing cattle stress. A summer study was conducted during 2007 using instrumented shade structures in conjunction with meteorological measurements to estimate relative effectiveness of various shade materials for 'full sun' days. Polyethylene shade cloth was used in three of the comparisons and consisted of effective coverings of 100%, 60% with a silver reflective coating, and 60% black material with no reflective coating. Additionally, one of the structures was fitted with a poly snow fence with an effective shade of about 30%. Each shade structure contained a solar radiation meter and a black globe thermometer to measure radiant energy received under the shade material. Additionally, meteorological data were collected as a non-shaded treatment and included temperature, humidity, wind speed, and solar radiation. Analyses of the collected data focused on a physiological model that predicts cattle respiration rate based on relative humidity, ambient temperature, solar radiation and wind speed. An associated heat stress index was used to determine the effectiveness of the shading options. Analyses of the data revealed that time spent in the highest stress category was reduced by all shade materials. Moreover, significant differences (p<0.05) existed between all shade materials (compared to no-shade) for hourly summaries of estimated respiration rate during peak daylight hours and for 'full sun' days.*

Keywords. *Feedlot, Heat, Humidity, Physiological Model, Shade, Threshold, Temperature, Weather*

Introduction

Cattle have remarkable ability to cope with environmental stressors, and within limits can adjust physiologically, behaviorally, and immunologically to minimize adverse effects (Hahn, 1999). High ambient temperature (T_a, C) and humidity, in combination with a solar load and low air movement, can exceed stressor limits resulting in loss of productivity and even death of the animal (Hahn and Mader, 1997; Gaughan et al., 2000; Lefcourt and Adams, 1996; Mader et al., 1999). Recognizing the potential severity of a heat stress event, and providing access to stress-reducing measures such as shade structures, can increase animal performance and reduce death losses.

The use of shade structures can reduce the solar load by as much as 30% (Bond and Laster, 1975), and has received attention as a means of mediating summer heat loads (Brown-Brandl, et al., 2005; Eigenberg et al., 2005; Bond and Laster, 1975; Blackshaw and Blackshaw, 1994). Parker (1963) evaluated the effectiveness of 14 combinations of shading materials (variety of metal roofing material that were either natural or painted, and various ceiling materials under the roof) using a radiometer, thermocouples, and black globe thermometers; however, no direct animal response data were collected.

Animal response to shade was difficult to measure by traditional methods of growth and feed conversion. Animal variability and dynamics, coupled with uncontrollable periods of stressful conditions, made cause/effect evaluation difficult or impossible. Development of an animal response model was later based on data collected within environmental growth chambers under well controlled periods of stress (Hahn, et al., 1997). The growth chambers allowed development of tools to measure animal dynamics; two primary measures were respiration rate (RR) and body temperature. Using animal responses to the stressful conditions in well- controlled chambers, measurements on animals in uncontrolled stressful environments were made with the same dynamic measurement tools. Response measures of body temperature and RR have been collected in outdoor shaded and un-shaded pens with additional measurements of temperature, humidity, solar radiation, and wind speed (Brown-Brandl, et al., 2005). The work in these naturally occurring stressful environments led to a model that relates four environmental factors (temperature, solar radiation, wind speed, and humidity) to RR (Eigenberg, et al., 2005). The use of the physiological model to evaluate shade material provides a measure directly related to animal stress.

In addition to a more representative animal response measurement, the variety of shade materials currently available have characteristics different from those tested in the 1960s. Shade materials available today are typically made of polyethylene material and offer flexibility, lower cost and lighter weight than some of the more traditional building materials. The flexibility and light weight offer innovative structural components for fabrication of shaded facilities.

Objective

The objective was to evaluate several shade materials for feedlot cattle using predicted stress response of the animal based on measured environmental parameters.

Materials and Methods

An earlier report (Eigenberg et al., 2007) described a short-term evaluation of shade materials that was conducted during 2006; this study was primarily conducted to establish the material and methods protocols. A more extensive study was conducted during the 2007 summer at the USMARC. Shade structures were built and instrumented with data collected from June 11 through August 7, 2007. Shade treatments were provided by self-supporting shade structures constructed of metal tubing and 0.3 mm thick poly-vinyl shade cloth that provided a gradation of shade including 100%, 60% with a silver reflective coating on the cloth material (60%-S), and 60% shade constructed with a black cloth material (60%-B). Additionally, a partial shade was provided using a snow-fence in lieu of the shade cloth; this covering provided an estimated 30% shade (SNOW). The center pen (Fig. 1) provided a no-shade reference treatment (OPEN). The shade structures were built on concrete surfaced pens (3.6 m × 12 m) that were separated by 3.6 m. Pens were oriented north/south (Fig. 1). The structures covered the south end of the Shade treatment pens to a length of approximately 6 m, and across the full width of 3.6 m. The structures were 3 m high at the peak, with the east side extending down to a height of 2.4 m, and the west side to a height of 1.8 m.

Instrumentation was placed under all treatments (Fig. 1); the OPEN treatment included a commercial weather station (Davis Instruments, Hayward, CA, USA) which measured solar radiation, ambient temperature, relative humidity, wind speed and black globe temperature every 15 minutes. The instruments under the treatments (60%-S, 60%-B, and 100% shade) recorded solar radiation (Davis Instruments, Hayward, CA, USA) and black globe temperature measurements every two minutes. The SNOW treatment measurements of solar radiation and black globe temperatures were measured at 30 second intervals to better capture the highly variable nature of the changing shade pattern. All of the data were averaged, combined and compared on fifteen-minute intervals.

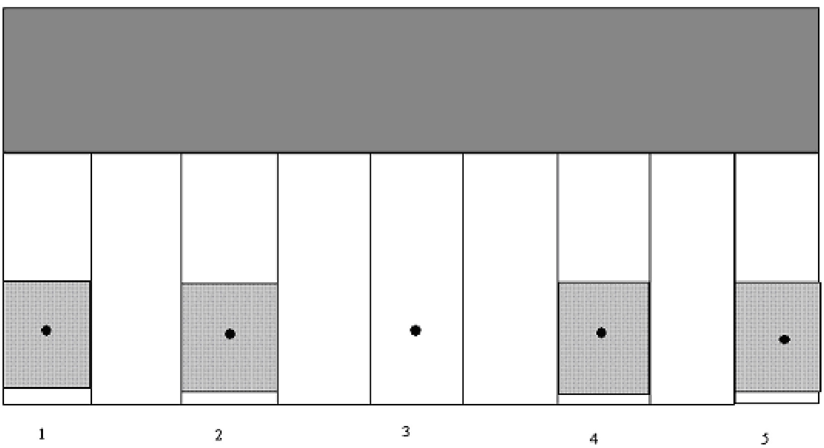

Figure 1. Drawing of shade study layout. Position 3 was location of weather station that monitored wind speed, relative humidity, solar radiation, and ambient temperature as reference for treatments. The treatment locations were 1) 100%, 2) 60%-silver, 3) open (no-shade), 4) 60%-black, 5) snow fence. The grey region at the top of the figure represents an existing metal livestock housing building.

Estimated RR was generated based on a model developed by Eigenberg et al. (2005) and shown as equation 1:

$$RR = 5.4*T_a + 0.58*RH - 0.63*WS + 0.024*RAD - 110.9 \qquad \text{(eq. 1)}$$

Where: RR is the respiration rate of cattle, breaths per min

T_a is ambient temperature, °C

RH is relative humidity, %

WS is wind speed, m/s

RAD is solar radiation, Watt/m^2

This equation was used to generate estimated RR values under each of the shade treatments to help assess the actual impact of shade on feedlot cattle. Data were combined from each treatment to generate 15 minute averages that were synchronized. The meteorological data (temperature, humidity, wind speed) were used in common for all treatments, with solar radiation data being the response variable to each shade treatment. The combined data were used to predict estimated RR for each treatment. Additionally, thresholds were established (Eigenberg et al., 2005) for ranges of RR. These values are:

Normal	RR ≤ 85 BPM
Alert	85 < RR ≤110 BPM
Danger	110 < RR ≤ 133 BPM
Emergency	RR > 133 BPM

The threshold values were applied to the estimated RR to establish shade treatment effectiveness. The solar radiation data, black globe thermometer data, and estimated RR data were analyzed using SAS PROC GLM Least Squares Means (SAS, 2000) for effect of treatment by hour. The statistical analyses also created probability tables allowing each treatment to be tested against the control treatment. Mean values with standard errors of all treatments were also generated using SAS.

Results and Discussion

The shades and equipment were set up and made operational on June 9, 2006; data acquisition occurred through August 29, 2006 with a total of 58 days of data being collected. The objective to evaluate shade material effectiveness was best accomplished using cloudless days. The dataset was evaluated visually to select days that represented 'full sun' days; Figure 2 provides an illustration of days that were selected to be used for the shade analysis. The study period included 39 days that were classified as cloudy leaving 19 days of 'full sun'.

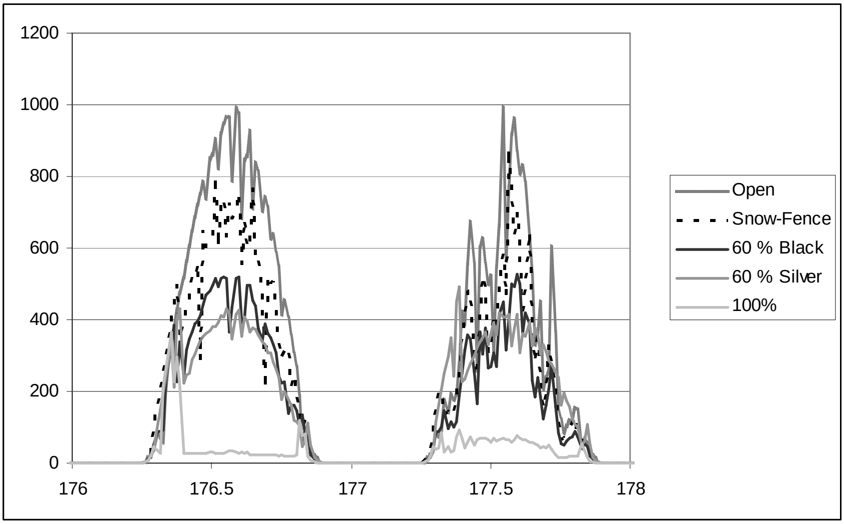

Figure 2. Comparison of sequential days for use in the analysis of the effect of shade; day 176 was chosen as representing 'full sun'. Day 177 was not included due to the effect of clouds.

The weather data were summarized for the 'full sun' days by computing hourly averages for the measurements of ambient temperature, dew point and wind speed. Those averages are shown in Figure 3 with ambient temperature displaying an anticipated semi-sinusoidal pattern. Dew point remained relatively constant over the 24-hour period, remaining between 16 and 19 degrees Celsius. The wind speed, on average, would pick up speed in the morning, reach maximum in the mid afternoon, and diminish around 9:00 PM.

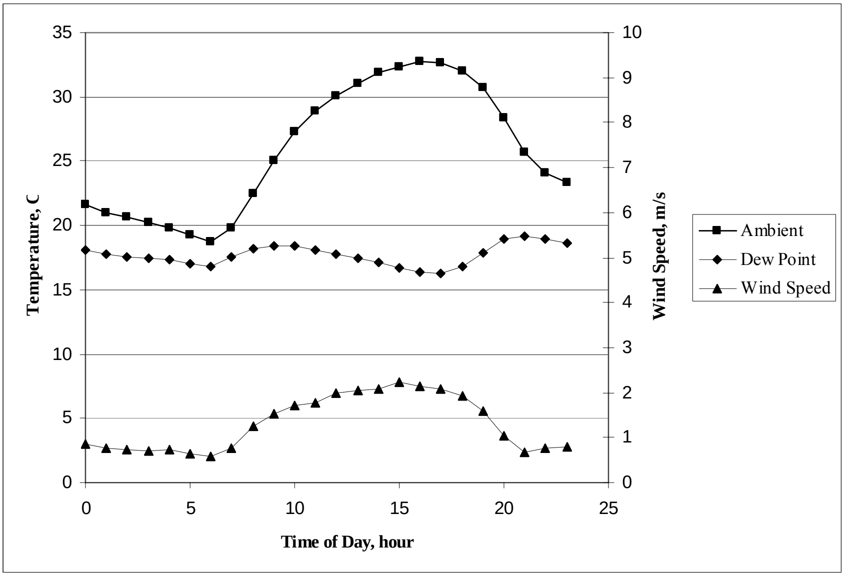

Figure 3. Weather data summarized as hourly averages (over 24 hours) for the 19 'full sun' days for the measurements of ambient temperature, dew point and wind speed (midnight = 0).

Gaughan et al. (2008) incorporated the black globe temperature into a new heat index for cattle. Valtorta et al. (1997) found that black globe temperature (BGT) is a good indicator of environmental stress in dairy cows. Black globe measurements were included in this study and are summarized as hourly averages (over 24-hours) for 'full sun' days in Figure 4. Figure 4 shows trends with the daytime BGT of the 100% material being lowest followed by 60%-S, 60%-B, SNOW, with OPEN treatment showing the highest BGT. An analysis of the period from 10:00 AM thru 6:00 PM indicated (data not shown) the average hourly BGT means to be different (p<0.05) for nearly all treatment/time combinations. The 11:00 AM treatments of 60%S and 60%-B were similar (p=0.34); 100% and 60%-S were similar at 5:00 PM and SNOW and 60%-B were similar at 6:00 PM (P=0.062).

Figure 5 summarizes solar radiation values over the 19 'full sun' days. The patterns for solar radiation resemble the black globe data in Figure 4. The trends for solar radiation daytime data begin with 100% as lowest solar radiation followed by 60%-S, 60%-B, SNOW and OPEN treatment at the highest solar radiation. A PROC GLM Least Squares Means analysis of the period from 10:00 AM thru 6:00 PM indicated (data not shown) the average hourly solar means to be different (p<0.05) for all treatment/time combinations.

Estimated RRs were computed (based on Eq. 1) for all treatments using weather data for solar radiation, ambient temperature, dew point and wind speed. The data were summarized to hourly intervals over the 19 days of 'full sun' and are plotted in Figure 6. All treatments showed significant mean differences when compared to the no-shade control; the estimated RRs decline with increasing shade cover (Table 1). Figure 7 (Eigenberg et al., 2005) is a plot resulting from a study conducted in 2001 using feedlot steers. The steers in that study were equipped with automated RR monitors measuring RR every 15 minutes 24 hours/day. Figure 7 was derived from that feedlot steer RR data as a summary of eight experimental periods, with a length of 4.5 days each. That same dataset (Eigenberg et al., 2005) was used to develop equation 1. Applying equation 1 to meteorological datasets to predict respiration rates (Fig. 6) produces an estimated response that appears similar to the actual feedlot steer data. Comparison of Figure 6 and Figure 7 supports a physiological model approach to shade material evaluation. The use of RR to determine shade effectiveness allows critical evaluation of a material's ability to reduce animal thermal stress during full sun exposure.

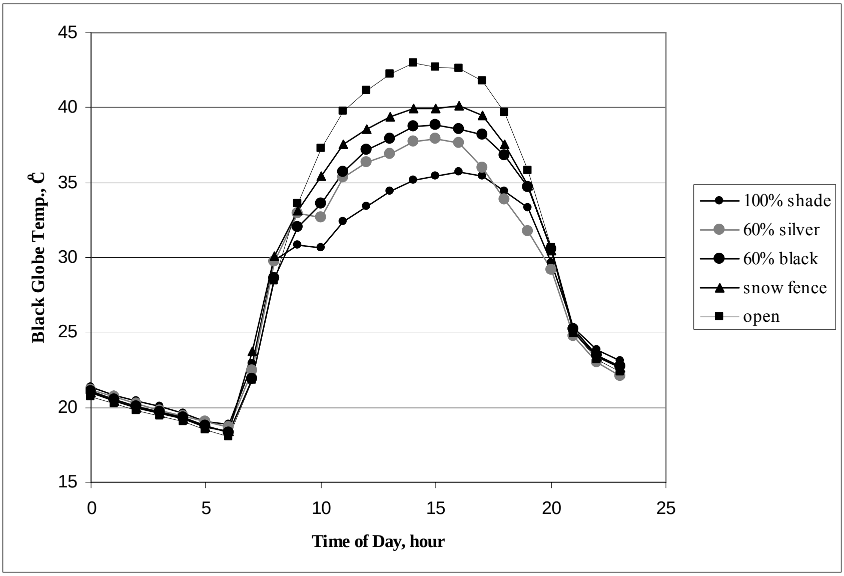

Figure 4. Black globe measurements summarized as hourly averages (over 24 hours) for the 19 'full sun' days (midnight = 0).

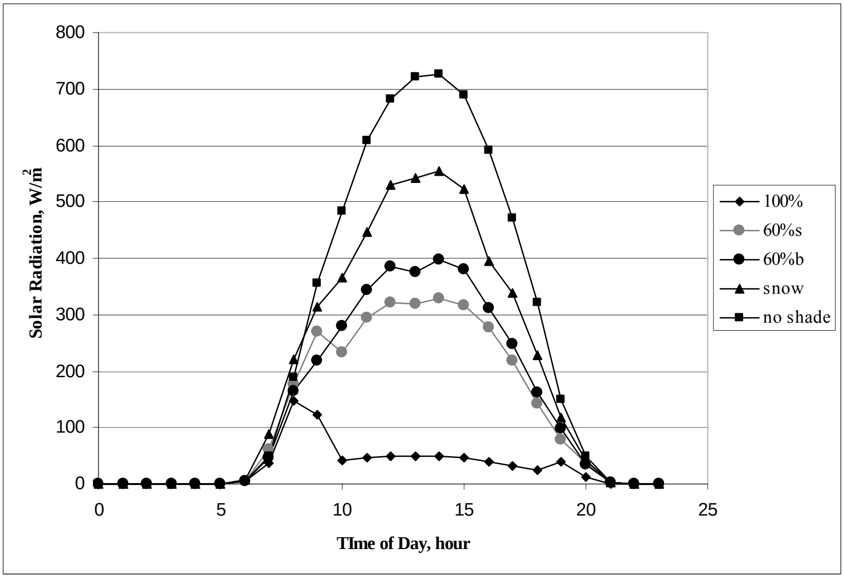

Figure 5. Solar radiation measurements summarized as hourly averages (over 24 hours) for the 19 'full sun' days (midnight = 0).

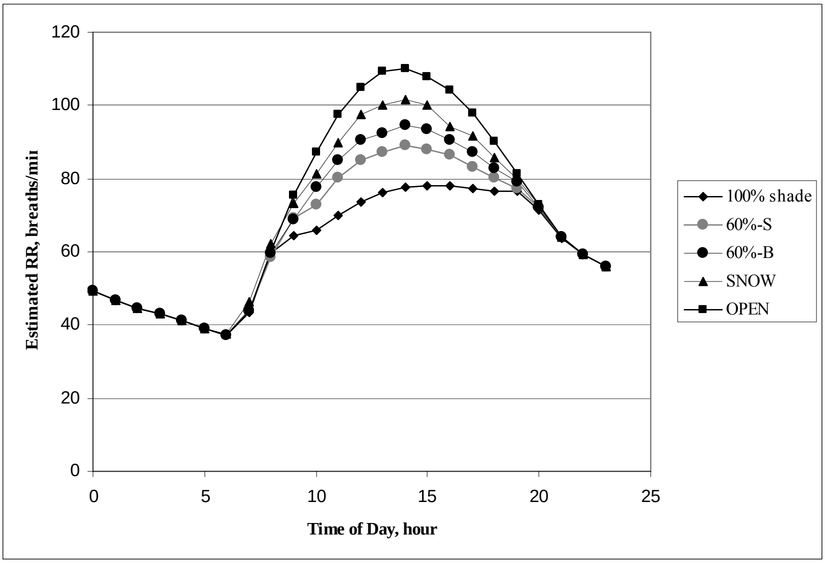

Figure 6. Estimated RR measurements summarized as hourly averages (over 24 hours) for the 19 'full sun' days (midnight = 0).

Table 1. Mean values as determined by SAS PROC (means shown with standard errors).

Time/ Trmt	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
Open, Est RR	88.9^{a} 6.5	98.2^{a} 6.9	105.0^{a} 7.4	109.2^{a} 8.3	109.9^{a} 9.2	108.0^{a} 8.8	104.1^{a} 9.0	97.9^{a} 8.7	90.2^{a} 8.7
Snow Est RR	81.3*^{b} 8.6	89.8*^{b} 9.6	97.4*^{b} 8.0	100.0*^{b} 8.9	101.7*^{b} 9.2	100.3^{*b} 9.2	94.1*^{b} 11.2	91.7*^{b} 8.2	85.7*^{b} 8.6
60% b Est RR	78.5*^{c} 6.5	85.2*^{c} 7.1	90.7^{*c} 7.6	92.4*^{c} 8.4	94.5*^{c} 8.9	93.6*^{c} 8.7	90.6*^{c} 9.0	87.1*^{c} 8.6	82.7*^{c} 8.3
60% s Est RR	75.6*^{d} 6.8	82.2*^{d} 7.6	86.8^{*d} 8.2	89.0*^{d} 8.6	90.9*^{d} 9.3	90.0*^{d} 9.6	88.1*^{c} 10.3	84.4*^{d} 9.9	80.9*^{c} 9.2
100% Est RR	66.3*^{e} 6.3	70.1*^{e} 7.3	73.5^{*e} 8.0	76.2*^{e} 8.5	77.8*^{e} 9.0	77.9*^{e} 8.8	77.9*^{d} 9.1	77.2*^{e} 8.4	76.6*^{d} 8.1

Asterisks indicate that the means are significantly different from the control treatment of open (p<0.05). Letters that differ in a column indicate estimated RR average values that are statistically different (p<0.05) other estimated RR averages in the column.

A comparison was made of time spent in each of the four thermal stress categories. The data were examined on 15-minute intervals and only midday data considered (10:00 AM – 6:00 PM), with the resulting stress being cumulated in one of the four stress categories. The total time spent was converted to percentages with the results displayed in Figure 8. The nineteen days analyzed revealed some interesting patterns. One-hundred percent shade cloth reduced the estimated stress level (based on solar radiation reduction) so that the cattle were exposed to the Normal category environmental condition 96% of the time. Figure 6 shows that 60%-S shade cloth resulted in the majority of time having been spent in the Normal category (about 77%), and 23% in the Alert category. Sixty percent black shade cloth (60%-B) was similar to 60%-S but showed more time in the Alert category at about 30% and less time in the Normal category (70%). Under 0.5% of the time was spent in the danger category for 60%-B. The SNOW treatment saw the first notable occurrence of the Danger category (about 4%), with Alert at 38%, and Normal at 58%. The reference treatment of OPEN resulted in about 14% of the time spent in Danger, 41% in Alert, and 44% in Normal for the selected period of 19 days.

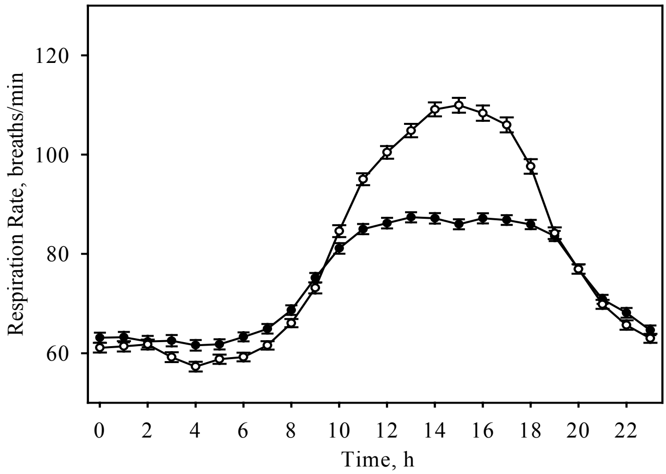

Figure 7. Respiration rates for steers in a 2001 study summarized over eight experimental periods of 4.5 day duration showing shade ( ) and no-shade ( ) treatments with standard error (midnight = 0). Figure from Eigenberg et al., 2005.

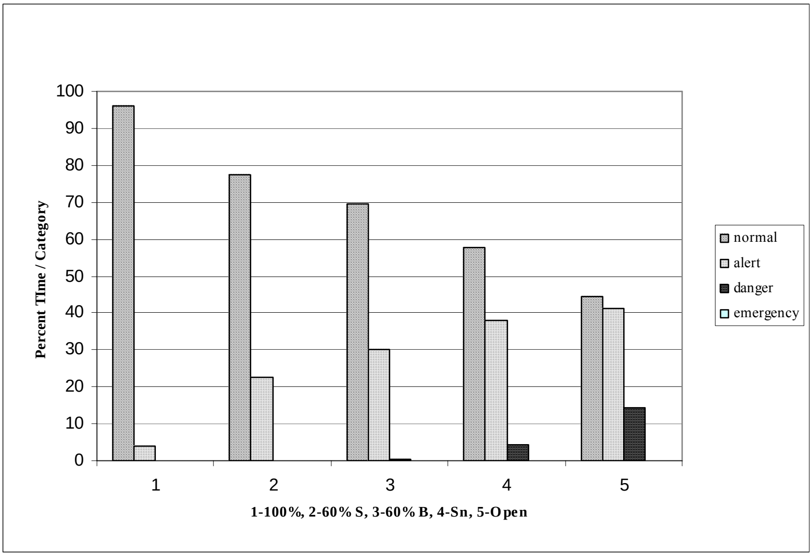

Figure 8. Comparison of time spent in each of the four thermal stress categories. The data were examined on 15-minute intervals during a 10:00 a.m. – 6:00 p.m. time span. The total time spent in each category was converted to percentages as displayed in this figure.

Generally, any of the shade materials reduced the thermal stress levels compared to an open lot; the snow fence reduced the time in the Danger category by a factor of nearly three. Shading of 60% or more nearly eliminated time spent in the Danger category. The 100% shade material nearly eliminated time in the Alert category (4%).

Sixty percent-silver shade cloth costs approximately 40% more than sixty percent-black shade cloth; one hundred percent shade cloth costs approximately 20% less than sixty percent-black shade cloth. The snow fence is the least expensive (costing about 50% less than sixty percent black) and may have additional advantages of catching less wind, as well as less chance for snow accumulation. Many factors must be considered in the design of a shade structure; this work will help direct future research efforts.

Conclusion

Several shade materials were evaluated using environmental measurements, which were then applied to a cattle physiological model. The study was conducted from mid-June through early-August of 2007. The material comparisons were based on days identified as being non-cloudy days. All of the tested shade materials reduced predicted heat stress and the associated time spent in more stressful conditions, when compared to the no- shade control treatment. The results represented in this paper are based on instrument-based predicted cattle responses. A study is planned to validate this methodology by evaluating feedlot cattle response under selected shade materials.

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