

Shade material evaluation using a cattle response model and meteorological instrumentation

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Abstract Shade structures are often considered as one method of reducing stress in feedlot cattle. Selection of a suitable shade material can be difficult without data that quantify material effectiveness for stress reduction. A summer study was conducted during 2007 using instrumented shade structures in conjunction with meteorological measurements to estimate relative effectiveness of various shade materials. Shade structures were 3.6 m × 6.0 m × 3.0 m high at the peak and 2.0 m high at the sides. 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. Data analyses was conducted using a physiological model based on temperature, humidity, solar radiation and wind speed; a second model using black globe temperatures, relative humidity, and wind speed was used as well. 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 during peak daylight hours and for ‘full sun’ days.

Keywords Feedlot · Heat load index · Meteorological [data] · Physiological model · Shade materials

Introduction

Cattle have a 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 (Leftcourt and Adams 1996; Hahn and Mader 1997; Mader et al. 1999; Gaughan et al. 2000). 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 solar load by as much as 30% (Bond and Laster 1975), and has received attention as a means of mediating summer heat loads (Bond and Laster 1975; Blackshaw and Blackshaw 1994; Brown-Brandl et al. 2005; Eigenberg et al. 2005). 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.

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Animal response to shade is 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 made 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.

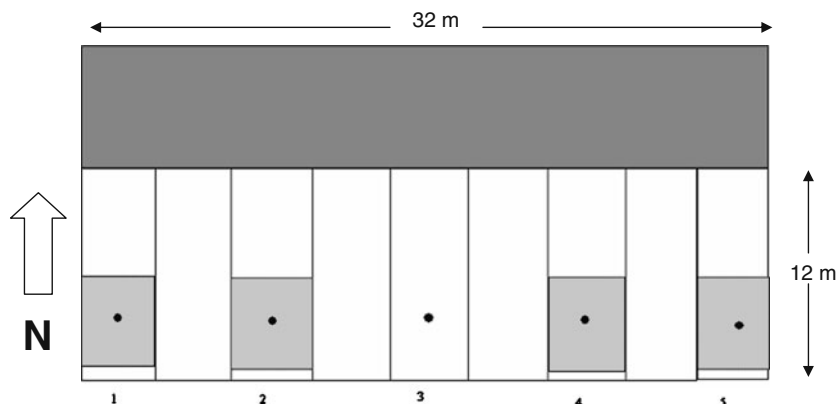
It is the objective of this work to evaluate several shade materials for feedlot cattle using the predicted stress response of the animal based on measured environmental parameters.

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 conducted primarily to establish the material and methods protocols. A more extensive study was conducted during the summer of 2007 at the US Meat Animal Research Center. Shade structures were built and instrumented with data collected from 11 June through 7 August 2007. The 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 in 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), which measured solar radiation, ambient temperature, relative humidity, wind speed and black globe temperature every 15 min. The treatments (60%-S, 60%-B, and 100% shade) recorded solar radiation (Davis Instruments) and black globe temperature measurements every 2 min. The SNOW treatment measurements of solar radiation and black globe temperatures were measured at 30 s intervals to better capture the highly variable nature of the changing shade pattern. All the

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



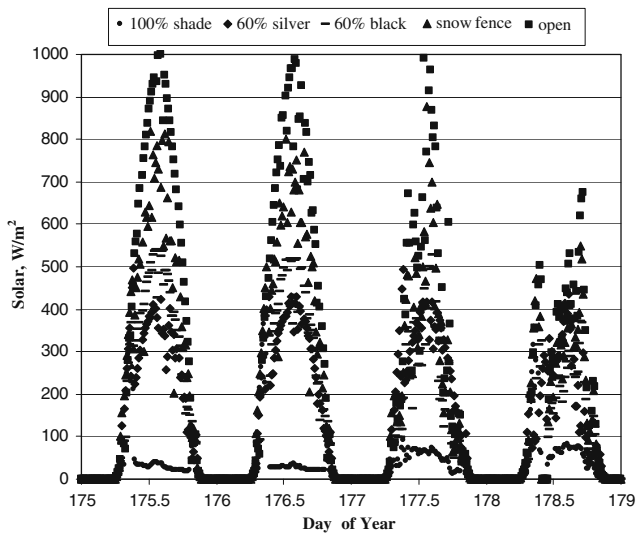


Fig. 2 Comparison of sequential days for use in the analysis of the effect of shade; days 175 and 176 were chosen as representing ‘full sun’. Days 177 and 178 were not included due to the effect of clouds

data were averaged, combined and compared on 15-min intervals.

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

$$RR = 5.4 \cdot T_a + 0.58 \cdot RH - 0.63 \cdot WS + 0.024 \cdot RAD - 110.9 \quad (1)$$

Where:

RR is the respiration rate of cattle (breaths per min)
 T_a is ambient temperature (°C)

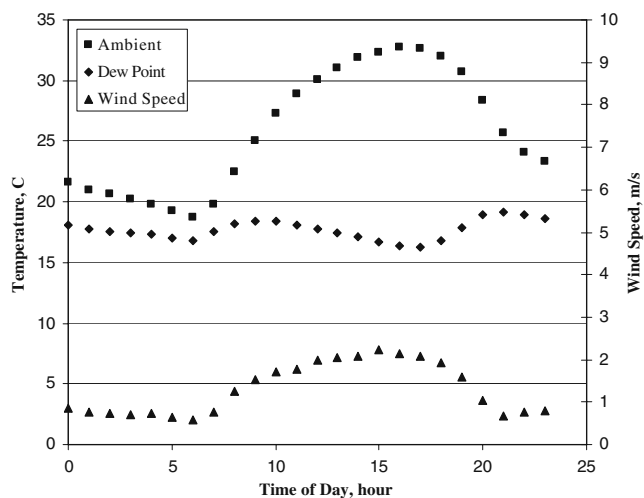


Fig. 3 Weather data summarized as hourly averages (over 24 h) for the 19 ‘full sun’ days for the measurements of ambient temperature, dew point and wind speed (midnight=0)

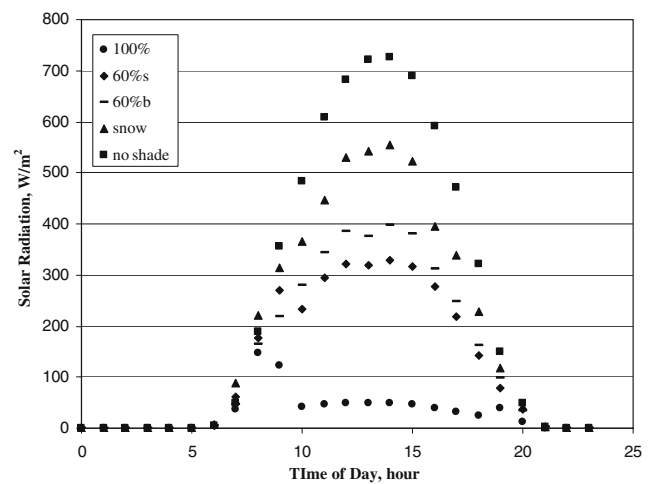


Fig. 4 Solar radiation measurements summarized as hourly averages (over 24 h) for the 19 ‘full sun’ days (midnight=0)

RH is relative humidity (%)
 WS is wind speed (m/s)
 RAD is solar radiation (Watt/m²)

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-min 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.

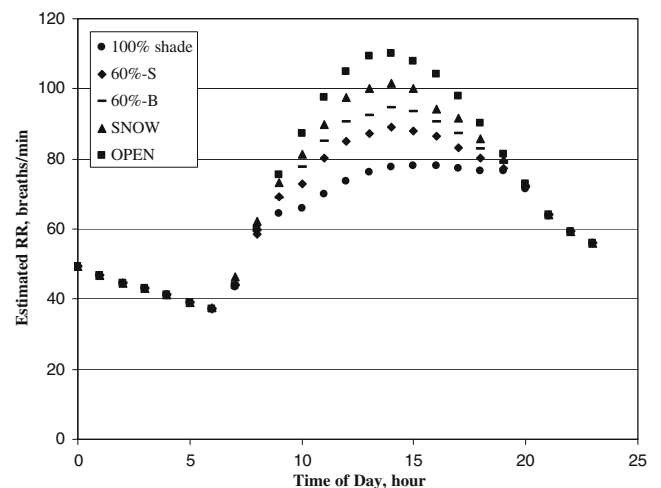


Fig. 5 Estimated respiration rate (RR; based on Eq. 1) summarized as hourly averages (over 24 h) for the 19 ‘full sun’ days (midnight=0)

Table 1 Mean values as determined by SAS PROC means shown with standard errors. Letters that differ in a column indicate estimated respiration rate (Est RR) average values that are statistically unlike ($P < 0.05$) other estimated RR averages in the column

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

*Means are significantly different from the control treatment OPEN ($P < 0.05$)

Additionally, thresholds were established (Eigenberg et al. 2005) for ranges of RR. These values are:

Normal	$RR \leq 85$ BPM
Alert	$85 < RR \leq 110$ BPM
Danger	$110 < RR \leq 133$ BPM,
Emergency	$RR > 133$ BPM

The threshold values were applied to the estimated RR to establish the shade treatments effectiveness.

Furthermore, the black globe measurements were used to calculate heat load index (HLI) values (Gaughan et al. 2008). The relationship for HLI is given by:

$$HLI_{BG>25} = 8.62 + (0.38 \cdot RH) + (1.55 \cdot BG) - (0.5 \cdot WS) + e^{(2.4 - WS)} \quad (2)$$

Where:

- HLI is the heat load index
- BG is black globe temperature (°C)
- RH is relative humidity (%)
- WS is wind speed (m/s)

A threshold HLI above which cattle of different genotypes gain body heat was developed for 7 genotypes (Gaughan et al. 2008). The threshold for unshaded black *Bos taurus* steers was 86, and this value was used for threshold analysis of the data in this study.

The solar radiation data, black globe thermometer data, and estimated RR data were analyzed using SAS PROC GLM Least Squares Means (SAS Institute 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 11 June 2007; data acquisition occurred through 7 August 2007, with a total of 58 days of data being collected. The objective to evaluate shade material effectiveness was best accomplished on cloudless days. The dataset was evaluated visually to select days that represent ‘full sun’ days; Fig. 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’.

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 Fig. 3 with ambient temperature displaying an anticipated semi-sinusoidal pattern. Dew point remained relatively constant over the 24-h period,

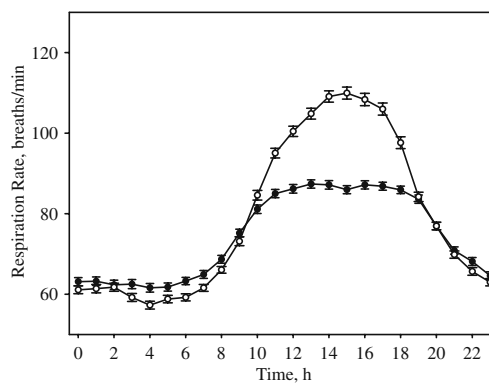


Fig. 6 Respiration rates for steers in a 2001 study summarized over eight experimental periods of 4.5-day duration showing shade (●) and no-shade (○) treatments with standard error (midnight=0). Figure from Eigenberg et al. 2005

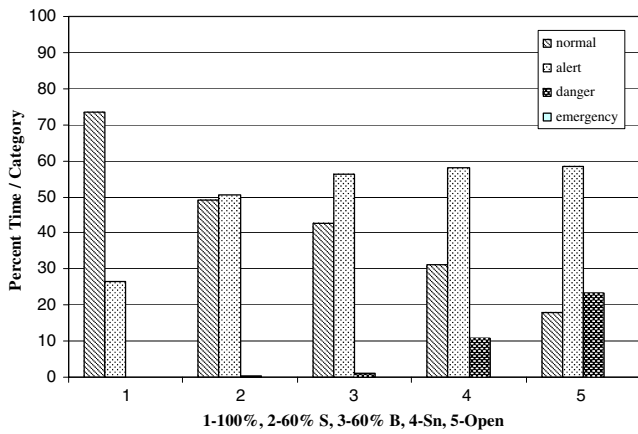


Fig. 7 Comparison of time spent in each of four thermal stress categories based on an estimated RR. The data were examined on 15-min intervals during a 10:00 a.m.–6:00 p.m. time span. The total time spent in each category was converted to percentages as displayed in this figure

remaining between 16 and 19°C. The wind speed, on average, would pick up speed in the morning, reach its maximum in the mid-afternoon, and diminish around 9:00 p.m.

Figure 4 summarizes solar radiation values over the 19 ‘full sun’ days. The trends for solar radiation daytime data begin with 100% as lowest followed by 60%-S, 60%-B, SNOW and OPEN treatment at the highest. A PROC GLM lsmeans analysis of the period from 10:00 a.m. through 6:00 p.m. indicated the average hourly solar means to be different ($P < 0.05$) for all treatment/time combinations (data not shown).

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

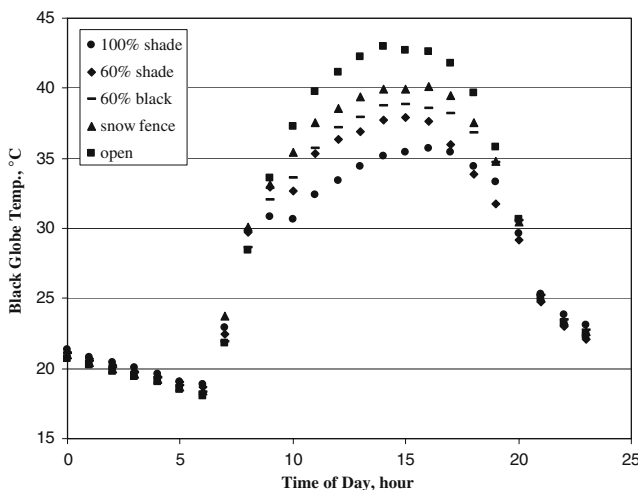


Fig. 8 Black globe measurements summarized as hourly averages (over 24-h) for the 19 ‘full sun’ days (midnight=0)

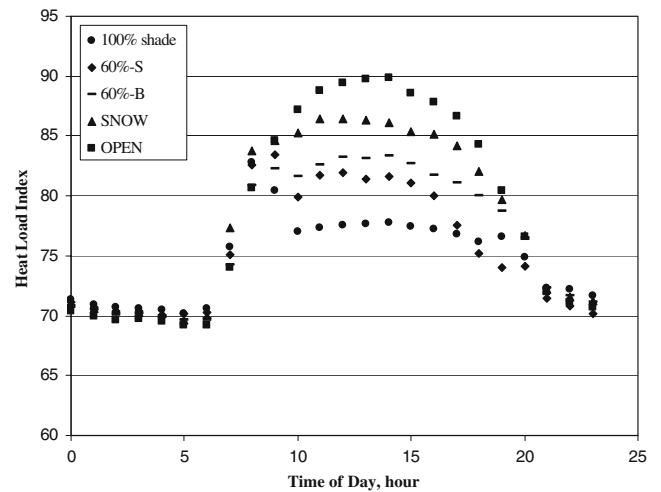


Fig. 9 Heat load index (based on Eq. 2) summarized as hourly averages (over 24-h) for the 19 ‘full sun’ days (midnight=0)

sun’ and are plotted in Fig. 5. All treatments show significant mean differences by all treatments when compared to the no-shade control; the estimated RRs decline with increasing shade cover (Table 1). Figure 6 (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 min, 24 h/day. Figure 6 was derived from this 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 Eq. 1. Applying Eq. 1 to meteorological datasets to predict RRs (Fig. 5) produces an estimated response that appears similar to the actual feedlot steer data. Comparison of Figs. 5 and 6 supports a physiological model approach to shade material evaluation. The use of RR to determine

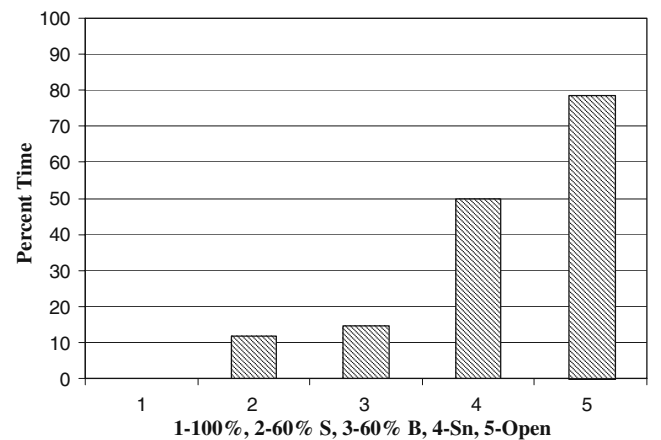


Fig. 10 Comparison of time spent in excess of the HLI threshold of 86 for black *Bos taurus* steers. The data were examined on 15-min intervals during a 10:00 a.m.–6:00 p.m. time span. The total time spent in each category was converted to percentages as displayed in this figure

shade effectiveness allows critical evaluation of a material's ability to reduce animal thermal stress during full sun exposure.

A comparison was made of time spent in each of the four thermal stress categories. The data were examined on 15-min intervals and only midday data considered (10:00 a.m.–6:00 p.m.), with the resulting stress being accumulated in one of the four stress categories. The total time spent was converted to percentages, with the results displayed in Fig. 7. The 19 days analyzed revealed some interesting patterns. The 100% 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 73% of the time, with about 27% of the time in the alert category, and no time spent in the danger category. Figure 7 shows that 60%-S shade cloth resulted in time spent in the Normal category of about 49%, with 51% in the Alert category. The 60% black shade cloth (60%-B) was similar to 60%-S but showed more time in the Alert category at about 56%, and less time in the Normal category (43%). Under 2% 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 11%), with Alert at 58%, and Normal at 31%. The reference treatment of OPEN resulted in about 23% of the time spent in Danger, 59% in Alert, and 18% in Normal for the selected period of 19 days.

Gaughan et al. (2008) incorporated the black globe temperature into a heat index, HLI, for cattle as detailed in **Materials and methods**. Black globe measurements are shown in Fig. 8 for all shade treatments. The black globe measurements were used to calculate HLI values (Eq. 2) in combination with measures of RH and WS. The HLI values are summarized as hourly averages (over 24-h) for 'full sun' days in Fig. 9. Figure 9 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. A PROC GLM lsmeans analysis of the period from 10:00 a.m. through 6:00 p.m. indicated (data not shown) the average hourly BGT means to be different ($P < 0.05$) for all treatment/time combinations with several exceptions. The 11:00 a.m. treatments of 60%S and 60%-B are similar ($P = 0.15$); 100% and 60%-S are similar at 5:00 p.m. and SNOW ($P = 0.18$); and 100% and 60%-S are similar at 6:00 PM ($P = 0.11$).

Threshold values were developed (Gaughan et al. 2008) for a variety of genotypes of cattle; the threshold for unshaded black *B. taurus* steers is 86 and was used as the reference value in this study. Time spent above this threshold for each of the shade treatments was examined on 15-min intervals and only midday data was considered (10:00 a.m.–6:00 p.m.) with stress being accumulated either above or below a HLI of 86. The total time spent above

HLI of 86 is displayed in Fig. 10. The 100% shade cloth eliminated time spent at an HLI above 86. Figure 10 shows that 60%-S resulted in about 12% of time above the reference HLI compared to 60%-B with 14% of the time above HLI of 86. The SNOW shade and the OPEN treatments showed 50% and 78% time spent, respectively, above the HLI of 86.

The danger category of the estimated RR and the HLI threshold of 86 resulted in similar estimates of shade effectiveness. The estimated RR showed reductions of time spent in the danger category of 54.3%, 95.3%, 99.2% and 100% for SNW, 60%-B, 60%-S, and 100% respectively. The HLI resulted in reductions of time spent above the threshold for *B. taurus* steers of 36.3%, 81.5%, 85.1%, and 100% for treatments of SNW, 60%-B, 60%-S, and 100% respectively.

The estimated RR response to the treatments showed that 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 about two. Shading of 60% or more nearly eliminated time spent in the Danger category. The 100% shade material greatly reduced time in the Alert category (to about 26%).

The 60%-S shade cloth costs approximately 40% more than 60%-B shade cloth; 100% shade cloth costs approximately 20% less than 60%-B shade cloth. The snow fence is the least expensive (costing about 50% less than 60%-B) 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 of this study are instrument-based predicted cattle responses; validation would require evaluation of feedlot cattle response under selected shade materials.

References

- Blackshaw J, Blackshaw A (1994) Heat stress in cattle and the effect of shade on production and behaviour: a review. Aust J Exp Agric 34:285–295. doi:10.1071/EA9940285

- Bond T, Laster D (1975) Influence of shading on production of Midwest feedlot cattle. *Trans ASAE*: 957–959
- Brown-Brandl TM, Eigenberg RA, Nienaber JA, Hahn GL (2005) Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, Part 1: Analyses of indicators. *Biosystems Eng* 91(4):451–462. doi:10.1016/j.biosystemseng.2004.12.006
- Eigenberg RA, Brown-Brandl TM, Nienaber JA, Hahn GL (2005) Dynamic indicators of heat stress in shaded and non-shaded feedlot cattle, Part 2: Predictive relationships. *Biosystems Eng* 91(1):111–118. doi:10.1016/j.biosystemseng.2005.02.001
- Eigenberg RA, Brown Brandl TM, Nienaber JA (2007) Shade material evaluation using a cattle response model. In: Proceedings of American Society of Agri Engineers Annual International Meeting, 17–20 June 2007, Minneapolis, MN. Paper no. 074082. Available at: <http://asae.frymulti.com/techpapers.asp?confid=min2007>
- Gaughan JB, Holt SM, Hahn GL, Mader TL, Eigenberg RA (2000) Respiration rate—is it a good measure of heat stress in cattle? *Asian Aust J Anim Sci* 13(suppl C):329–332
- Gaughan JB, Mader TL, Holt SM, Lisle A (2008) A new heat load index for feedlot cattle. *J Anim Sci* 86(1):226–234
- Hahn GL (1999) Dynamic responses of cattle to thermal heat loads. *J Anim Sci* 77:10–20
- Hahn GL, Mader TL (1997) Heat waves in relation to thermoregulation, feeding behavior and mortality of feedlot cattle. In Proceedings, Fifth International Livestock Environment Symp (1):563-571 ASAE SP01-97, Minneapolis, MN
- Hahn GL, Parkhurst AM, Gaughan JB (1997) Cattle respiration rate as a function of ambient temperature. Paper MC97-121. ASAE, St. Joseph, MI
- Leftcourt AM, Adams WR (1996) Radiotelemetry measurement of body temperatures of feedlot steers during summer. *J Anim Sci* 74:2633–2640
- Mader TL, Dahlquist JM, Hahn GL, Gaughan JB (1999) Shade and wind barrier effects on summertime feedlot cattle performance. *J Anim Sci* 77:2065–2072
- Parker BF (1963) Heat transmission characteristics of sloped roofs exposed to solar radiation. *Trans ASAE* 6(1):1–5
- SAS Institute (2000) SAS System for Windows. Version 8. SAS Institute, Cary, NC