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Impact of Night-Time Cooling on Heat Load in Feedlot Cattle

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Abstract

The current study was undertaken at the University of Queensland (UQ) to further investigate and quantify the effects of summer conditions on the physiology (rumen temperature, blood metabolites, panting) and performance (health, growth, efficiency and carcass) of feedlot cattle. Three breeds were used: Angus (n=12), Brahman (n=12) and Charolais (n=12), and two treatments: shade (3 m2/animal) or no shade was imposed. The cattle entered the UQ feedlot on the 29th October 2012 and exited the feedlot on 14th April 2013. The information obtained will be used to modify the existing heat load index (HLI) and risk assessment program (RAP) to improve management response to adverse events. Heat stress continues to cause production losses over the summer months. And although stock losses are infrequent an extreme weather event occurred while the study was being undertaken which resulted in significant cattle losses in Central Queensland. The UQ emergency heat load plan was activated on the 12th January 2013.

The study confirmed the importance of shade as a method of reducing the impact of hot weather on feedlot cattle. An unexpected outcome was the use of shade by Brahman cattle (24.7% at 1400 h). Angus made the most use of shade (81.5% at 1200 h). At the same time only 33.5% of Charolais were using shade.

Angus and Charolais cattle with access to shade had lower rumen temperatures (up to 1 oC for Angus and 0.5 ^{o}C for Charolais) compared with their un-shaded counterparts. Brahman rumen temperature was not affected by shade treatment. Overall shaded and un-shaded Angus had the highest rumen temperatures, followed by Charolais, and Brahman.

Examination of panting score data also provided an unexpected outcome. Brahman steers had the greatest overall increase (from minimum to maximum) in panting score (87 and 97% respectively for un-shaded and shaded steers). Albeit from a very low minimum. The increase in Angus was 40 and 47% respectively for un- shaded and shaded steers. For all breeds the increase in PS was greatest in the shaded treatment. This suggests that shade allows improved thermo regulation via respiration.

The study used the rumen and panting data to determine heat gain and heat loss from the three breeds. From these data the rate of heat loss was quantified, and adjustments to the HLI thresholds for heat loss (from accumulated heat) suggested. Further analysis of the data will provide additional information.

The data from the southern feedlot suggest that there is a 40 day acclimation period for cattle to adjust to summer conditions.

A new HLI has been developed and is undergoing evaluation over the summer 2013/14. Recommendations for changes to HLI thresholds have been made.

Executive summary

Heat stress continues to cause production losses over the summer months. And although stock losses are infrequent, extreme weather events can lead to significant cattle losses. The Australian feedlot sector through financial input from MLA and ALFA has proactively researched the effects of high heat load on cattle well-being and productivity. Furthermore, a number of recommendations and strategies have been established to help livestock managers plan for and react to heat load challenges. The Heat Load Index (HLI) and the Risk Assessment Programme (RAP) which were established in the mid 2000's are two key factors in managing heat load. Feedback from users of the HLI and the RAP suggested that some modifications/adjustments were required in a couple of areas.

The objectives of Project B.FLT.0150 were to: Update the HLI and RAP by specifically investigating:

(a) The effect of night time cooling

(b) The effect of humidity and temperature in the early morning

(c) The effect of early summer conditions in southern Australia

The effects of (a) and (b) were determined by identifying and documenting the relationship between steer rumen temperature, panting score, blood metabolites, feed efficiency and climatic parameters during summer in a feedlot with or without access to shade. This work was undertaken at the University of Queensland research feedlot facility at Gatton. The effect of (c) was obtained by using field data collected from a feedlot located in southern NSW.

The weather conditions experienced over the summer of 2012/13 (Gatton) and 2011, 2012 in southern NSW were sufficient to elicit a heat stress response in the cattle at both sites. The provision of shade reduced the impact of ambient heat load at both locations but did not entirely remove the effects. In southern cattle the effect of shade was more pronounced in early summer (Oct/Nov). The provision of shade reduced the thermal stress on Bos taurus cattle at Gatton, but had minimal impact on Bos indicus (100%) cattle. Shade usage is probably the best behavioural measure (apart from panting) of thermal stress.

Rumen temperature is a useful indictor of the thermal status of an individual and may be useful in determining the thermal tolerance of cattle. The increase in rumen temperature in relation to the time of the day and HLI was not breed dependent. The change in rumen temperature over time, particularly at night is a useful tool for determining heat loss, and more work is required in this area. The 94% correlation between rumen temperature and rectal temperature suggests that rumen temperature can be reliably used as a measure of body temperature. However, care needs to be taken when interpreting the data. Outliers (particularly low values) need to be removed in order to reduce bias resulting from water intake.

The panting score data supports the recommended changes in the HLI thresholds for Bos indicus and Bos taurus steers (see Recommendation 2). The data further highlights the importance of early morning panting score observation of Bos taurus (Angus) cattle, especially when AHLU ≥ 25 at 0300 h or there has been less than 6 h of 0 AHLU overnight. Furthermore, there is a trend in the data that suggest that night time feeding behaviour may influence cattle heat load status, and this could influence early morning heat dissipation

Differences in eating behaviour between Brahman, Angus and Charolais steers especially during periods of hot weather may explain some of the differences in thermal tolerance. This is an area where more work is required. It is possible that recommendations for feeding later in the day may be detrimental to cattle when they do not have sufficient night time relief.

The use of thermal imaging has potential and least as a scientific tool to assess heat flow from cattle. Further analysis of data collected from this study is underway. The initial indications are that heat flow from cattle can be assessed provided ambient weather conditions are known.

There is a strong indication from this study that Southern Bos taurus cattle take approximately 40 days to acclimate to summer weather conditions. However, this may be somewhat skewed by high rainfall events. Shade ameliorates the effects of early summer conditions at midday, over the first 40 days. There is not sufficient data to state that Southern Bos taurus cattle are physiologically different to northern Bos taurus cattle. This will need to be further investigated.

A new version of the HLI has been developed (primarily based on UQ data). The new HLI (HLI2) will be field tested at Gatton over the summer 2013/14 (existing MLA study) and a report will be produced. The new HLI will require robust examination before any recommendations on its use can be made.

Based on the current results from this study the following recommendations have been made.

Recommendation 1: Shade should be considered as the primary method to alleviate heat load for black Bos taurus feedlot cattle in areas were high heat load is expected

Recommendation 2: Suggested adjustments to HLI thresholds are: Brahman – heat dissipation commences when HLI is 92 (assuming it has reached a maximum above the 96 unit threshold); Angus – 77 unit threshold if no access to shade and for shaded cattle 84 (when the 86 thresholds has been reached); Charolais – 84 unit threshold (assuming the 89 threshold has been reached)

Recommendation 3: The White Coat threshold be increased to + 4

Recommendation 4: Further investigation to determine the effect of early morning relative humidity on heat load coming into a 'new' day (NB this will be done in conjunction with FLOT 1057 over summer 2013/14)

Recommendation 5: Further investigation to quantify and revise climatic predictors of heat stress as identified in the project data, specifically in relation to Recommendation 2. (NB this will be done in conjunction with FLOT 1057 over summer 2013/14)

Recommendation 6: Angus and Charolais consumed a larger portion of feed at night; therefore, it is recommended that a study be undertaken to specifically look at night time feeding behaviour during the summer, and relate this to changes in body temperature and heat dissipation

Recommendation 7: The threshold for non-acclimated Bos taurus cattle be maintained at -5: However, there is a need for more data to be collected in southern and northern feedlots for the period mid-September to mid-December in order to further refine the acclimation threshold

Recommendation 8: the new HLI be field tested at Gatton over the summer of 2013/14, and if it proves reliable a larger assessment be undertaken (multiple site analysis using existing data)

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1 Background

1.1 Introduction

The Australian feedlot industry continues to review heat stress reduction methodologies to maintain animal production and enhance animal welfare through minimizing heat load event related morbidities and mortalities.

Heat load has a considerable impact on the productivity and welfare of livestock. The Australian feedlot industry has adopted several strategies to reduce this impact including use of environmental stress indicators (temperature humidity index, the heat load index and the accumulated heat load units), animal stress indicators (panting score/respiration rate), reduced stocking density, provision of shade, improved pen manure management and feeding management (once a day feeding in the afternoon, use of a heat stress ration). These practises are designed to improve physical and metabolic comfort of cattle during a heat stress event. However, there remain many gaps in the understanding of how cattle react to their environment (core body temperature and physical signs of stress) and the implementation of alleviation strategies that may be capable of improving the coping capacity of cattle during summer. The ability to predict the effects of forecasted hot climatic conditions on livestock is important to producers especially in terms of welfare and performance (Gaughan et al. 2008b), particularly in intensive production systems (feedlots). By using a combination of local climatic conditions and animal responses, feedlot managers are able to implement strategies to reduce the impact of severe hot climatic conditions on animal performance and welfare (Gaughan et al. 2008b).

The Risk Assessment Program (RAP) which has been developed for the Australian feedlot industry shows that shade may not be required where *Bos indicus* animals are used, and that nutritional management may offset the need for shade in some areas where *Bos taurus* cattle are used. The RAP model suggests that heat load can be managed by the use of shade and/or nutrition. The efficacy of shaded in ameiorating the effects of high heat load was completed at UQ Gatton over summer 2012/13.

1.2 Previous Research

There has been a number of research projects conducted in the area of heat load management in the Australian feedlot industry. A list of previous research projects funded by Meat and Livestock Australia Ltd. is shown below.

- FLOT.307, 308 & 309 – Recommendations for reducing the impact of elements of the physical environment on heat load in feedlot cattle.
- FLOT.310 – Measuring microclimate variations in two Australian feedlots.
- FLOT.312 – Heat stress software development.
- FLOT.313 – Forecasting feedlot thermal comfort.
- FLOT.315 – Applied scientific evaluation of feedlot shade design.
- FLOT.316 – Development of an excessive heat load index for use in the Australian feedlot industry.
- FLOT.317 – Measuring the microclimate of eastern Australian feedlots.

- FLOT.327 – Reducing the risk of heat load for the Australian feedlot industry.
- FLOT.330 – Validation of the new Heat Load Index for use in the feedlot industry
- FLOT.335 – Improved measurement of heat load in the feedlot industry.
- B.FLT.0337 – Assessment of varying allocations of shade area for feedlot cattle – Part 1 120 days on feed
- B.FLT.0343 – Assessment of varying allocations of shade area for feedlot cattle – Part 2 182 days on feed
- B.FLT.0345 – Assessment of Betaine and Glycerol as Ameliorants of Heat Load in Feedlot Cattle

Major outputs from these projects include the development of new measures of heat load including the Heat Load Index (HLI), the Accumulated Heat Load Units (AHLU) and a computer based risk assessment package, the Risk Analysis Program (RAP).

2 Project objectives

The objectives of Project B.FLT.0150 were to;

1. Identify and document the relationship between steer core body temperature, physical animal and behavioural response (respiration rate/panting score/; blood metabolites) and climatic parameters during heat stress events in a feedlot field environment with or without access to shade.
2. Identify and determine the effect of night-time weather on heat loss from cattle.
3. Identify and determine the effect of early morning relative humidity on physiological and behavioural reposnse of cattle night-time weather on heat loss from cattle.
4. Further quantify and revise climatic predictors of heat stress as identified in the project data.
5. Further quantify the effect of shade on alleviation of heat stress.
6. To revise and update the heat load index (HLI) and the risk assessment program (RAP)

3 Methodology

3.1 Animal Ethics Approval

This project was approved (SAFS/335/11/MLA) by the University of Queensland Animal Ethics Committee.

3.2 Methodology

3.2.1 Study Design and Treatments

The cattle were inducted and allocated to their respective treatment pen on 16 October 2012. That day is referred to as day 0 or days on feed (DOF) 0. The observational study commenced on 31 October 2012. Thirty-six steers (12 Angus, 12 Charolais and 12 Brahman) with a non-fasted live weight of 318.5 ± 6.7 kg were used in the study. Cattle were purchased from two sources in Queensland: the Angus and Charolais from the Darling Downs and the Brahmans from the Burnett region. The steers were on feed for 180 days, from 16 October 2012 until 14 April 2013. The steers were not implanted with HGP's.

Two steers from each breed (i.e. 2 Angus, 2 Charolais and 2 Brahman) were allocated to two treatment groups; un-shaded and shaded pens, treatments were used in a replicated study of three pens per treatment. The treatments (T) were:

- T1 = no shade
- T2 = shade (3 m^2/ animal)

3.2.2 Vaccination Protocol

The vaccination protocol followed post arrival for each steer was:

16 October 2012

- 2 mL dose Ultravac 5 in 1 (adjuvant vaccine) (Pfizer Animal Health).
- 2 mL dose Webster's Bovine Ephemeral Fever Vaccine (Living®) (Fort Dodge Australia Pty. Ltd.).
- 2 mL dose Coopers Bovillis MH (Inactivated *Mannheimia haemolytica).*
- 1 mL/100 kg liveweight Cydectin® Pour On for cattle and red deer (5g/L moxidectin solvent, 150 g/L hydrocarbon liquid) (Fort Dodge Australia Pty. Ltd.).

30 October 2012

- 2 mL dose Ultravac 5 in 1 (adjuvant vaccine) (Pfizer Animal Health).
- 2 mL dose Webster's Bovine Ephemeral Fever Vaccine (Living®) (Fort Dodge Australia Pty. Ltd.).
- 2 mL dose Coopers Bovillis MH (Inactivated *Mannheimia haemolytica).*

13 February 2013

- 1 mL/100 kg liveweight Cydectin® Pour On for cattle and red deer (5 g/L moxidectin solvent, 150 g/L hydrocarbon liquid) (Fort Dodge Australia Pty. Ltd.).

27 March 2013

- 1 mL/100 kg liveweight Cydectin® Pour On for cattle and red deer (5 g/L moxidectin solvent, 150 g/L hydrocarbon liquid) (Fort Dodge Australia Pty. Ltd.).

3.2.3 Feedlot Description

The research feedlot has 12 pens with an area of 162 m^2. The pens are on an east west alignment. The surface of the pens was soil. Concrete feed bunks were located at the front of each pen. The linear feed bunk area/steer was 0.7 m^2/animal and linear water trough area was 0.17 m^2/animal. The stocking density was 27 m^2. Three shaded pens and 3 un-shaded pens were used. The shade was provided by shade cloth (90% solar block) attached to a 4 m high structure. The shade footprint at midday was 3 m^2/animal. Pen maintenance was undertaken every 30 days. This included manure removal, filling in holes in the pen surface, and repairs to fencing if required. The pen dimensions and the location of shade and water troughs are presented in Appendix 1.

3.2.4 Live Animal Phase Measurement Schedule of Events

A description of the date and measurement schedule for the study during the live animal phase is presented in Appendix 2.

3.2.5 Allocation of Cattle to Treatment Pens

Animals were allocated into pens based on their live weight so that the average pen weights were approximately equal.

3.2.6 Feeding Management Program

The feeding management used in the study was a modified ‘Clean Bunk at Midday’ program (Lawrence 1998). The diets fed to the cattle were commercial rations formulated, milled, mixed and delivered to the feedlot by Riverina Stock Feeds (Oakey Qld) (Appendix 3). Cattle were stepped up from a starter 2 diet to a finisher diet over the first 30 days in the feedlot. Cattle were fed once each day at approximately 1430 h (although there was some weather induced variations to feeding times). Bunks were read at 0700 h and 1200 h each day and feed offered adjusted as required. Refusals were collected immediately prior to afternoon feeding and weighed. Feed samples were collected from each feed delivery and stored in a freezer for later nutritional analysis. Water troughs were cleaned twice a week and more often if required.

3.2.7 Weather data

Ambient temperature (TA, °C), relative humidity (RH, %), wind speed (WS, m/s), and solar radiation (SR, W/m^2) were measured at 10 min intervals by an automated weather station (Davis Pro V2). The weather station was located in the middle of a laneway in front of the feedlot (Figure 1). Rainfall was measured daily at 0900 h. The weather data was used to calculate the HLI and AHLU (Gaughan et al. 2008c).

Figure 1 Automated weather station.

3.2.8 Heat Waves

For the purpose of this study a heat wave is defined as: three or more consecutive days when the mean HLI for un-shaded pens was ≥ 86 and the AHL was ≥ 50 between 0800 and 1800 h (Sullivan et al. 2011). If heat wave conditions existed or were likely (based on Katestone forecast www.katestone.com.au/mla) then animal observations and data collection (see section 3.3 Observational data collection) was done every hour between 0600 and 1800 h.

3.2.9 Pen Surface Temperature

The surface temperature of shaded, un-shaded, dry, and wet surfaces within the shaded and un-shaded pens was obtained by holding an infrared sensor (Fluke Australia Pty Ltd, Castle Hill, NSW, Australia) 1 m above and facing the ground.

3.2.10 Water Trough Temperature

Water trough temperature was recorded every 10 min using a HOBO Water Temp Pro V2.

3.2.11 Acquisition of Body Temperature Data

Body temperature (rumen) was recorded at 10 minute intervals using Smartstock (Pawnee, OK, USA) rumen boluses. Data was transmitted to a base station and recorded using TechTrol Inc. software (Pawnee, OK, USA). The bolus is an active RFID transmitter that will transmit an RF based signal up to about 90 m to an integrated data base system. The transmission range is approximately 90 m and gives a total diameter of approximately 180 m. The rumen bolus is cylindrical in shape with a diameter of 3.1 cm and a length of 8.3 cm with a total weight of 117 g (Figure 1). At each cattle blood collection (see below) rectal temperature data was obtained to check the relationship with rumen temperature.

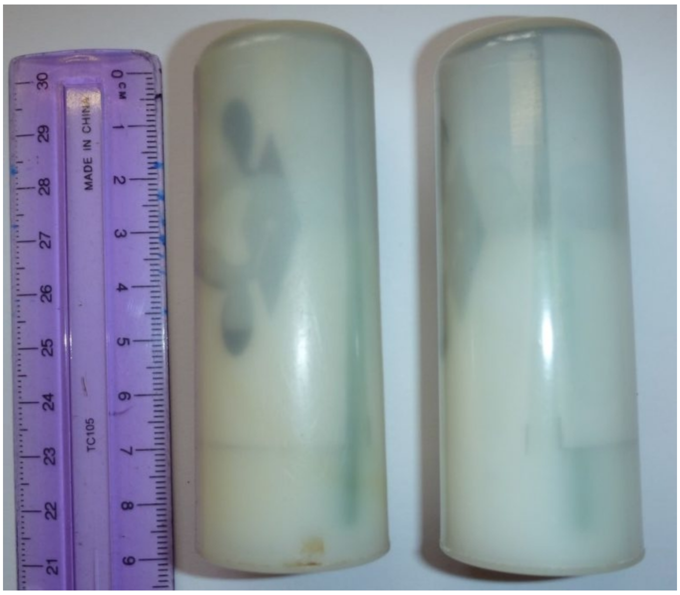


Figure 2 A new bolus on the right and a recovered bolus on the left.

3.3 Observational Data Collection Southern Feedlot

An observational study was undertaken at a commercial feedlot in southern NSW. The study was conducted on two occasions (i) mid-October to mid-December 2011 (Period 1) and (ii) mid-October to mid-December 2012 (Period 2). Both periods ran for 61 days. The cattle used in the study were mostly Angus, however there were *Bos taurus* cross cattle in the mix. Within each occasion 7 pens were observed (approx. 200 animals/pen). The pens used were chosen on the basis of days on feed (DOF), so that within each year five pens of shaded cattle were observed that were approximately 1, 30, 60, 70, 90 DOF at the commencement of observations. Two un-shaded pens with 30 DOF at commencement were also used.

The following observational date were obtained for each animal at approximately 0600 h, 1200 h and 1700 h each day: panting score (see below 3.4.1), location in pen (under shade, in sun), activity (feeding, drinking, ruminating) and posture (standing, lying). Over the two data collection period's 3524 animals were observed. Due to some missing data there were 56 days of data from Period 1 and 53 days from Period 2. Within the days there were also some missing data points. Nevertheless 345,352 animal observations were used in the data analysis.

3.4 Observational Data Collection UQ

The following observational date were obtained for each animal at 0600 h, 0800 h, 1000 h, 1200 h, 1400 h, 1600 h, and 1800 h each day (except during heat waves: see 3.2.8): panting score (PS), location in pen (under shade, in sun), activity (feeding, drinking, ruminating) and posture (standing, lying).

3.4.1 Panting Score

Panting scores were visually assessed using the 0 – 4.5 scale, with panting score 0 being an animal under no heat load, and 4.5 being a severely heat stressed animal (Gaughan et al. 2008a; Mader et al. 2006) between October and December (Table 1). A modified panting score system was used from January 1 (Table 2).

Panting score was the key physiological and behavioural factor used in development of the HLI, and in establishing the heat load thresholds (Gaughan et al. 2008a). Individual panting scores are used to calculate a mean panting score (MPS) for each pen at each observational time. The stress level on cattle can be assessed using MPS: 0 to 0.4 minimal heat load – no stress; 0.4 to 0.8 moderate heat load – slight stress; 0.8 to 1.2 high heat load – moderate heat load; >1.2 extreme heat load cattle highly stressed (Gaughan et al. 2008a).

Table 1: Original panting score and breathing conditions.

Panting Score	Breathing Condition
0	No panting
1	Slight panting, mouth closed, no drool, easy to see chest movement
2	Fast panting, drool present, no open mouth
2.5	As for 2, but occasional open mouth panting, tongue not extended
3	Open mouth and excessive drooling, neck extended, head

3.5	As for 3, but with tongue out slightly and occasionally fully extended for short periods
4	Open mouth with tongue fully extended for prolonged periods with excessive drooling. Neck extended and head up
4.5	As for 4, but head held down. Cattle "breath" from flank. Drooling may cease.

(Adapted from Gaughan et al. 2008a and Mader et al. 2006)

Table 2: Modified panting score and breathing conditions.

Panting Score	Breathing Condition
0	No panting
1	Slight panting, mouth closed, no drool, slight chest movement
1.5	Fast panting, mouth closed, no drool, fast easily observed chest movements
2	Fast panting, drool present, no open mouth
2.5	As for 2, but occasional open mouth panting, tongue not extended
3	Open mouth and excessive drooling, neck extended, head
3.5	As for 3, but with tongue out slightly and occasionally fully extended for short periods
4	Open mouth with tongue fully extended for prolonged periods with excessive drooling. Neck extended and head up
4.5	As for 4, but head held down. Cattle "breath" from flank. Drooling may cease.

3.4.2 Observations – Night

Cattle were also assessed every 2-h during night-time (approximately 1800 to 0800 h the next morning) at 14 d intervals over the trial period. These data included panting score, location in pen, and posture.

3.4.3 Blood Collection

Blood (40 mL) was collected from 18 steers (2 from each breed × treatment) at 7 day intervals from day 8 (NB: the steers in this group were also bled on day 32, 74 and 123 which corresponded with heat waves). Blood collection from the remaining 18 animals occurred on a monthly basis on days 8, 36, 64, 99 and 127.

Blood was obtained for each steer via jugular venepuncture into four 10 mL vacuum tubes (BD Vacutainer®, Franklin Lakes, USA). Three tubes contained the anticoagulant lithium heparin and the remaining vacutainer contained no anticoagulant. Immediately following collection, the lithium heparin (anti-coagulant vacutainers samples were chilled on ice before centrifugation, with plasma separated from cells within 2 h of collection. Plasma separation protocols (lithium heparin tubes) were centrifuged at 1575 × g (3500 rpm) at 4 °C for 10 min. Plasma was frozen (-20 ˚C) within 8 h, and stored at -80 ˚C until assayed. Blood parameters from the monthly samples (n=5) were assayed for electrolytes (potassium, chloride, bicarbonate and sodium), lipids (cholesterol and triglycerides), glucose, insulin, creatine kinase, haptoglobin (acute phase protein), cytokine (interleukin 6) and heat shock protein 70 (hsp70). See Appendix 6 for details on blood assays.

3.4.4 Liveweight, Body Condition Score and Hip Height

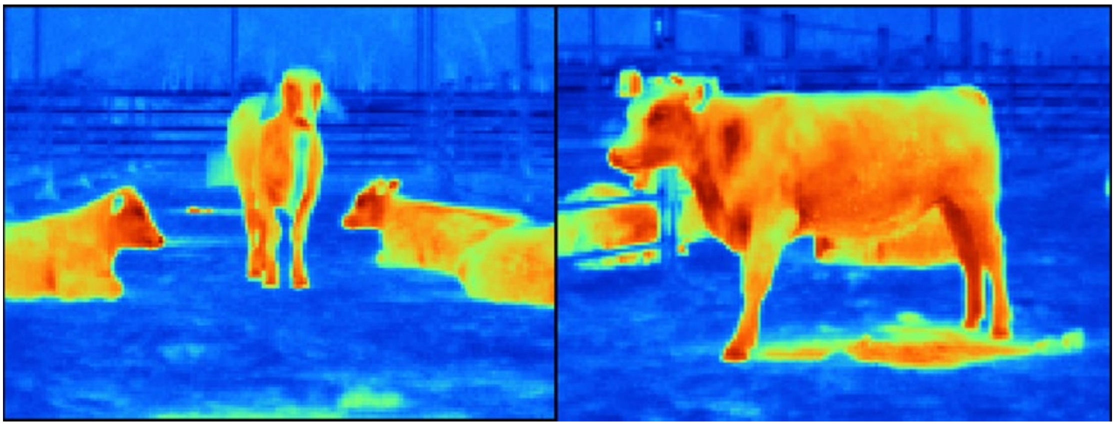
Non fasted (full) liveweight (kg) was recorded at induction on 16 October 2012 and then at 7 day intervals (in the morning prior to afternoon feeding) for the duration of the study. Body condition score on a scale of 1 to 5 using visual assessment and palpation was obtained on days 8, 36, 64, 99 and 127. Hip height was measured on days 8, 36, 64, 99 and 127.

3.4.5 Video Images

Three video cameras were set up to cover all 6 pens for the duration of the study. The cameras were located 12 m in front of the feedbunks and had a field of view to the rear of the pens. Red lights were set up adjacent to pens to allow night time recording. The video footage will allow an assessment of night time activity, especially eating behaviour and provide additional behavioural data when at times when the visual assessments were not made.

3.4.6 Thermal Images

When night time observations were undertaken thermal images of individual animals were also obtained every 2 h using a thermal camera (Fluke Ti-25, Fluke Australia Pty Ltd, Melbourne)(Figures 3 and 4). During heat wave events night-time observations were also conducted. Changes in heat intensity radiating from the animals will be investigated within and between breed and treatment over time. These data will allow the assessment of night time heat loss.



A B

Figure 3 Thermal image (A) cattle in feedlot at 0200 h on the 12.11.2012; (B) Angus steer in feedlot at 0200 h on the 12.11.2012.

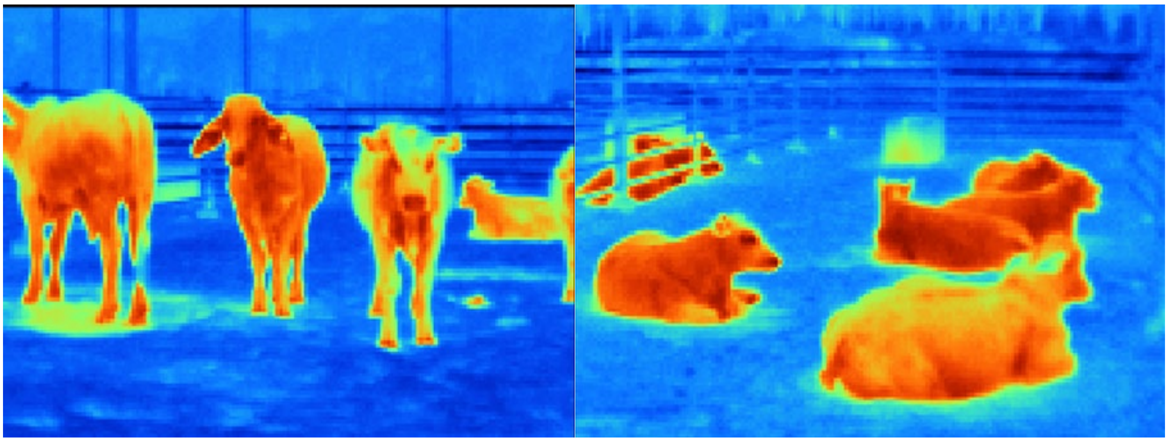


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Figure 4 Thermal image (A) of cattle in feedlot at 0200 h on the 26.11.2012; (B) image of cattle in feedlot at 0000 h on the 07.01.2013.

3.4.7 Heat Load Management Plan

The protocol for the management of the steers during a high heat load event is described in Appendix 3.

3.4.8 Exit Procedures

The end of the study was on 2 April 2014 (Day 168). Feedlot exit was on 14 April 2013 (Day 180). The steers were fed as normal in the afternoon of the day prior to exit (Day 179). In summary, steers were drafted and loaded onto trucks for the journey to Kilcoy Pastoral Company, Kilcoy.

3.5 Statistical Analysis – UQ Data

3.5.1 General

The UQ study was designed with each animal as an experimental unit, with each observation collecting data on all animals at each time point throughout the day.

Ten-minute rumen temperature data were converted into an hourly average for each animal over the duration of the study. Interactions of averaged data between breed and treatment groups were then analysed using mixed procedure (PROC MIXED; SAS Inst. Inc. Cary, NC) for hourly changes in diurnal patterns by breed, treatment and breed × treatment groups.

The analysis of variance (ANOVA) of mean panting score, shade usage and behaviour (eating, drinking, standing, lying, and ruminating) were performed using General Linear Model (GLM; Minitab® 16.2.0, 2010 Minitab, Inc.). The model analysed breed (Angus, Charolais, and Brahman) and treatment (shaded or un-shaded), HLI and AHLU, time of day (0600, 0800, 1000, 1200, 1400, 1600, 1800 h), day, and the interaction of day × observation time as fixed factors. Least squares means (LSMeans) were used to as an estimate for the treatment effects. Where significance ($P < 0.05$) was detected, the means were compared using Multiple Comparison (Tukey Method, Minitab® 16.2.0, 2010 Minitab, Inc.).

Blood metabolites were also analysed using the analysis of variance (ANOVA) General Linear Model (GLM; Minitab® 16.2.0, 2010 Minitab, Inc.). The model analysed each metabolite for breed (Angus, Charolais, and Brahman), treatment (shaded or un-shaded) and breed × treatment responses with sampling week as a covariate. Where significance ($P < 0.05$) was detected, the means were compared using Multiple Comparison (Tukey Method, Minitab® 16.2.0, 2010 Minitab, Inc.).

3.5.2 Weather

Data were logged by the weather station every 10 minutes. Information was imported directly from a file produced by the weather station data-logger. Data for air temperature, relative humidity, black globe temperature, wind speed was used to calculate the heat load index and various thresholds for accumulated heat load units (AHLU). The AHLU was examined in order to locate periods of likely heat stress on the different breed and shade treatment groups.

3.5.3 Live Weight and Growth

These data consisting of weights, body condition scores and hip heights. Average daily gain per animal, pen and breed x treatment group was calculated for each 7 day interval.

3.5.4 Body Temperature

All valid observations were combined into a single data set with more than 650,000 records. Each observation was identified by an animal number and actual observation time (different for each transmitter). For each animal on each day, the average hourly temperature reading was derived. This daily summary was further processed so that the average for each breed x treatment group was determined.

3.5.5 Panting Score

Panting score was recorded on a 0 to 4.5 scale. The scale used had been designed to behave in a reasonably linear fashion, so for whole trial, the mean panting score was calculated for each animal and observation time point.

3.5.6 Shade Usage

Shade usage was recorded on each individual at each observational time point. These data were then used to calculate the proportion of each breed × treatment group utilising the shade at each time point.

3.5.7 Blood metabolite

Monthly blood samples (sample weeks 1, 4, 9, 14 and 18) were analysed for electrolytes (potassium, chloride, bicarbonate and sodium), lipids (cholesterol and triglycerides), glucose, insulin, creatine kinase, haptoglobin (acute phase protein), cytokine (Interleukin 6) and heat shock protein 70 (hsp70).

3.6 Statistical Analysis Southern Feedlot Data

The percentages of cattle recorded for each panting score, location in pen and posture were transformed to a normalized distribution using squared root-arcsine transformation before being statistically analysed. The data were analysed using the PROC Mixed procedure of SAS (SAS Institute, Cary, NC). As there were only a few animals with a PS>3.0, the number of cattle observed as 3.5, 4.0 and 4.5 were combined as a single number. The transformed PS, location in pen and posture were analysed using a repeated measures model which included DOF, day, year, pen type (shade or no-shade), and observation time (and all interactions) as fixed effects and animal as a random effect. The specified term for the repeated statement was day. For the analysis, days on feed (DOF) were used as also used as a covariant. Further analysis (PROC GLM) was undertaken to determine the effect of DOF on panting score.

4 Results and Discussion – UQ Data

The UQ study commenced in October 2012 with an animal based study. The animal component finished in April 2013, and laboratory analysis of samples collected from the animals commenced in June 2013. Due to delays in obtaining some reagents from overseas and some problems with some of the kits (heat shock protein) sample analysis took longer than expected. There

4.1 Weather Conditions

Overall, the weather conditions during the study period were average for the Gatton area with some intermittent hot days over 35 °C (see Appendix 7 for a monthly summary of weather data). During the study period the climatic conditions were sufficient to incite significant heat load responses in the cattle on most days. There were 5 major heat events during the study, however only one lead to a significant problem (see section 4.1.1). There were some high rainfall events, one of which (Cyclone Oswald) lead to local flooding in late January 2013 (Figure 5). During the period 24th to 27th January there was very low solar load (Figure 10) and high rainfall which resulted in cold cattle, especially the Brahmans which were shivering. The days immediately following this event were hot, and pens boggy which increased in pen relative humidity. Graphical summaries of the weather conditions throughout the study period are presented in Figures 5 to 10.

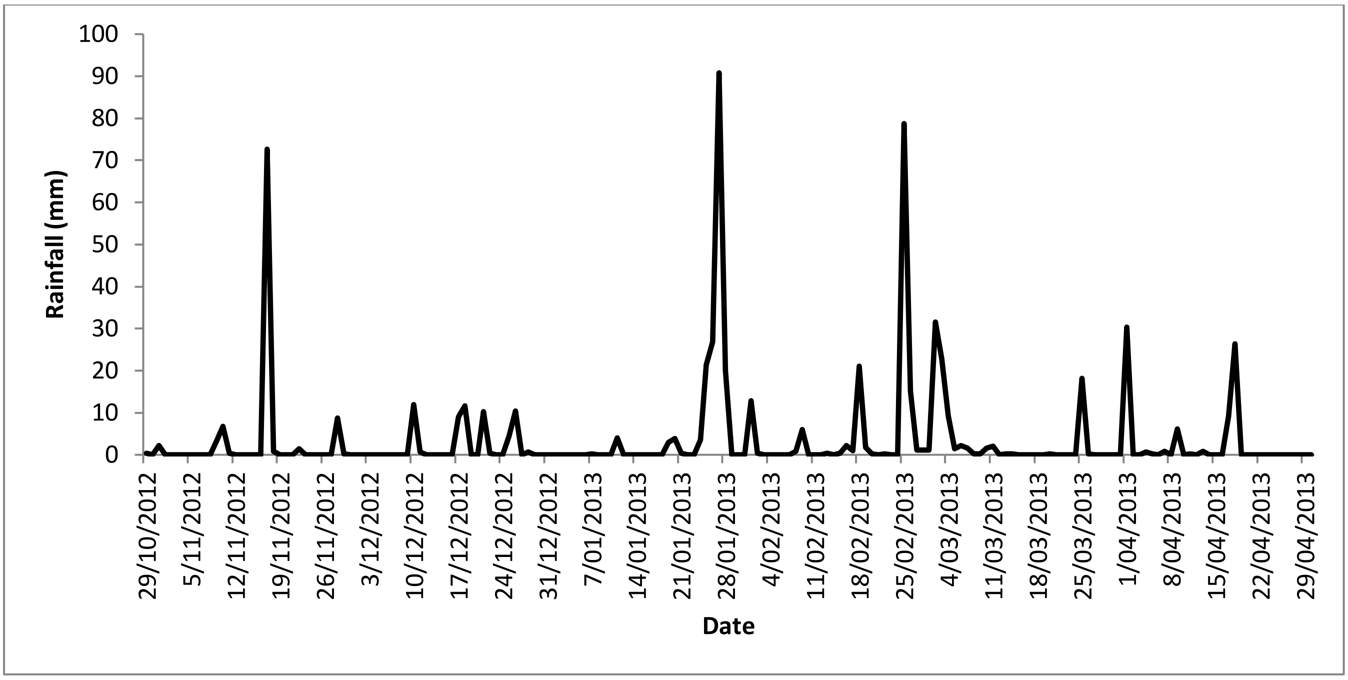

Figure 5 Rainfall events over the duration of the study

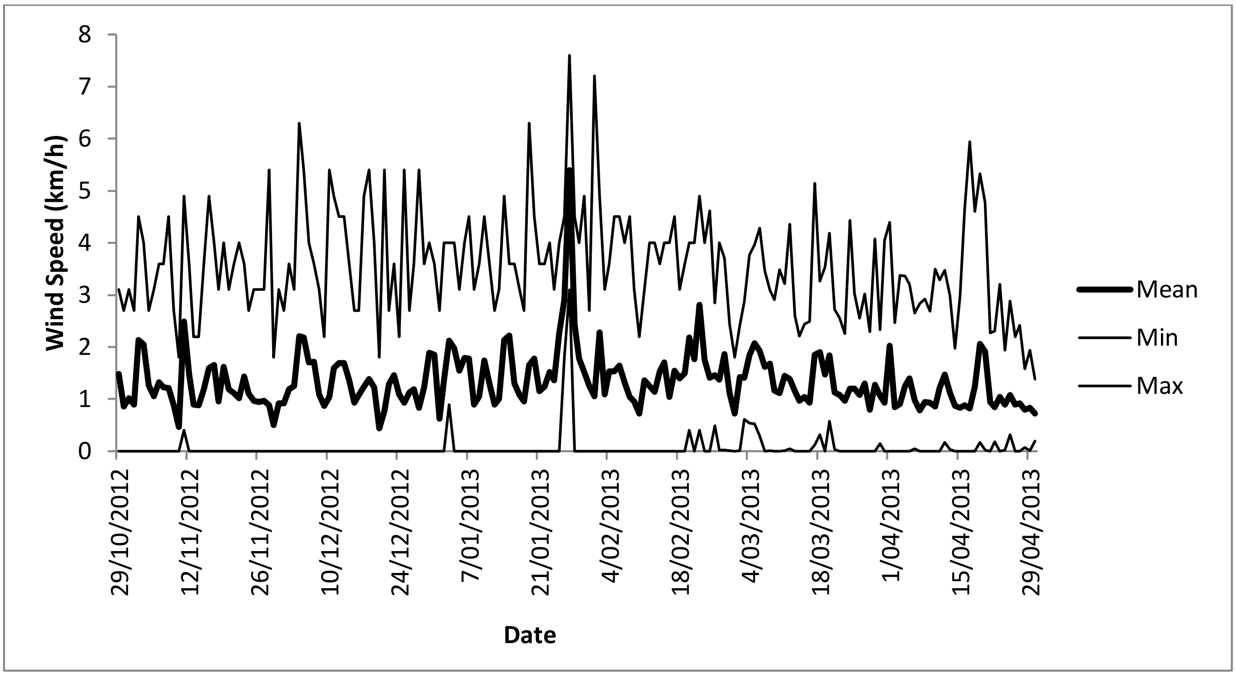

Figure 6 Minimum, mean and maximum wind speed over the duration of the study

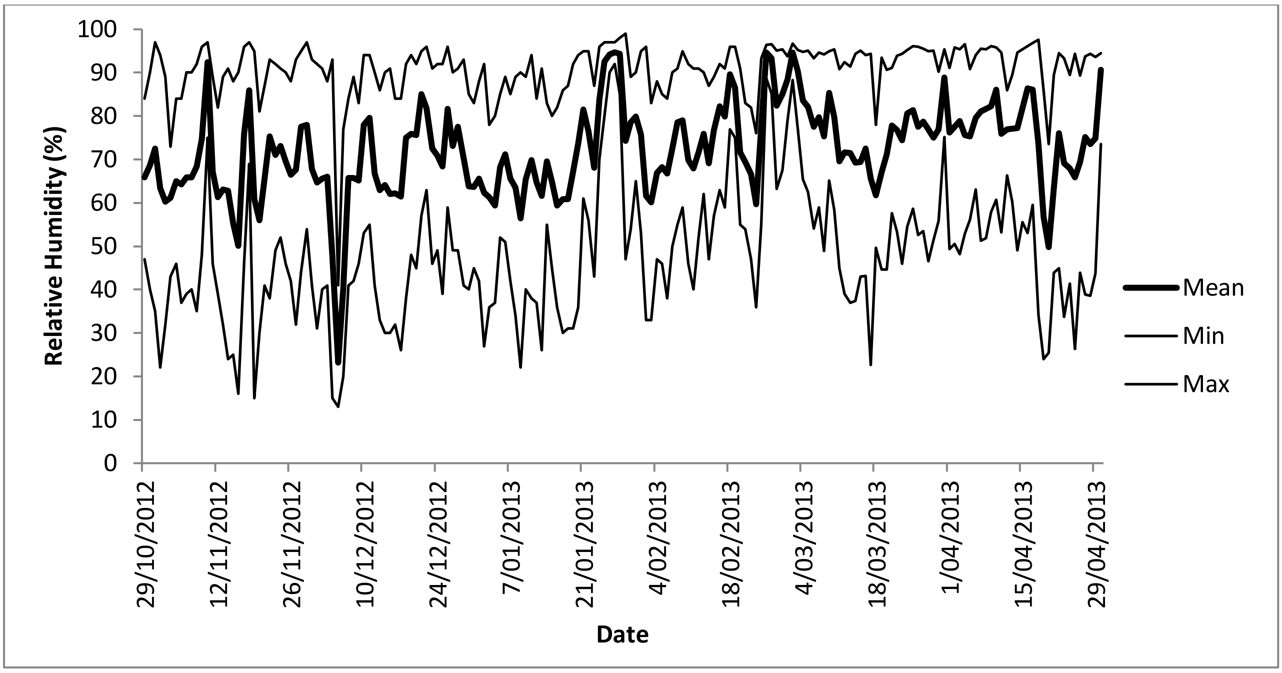

Figure 7 Minimum, mean and maximum relative humidity over the duration of the study

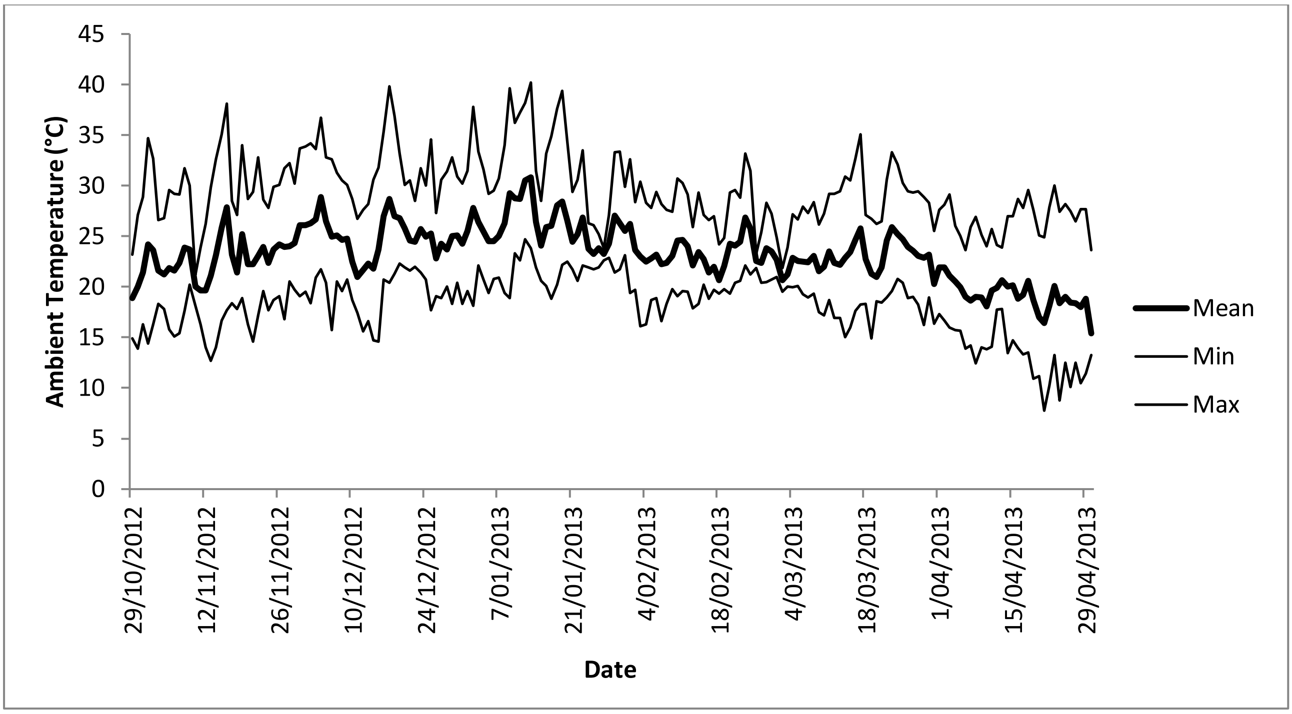

Figure 8. Minimum, mean and maximum ambient temperature over the duration of the study

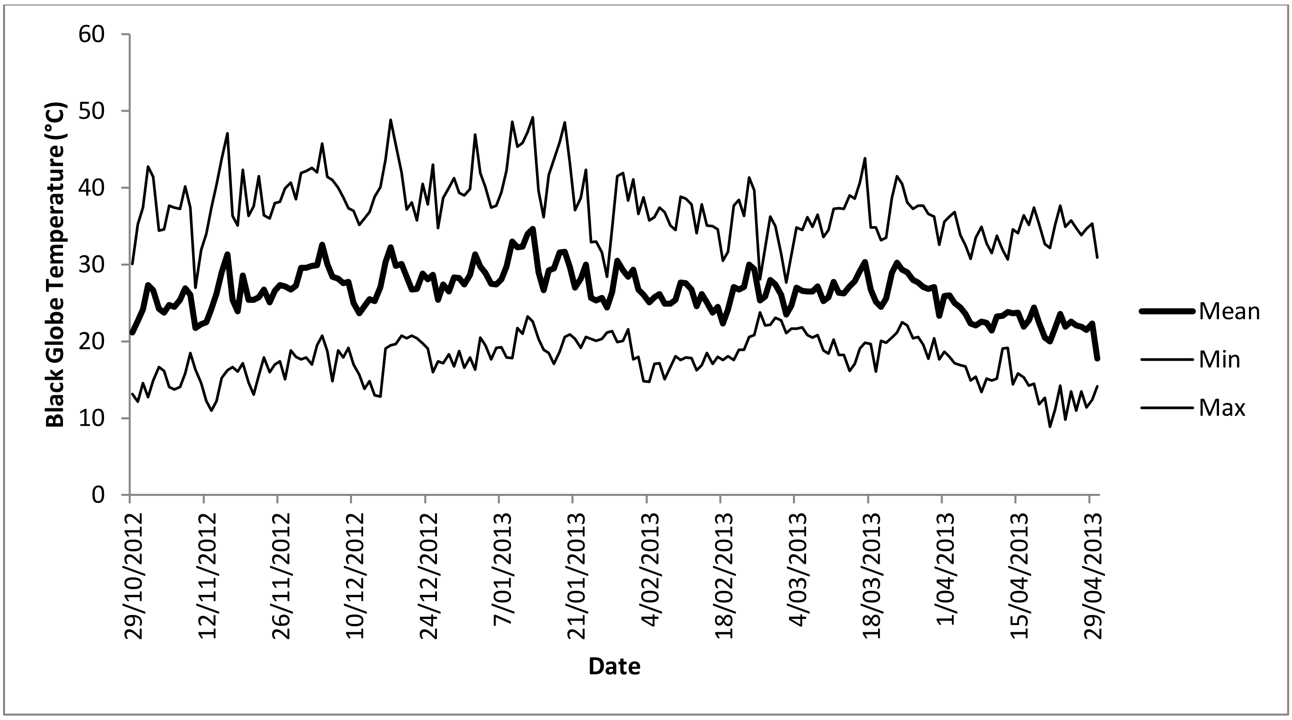

Figure 9 Minimum, mean and maximum black globe temperature over the duration of the study

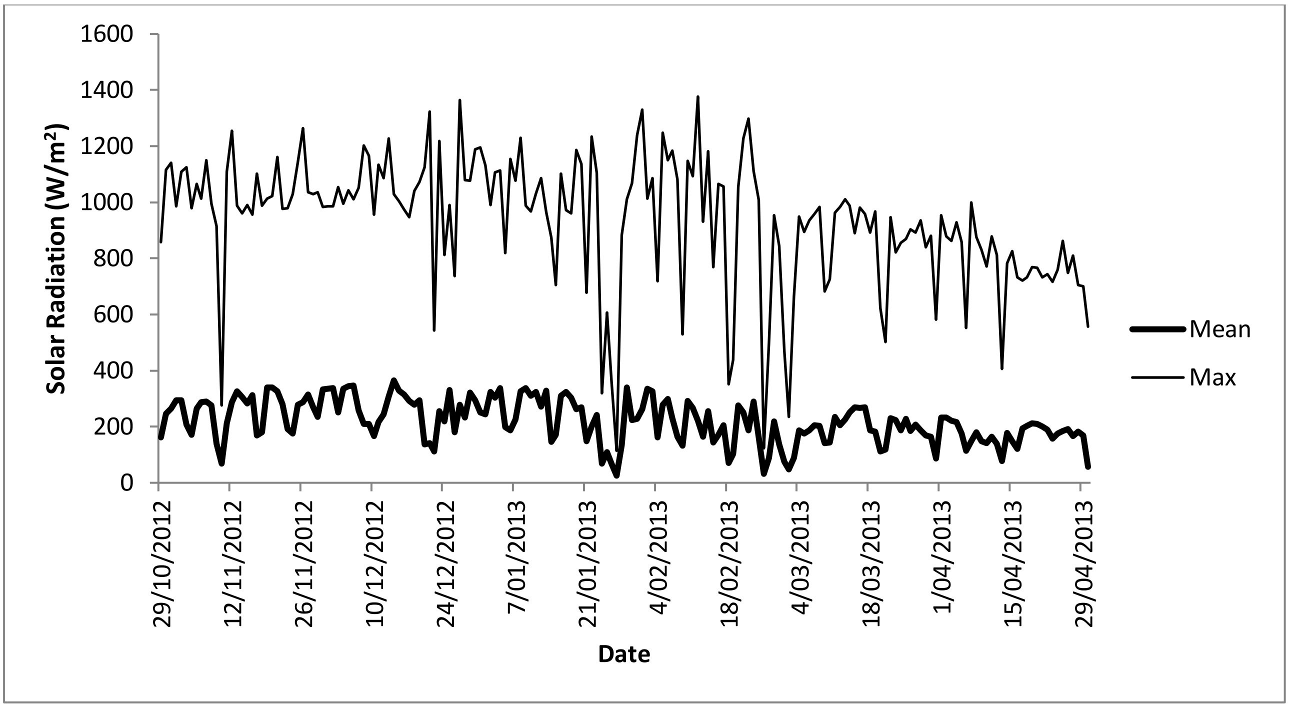

Figure 10 Mean and maximum solar radiation over the duration of the study

4.1.1 Heat Load Index and Accumulated Heat Load Units

The minimum, mean and maximum HLI calculated for each day of the study period is shown in Figure 11. There were 142 days with a maximum HLI > 86, 99 days with HLI > 90, 37 days with a HLI > 95 and 4 days when HLI >100. The maximum HLI recorded was 101.5 (1600 h, January 13 2013). The maximum HLI were sufficient to induce heat stress in the un-shaded cattle for at least 142 days of the study. However throughout most of the period there was sufficient night-time cooling to allow the cattle to dissipate accumulated body heat back to the environment. The HLI < 60 on 147 nights, and was less than 55 on 60 of these nights.

The accumulated heat load units (AHLU) calculated during the study period is presented in Figure 12. Using the reference animal (un-shaded Angus steer, 100 days on feed) as defined by Gaughan et al. (2008a), heat load events (AHLU >50) occurred in November 2012, December 2012, January 2013, February 2013 and March 2013. The maximum AHLU (213) was obtained on the 13th January 2013. However AHLU values greater than 100 were only recorded over four consecutive days between 11th January 2013 and 14th January 2013 (Figure 10). The mid-January heat wave was the most intense 'heat' period during the study (Figure 13). The heat load management plan was invoked on the 12th January and all un-shaded cattle were moved to shaded pens (see Appendix 4 for details).

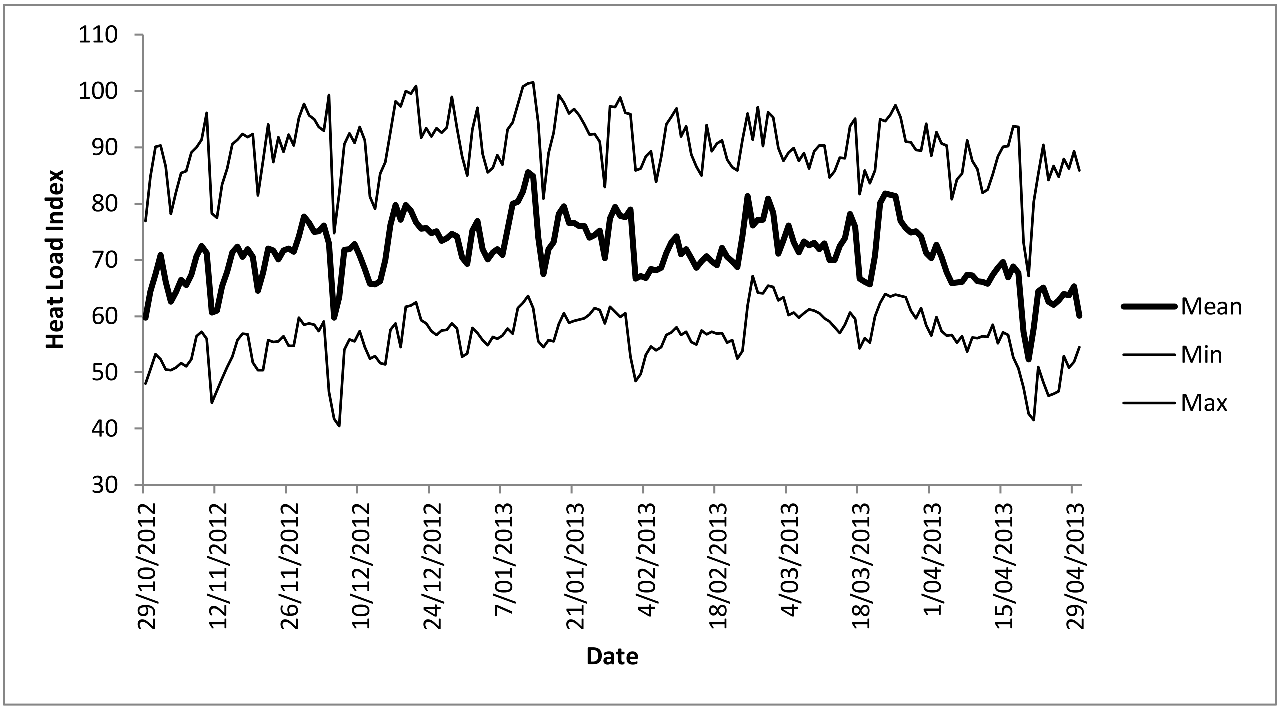

Figure 11 Minimum, mean and maximum heat load index over the duration of the study

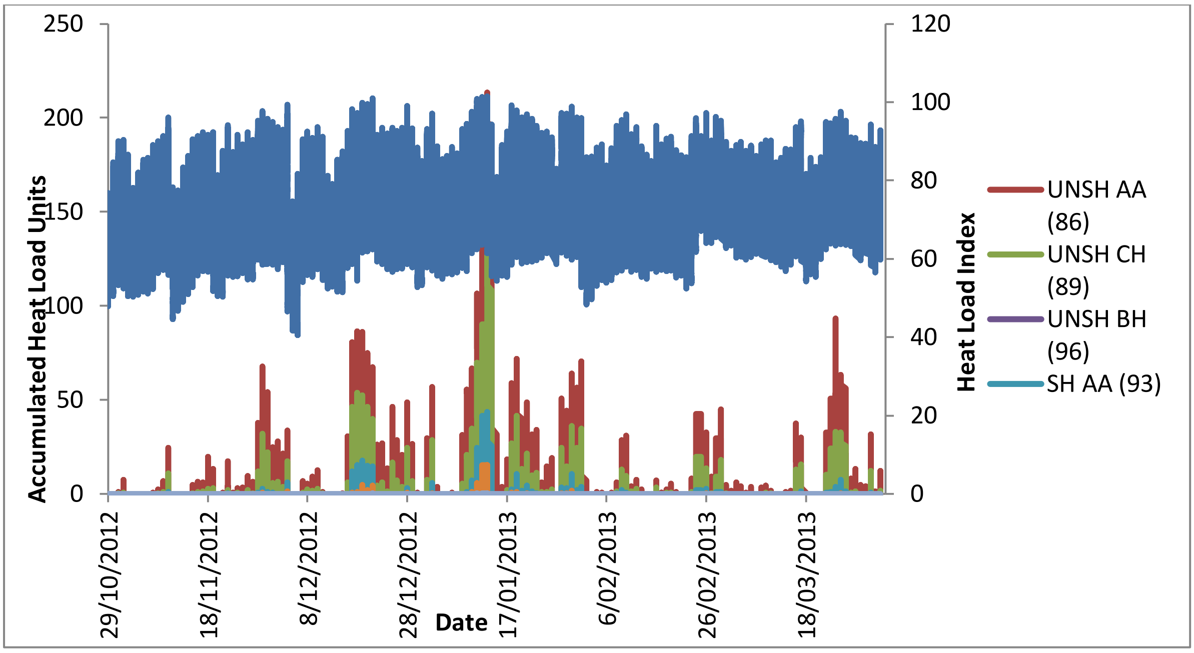

Figure 12 Heat load index and accumulated heat load units for un-shaded Angus (86), un-shaded Charolais (89), un-shaded Brahmans (96), shaded Angus (93), shaded Charolais (96) and shaded Brahman (100) calculated at 10 minute intervals (values in brackets are HLI thresholds).

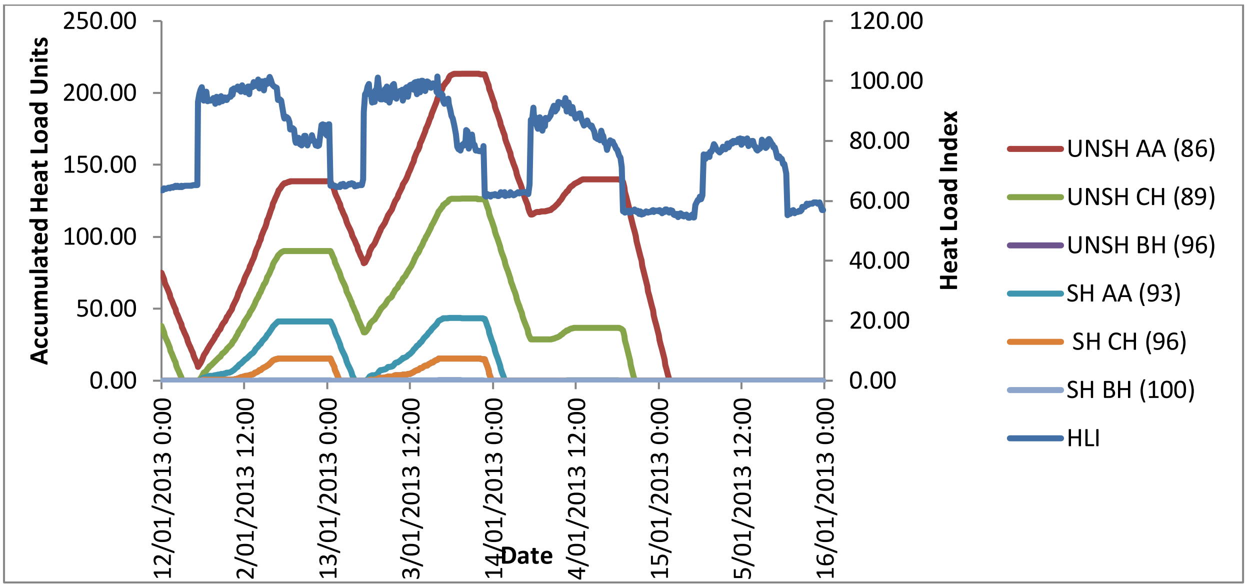

Figure 13 12th to 15th January 2013 heat wave: heat load index (HLI) and accumulated heat load units (AHLU) for un-shaded Angus (86), un-shaded Charolais (89), un-shaded Brahmans (96), shaded Angus (93), shaded Charolais (96) and shaded Brahman (100). The HLI and AHLU were calculated at 10 minute intervals.

4.2 Animal Health

The only major health issue was footrot following the rain event in January. Three animals (1 Brahman, 1 Charolais and 1 Angus) were removed from the un-shaded pens, and 1 Brahman was removed from a shaded pen to the sick pen and did not return to the study.

4.3 Liveweight and Average Daily Gain

The average weekly liveweight (kg) of each breed x treatment group are presented in Figure 14. Performance at the commencement of the study was flat as cattle adapted to feed, weather and the pen conditions. The average daily gain of the cattle was lower than expected. There were treatment and breed differences ($P < 0.05$) for ADG. The ADG for shaded cattle (all breeds combined) was 841 g/d ± 113 g/d and for the un-shaded cattle the ADG was 748 g/d ± 194 g/d. For the un-shaded cattle the ADG's were 906 g/d, 900 g/d and 551 g/d respectively for Angus, Charolais and Brahman. For the shaded cattle the ADG's were 1000 g/d, 1010 g/d and 482 g/d respectively for Angus, Charolais and Brahman. The ADG (treatments combined) of the Brahmans was 538 g/d ± 98 g/d, the Charolais 905 g/d ± 102 g/d and Angus 952 g/d ± 77 g/d. The lower than expected ADG was largely due to the weather conditions which resulted in variable feed intake across the study. Surprisingly the un-shaded Angus had the highest mean finish weight (481 kg).

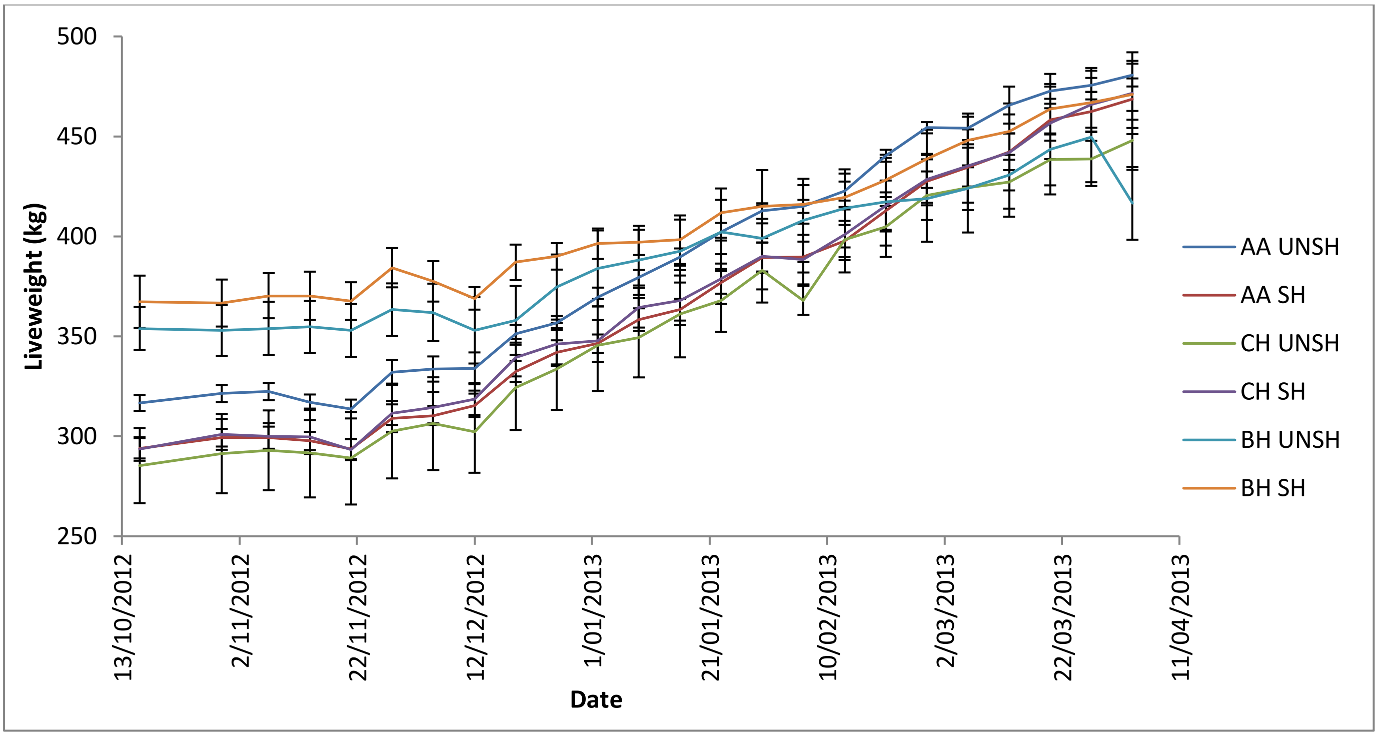

Figure 14 Weekly liveweight (kg ± se) for each breed × treatment group over the duration of the study.

4.4 Hip Height

The average of each breed x treatment group and their associated average increase in hip height measurements are presented in Figure 15. The Brahmans which started off with a greater hip height also finished with a greater hip height. There were no breed (P>0.05) or breed x treatment (P>0.05) differences between the Angus and Charolais.

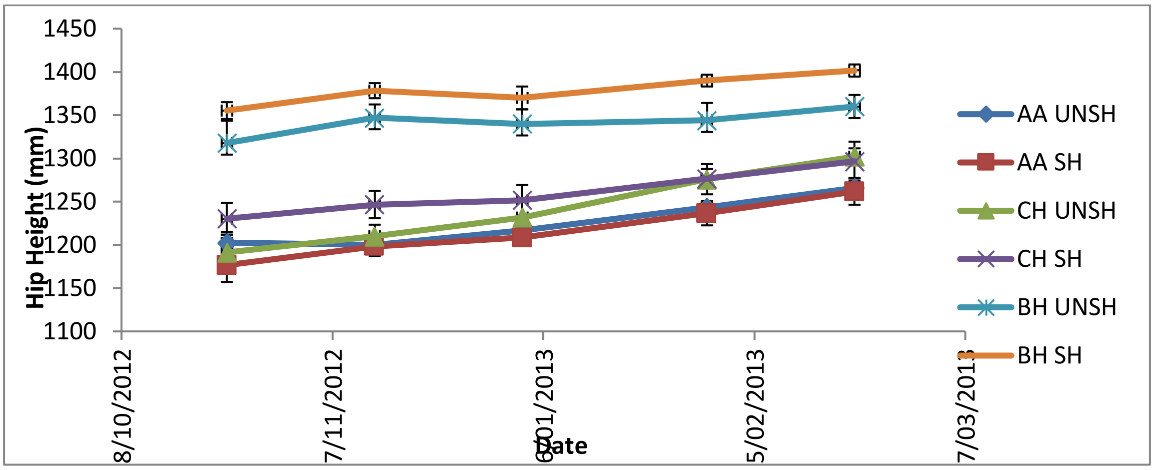

Figure 15 Hip height (mm) measurement changes in breed x treatment groups throughout the duration of the study

4.5 Feed Intake and Feed: Gain

As feed intake was not measured individually it was not possible to separate out breed differences therefor only treatment effects are provided. There were no treatment differences (corrected for animal number) in feed usage and feed efficiency. Feed to gain was higher (P = 0.10) for the un-shaded cattle (10.1:1) compared with the shaded cattle (9.4:1). A heat wave ration (decrease concentrate component by 10% and added roughage) was introduced between 11th January and 14th January. There were large variations in feed intake across pens (within and between treatments). Cattle were adversely affected by the heat wave and rain event in January and it took until mid-February for shaded cattle to fully recover feed intake. From mid-February feed intakes remained above 10 kg/animal. The un-shaded cattle took longer to recover and even by mid-March intakes remained variable.

4.6 Rumen Temperature

Rumen temperature data was obtained over 130 days between the 23rd November 2012 and the 2nd April 2013 utilizing all animals within the study. Rumen temperature was logged at 10 min intervals using transponder rumen bolus's (RFID transmitter; Smartstock™ Pawnee, OK, USA). The active RFID transmitter transmits an RF based signal approximately 90 m to an integrated data base and base station. The signal is converted to °C and recorded to a computer using TechTrol Inc. software (Pawnee, OK, USA).

Ten minute rumen temperature data were converted into an hourly average for each animal over the duration of the study. Outliers were removed and data normalised. Interactions of averaged data between breed and treatment groups were then analysed using mixed procedure (PROC MIXED; SAS Inst. Inc. Cary, NC). There was no effect of treatment (P = 0.93) or breed × treatment (P = 0.97). However, there was an effect of breed (P = 0.0006); time of day (Hour; P < 0.0001); breed × hour (P < 0.0001); treatment × hour (P < 0.0001); and breed × treatment × hour (P < 0.0001) (Figure

16). A similar temperature pattern was seen between breeds and treatments with minimum rumen temperature occurring at approximately 0930 h, and maximum rumen temperature occurring at approximately 1600 h. There was a 94% correlation between rumen temperature and rectal temperature (rectal temperature 1 °C lower when data obtained).

Breed × treatment × hour differences were seen in Angus and Charolais cattle. On average rumen temperature of shaded Angus steers was 0.47 °C and 0.44 °C lower than that un-shaded Angus steers at 1400 h ($P < 0.05$) and 1500 h ($P < 0.05$) respectively (Figure 17). Furthermore the rumen temperature of shaded Charolais steers were significantly ($P < 0.05$) lower than un-shaded Charolais steers: 0.46 °C, 0.52 °C, 0.54 °C, 0.52 °C, 0.56 °C, 0.59 °C and 0.53 °C at 0600, 1000, 1100, 1200, 1300, 1400 and 1500 h respectively (Figure 18).

The minimum rumen temperature ($P<0.05$) of the un-shaded Angus was lower than that of the shaded Angus. A similar finding for Angus steers (rectal temperature) has been reported by Gaughan et al. (2010a). The un-shaded Charolais had a greater ($P<0.05$) rumen temperature at all times, whereas here were no differences ($P > 0.05$) between the rumen temperatures of shaded and un-shaded Brahman steers (Figure 19). The increase in rumen temperature at 2000 h is associated with feed intake from 1430 h.

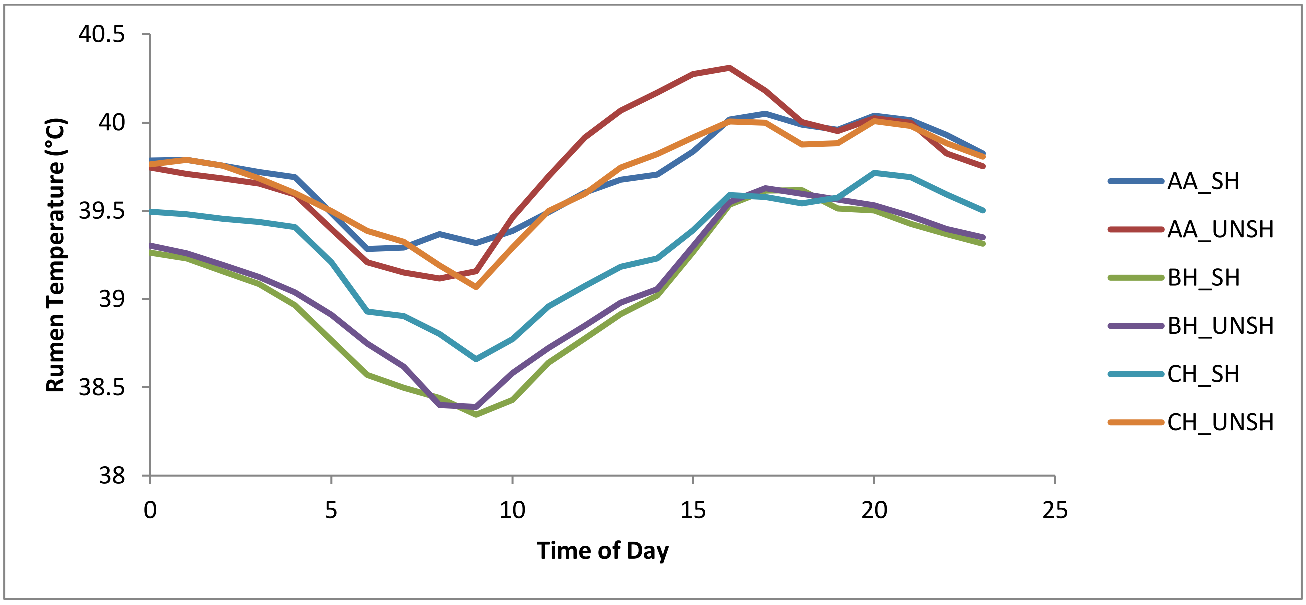

Figure 16 Diurnal changes in rumen temperature of un-shaded Angus, un-shaded Charolais, un-shaded Brahmans, shaded Angus, shaded Charolais and shaded Brahman steers.

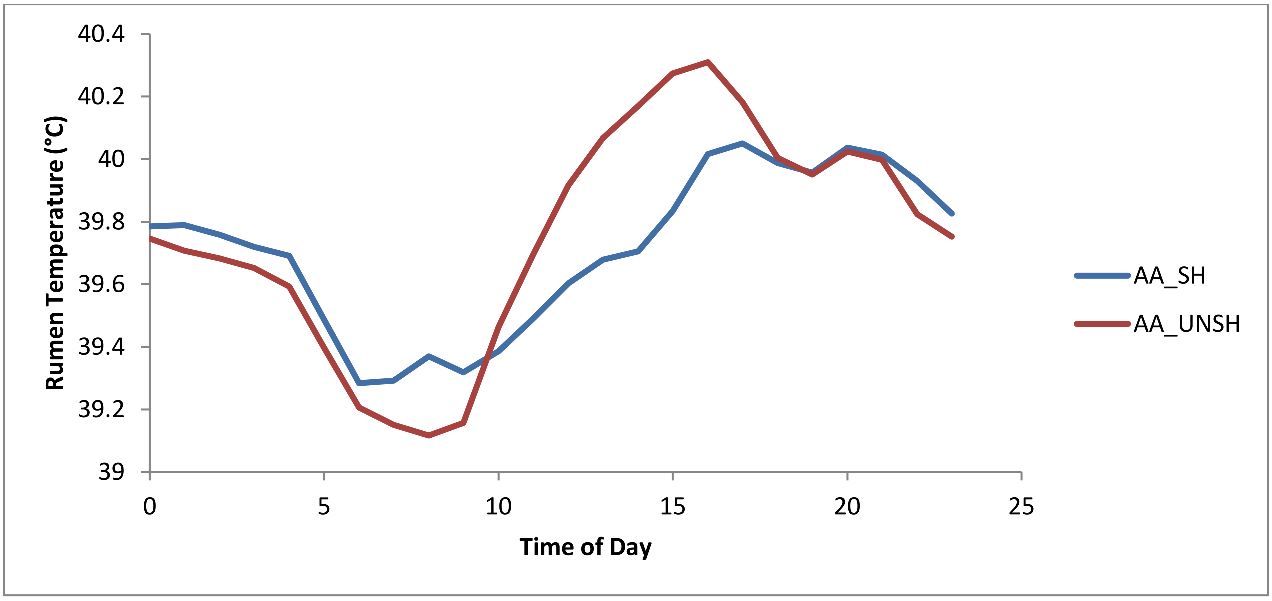

Figure 17 Diurnal changes in rumen temperature of un-shaded Angus and shaded Angus steers.

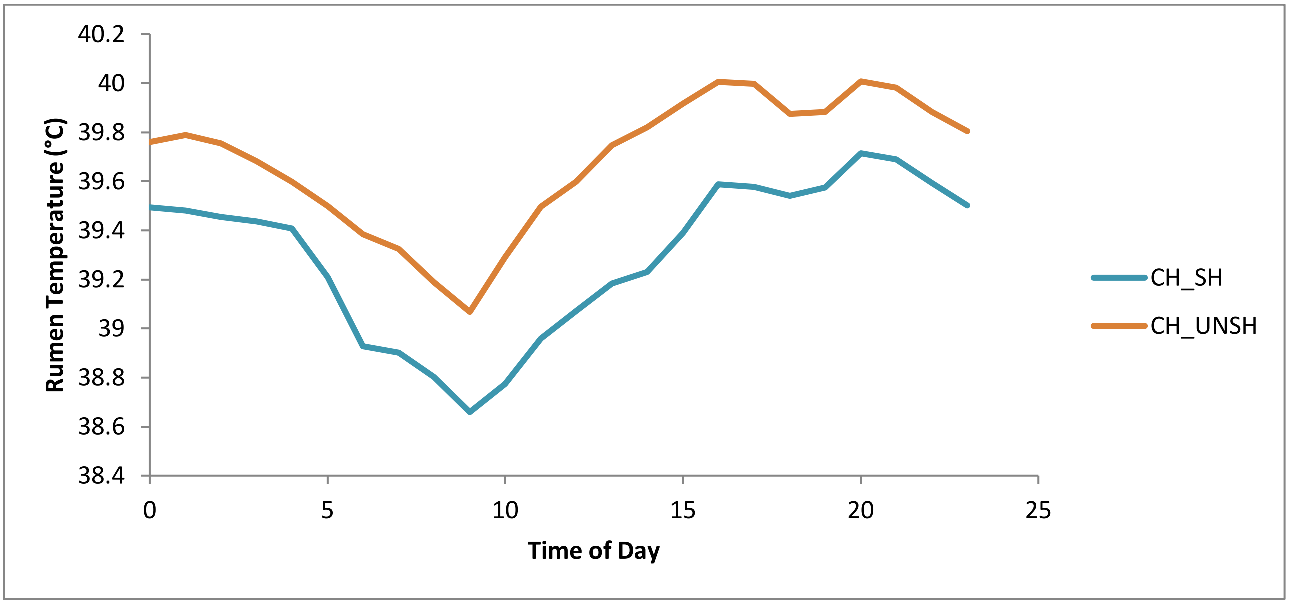

Figure 18 Diurnal changes in rumen temperature of un-shaded Charolais and shaded Charolais steers.

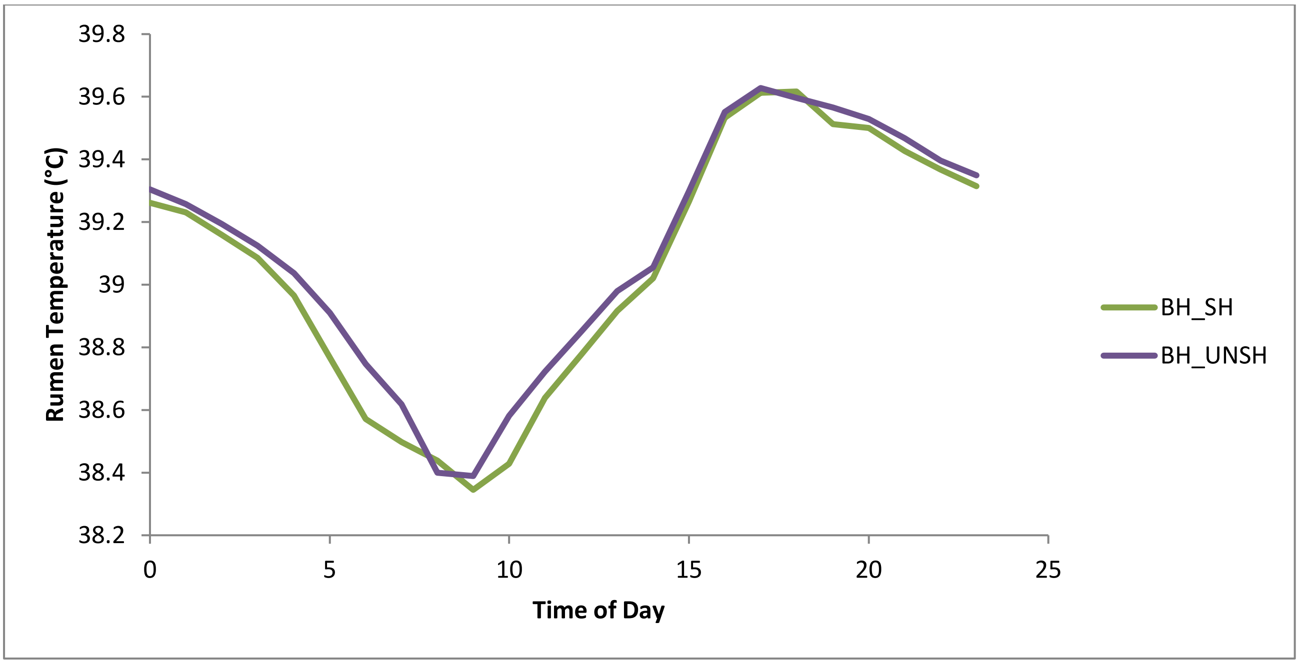

Figure 19 Diurnal changes in rumen temperature of un-shaded Brahman and shaded Brahman steers.

On a breed by breed comparison the un-shaded Angus steers had average rumen temperatures that were higher ($P < 0.05$) than Brahman steers between the hours of 0000 and 2100 (Figure 20 and Table 3). Additionally, un-shaded Brahman steers on average had rumen temperatures that were lower ($P < 0.05$) than un-shaded Charolais steers (Table 4).

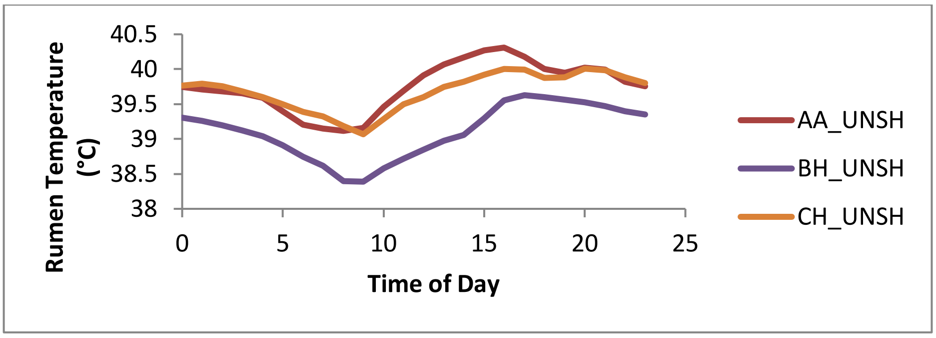

Figure 20 Diurnal changes in rumen temperature of un-shaded Angus, Charolais and Brahman steers.

Table 3 Differences ($P < 0.05$) in rumen temperature (° C) between un-shaded Angus and Brahman steers

Breed	Breed	Time	Difference in Rumen Temperature (°C) (Angus to Brahman)
AA	BH	0000	+ 0.44
AA	BH	0100	+ 0.45
AA	BH	0200	+ 0.49
AA	BH	0300	+ 0.53
AA	BH	0400	+ 0.55
AA	BH	0500	+ 0.49
AA	BH	0600	+ 0.46
AA	BH	0700	+ 0.53
AA	BH	0800	+ 0.72
AA	BH	0900	+ 0.77
AA	BH	1000	+ 0.88
AA	BH	1100	+ 0.97
AA	BH	1200	+ 1.06
AA	BH	1300	+ 1.09
AA	BH	1400	+ 1.11
AA	BH	1500	+ 0.98
AA	BH	1600	+ 0.76
AA	BH	1700	+ 0.55
AA	BH	2000	+ 0.49
AA	BH	2100	+ 0.53

BH = Brahman; AA = Angus

Table 4 Differences ($P < 0.05$) in rumen temperature (° C) between un-shaded Brahman and Charolais steers

Breed	Breed	Time	Difference in Rumen Temperature (°C) (Brahman to Charolais)
BH	CH	0000	-0.46
BH	CH	0100	-0.53
BH	CH	0200	-0.56
BH	CH	0300	-0.56
BH	CH	0400	-0.56
BH	CH	0500	-0.59
BH	CH	0600	-0.64
BH	CH	0700	-0.70
BH	CH	0800	-0.79
BH	CH	0900	-0.68
BH	CH	1000	-0.71
BH	CH	1100	-0.78
BH	CH	1200	-0.75
BH	CH	1300	-0.77
BH	CH	1400	-0.77
BH	CH	1500	-0.62
BH	CH	1600	-0.45
BH	CH	2000	-0.48
BH	CH	2100	-0.51
BH	CH	2200	-0.49
BH	CH	2300	-0.46

BH = Brahman; CH = Charolais

Shaded Angus steers had an average rumen temperature that was higher ($P < 0.05$) than shaded Brahman steers (Figure 21 and Table 5). Additionally the rumen temperature of shaded Angus steers were higher ($P < 0.05$) than shaded Charolais steers by 0.56 °C, 0.66 °C, 0.61 °C, 0.53 °C, 0.53 °C, 0.49 °C, 0.48 °C, 0.44°C, 0.47 °C and 0.45 °C at 0800, 0900, 1000, 1100, 1200, 1300, 1400, 1500, 1700 and 1800 h respectively (Figure 21). The rumen temperature of shaded Brahman steers was 0.44 °C lower ($P < 0.05$) at 0400 and 0500 h (Figure 21).

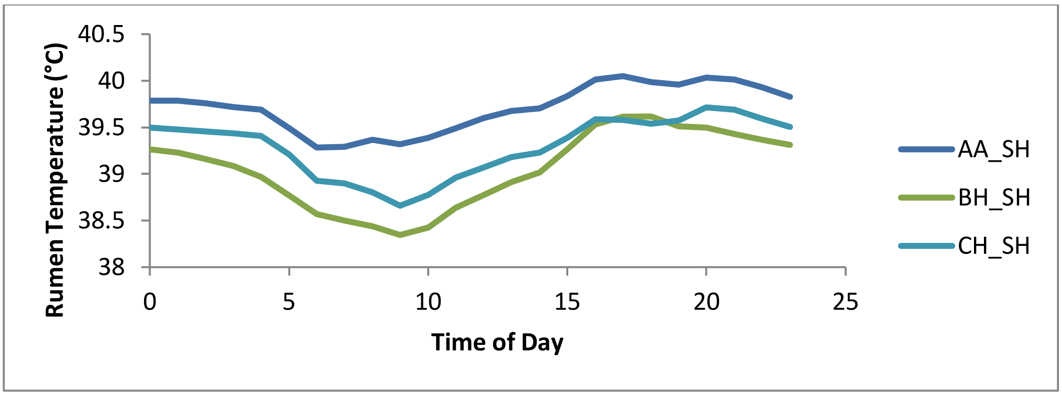

Figure 21 Diurnal changes in rumen temperature of shaded Angus, Charolais and Brahman steers.

Table 5 Differences (P < 0.05) in rumen temperature (° C) between shaded Angus and Brahman steers

Breed	Breed	Time	Difference in Rumen Temperature (°C) (Angus to Brahman)
AA	BH	0000	0.52
AA	BH	0100	0.56
AA	BH	0200	0.60
AA	BH	0300	0.63
AA	BH	0400	0.73
AA	BH	0500	0.72
AA	BH	0600	0.71
AA	BH	0700	0.79
AA	BH	0800	0.93
AA	BH	0900	0.97
AA	BH	1000	0.96
AA	BH	1100	0.85
AA	BH	1200	0.83
AA	BH	1300	0.76
AA	BH	1400	0.68
AA	BH	1500	0.57
AA	BH	1600	0.48
AA	BH	1700	0.44
AA	BH	1900	0.44
AA	BH	2000	0.54
AA	BH	2100	0.59
AA	BH	2200	0.56
AA	BH	2300	0.51

AA = Angus; BH = Brahman

4.7 Estimation of Rate of Change in Body Heat

The differences between the minimum and maximum rumen temperature over time were used to estimate the change in body heat.

The change in rumen temperature between 0800 and 1600 (minimum temperature to maximum temperature) was used as an indicator of heat gain and the change between 1600 and 0800 was used as an indicator of heat loss. Cattle did consume feed during the later period which may have had some impact on heat loss.

4.7.1 Heat Gain

The un-shaded Angus gained 1.20 °C between 0800 and 1600 or 0.15 °C/h, the Charolais gained 0.81 °C or 0.10 °C/h and the Brahmans 1.18 °C or 0.15 °C/h. For the shaded cattle the Angus gained 0.66 °C between 0800 and 1600 or 0.08 °C/h, the Charolais gained 0.79 °C or 0.10 °C/h and the Brahmans 1.16 °C or 0.15 °C/h. The change in rumen temperature for un-shaded Brahmans and Angus were similar, however the Brahmans started from a lower 0800 h rumen temperature compared with the Angus (38.4 °C vs. 39.11 °C). Overall there were little differences in total heat 'gain' for shaded and un-shaded Brahman and Charolais. However, the un-shaded Charolais started from a higher rumen temperature compared with the shaded Charolais (39.2 °C vs. 38.8 °C). The shaded and un-shaded Brahmans had the same maximum and minimum temperatures (39.6 °C and 38.4 °C). Rumen temperature increases for all breeds commenced when HLI was 86 ± 4.2. This is the threshold for an increase in rectal temperature and panting previously determined for un-shaded Angus (Gaughan et al. 2008a). The HLI threshold of 86 for un-shaded Angus appears to be robust as does the +5 adjustment factor for shade (2 to 3 m2/SCU). It is not currently clear why an increase in rumen temperature also occurred in the Brahmans and Charolais when the HLI was approximately 86. The HLI threshold for these breeds is 96 and 89 respectively, and based on the ± 4.2 error term the Charolais are within the expected limits. However, it is important to remember that rumen temperature cannot be looked at in isolation other factors such as activity and panting score also need to be considered. At this stage there is no compelling evidence to change the un-shaded or shaded thresholds for the Angus, Brahmans or Charolais.

4.7.2 Heat Loss

The rate of heat loss was similar between the shaded and un-shaded Brahman (0.07 °C/h) and the shaded and un-shaded Charolais (0.05 °C/h). The rate of loss was twice as much for the un-shade Angus compared with the shaded Angus (0.08 °C/h vs. 0.04 °C/h). It should also be noted that the heat gain (°C/h) was twice as much for the un-shaded cattle. Thus the heat loss from the Brahmans was greater ($P<0.05$) compared with the Charolais and the shaded Angus and similar ($P=0.08$) to that of the un-shaded Angus.

In order to determine the relationship between heat loss and the mean maximum HLI at 1600 h (86.52 units) and the mean minimum at 0800 h (75.73). These times were used because they corresponded to the maximum and minimum rumen temperatures. The change in HLI units was 0.67 units per hour. The accumulated heat load unit (AHLU) mean maximum at 1600 h was 22.40 units and mean minimum at 0800 h was 6.10 units. This represents a reduction of 16.3 units over 16 hours (1.02 units/h) (on average).

Thus on average for every 0.67/h reduction in HLI and 1.02/h reduction in AHLU will represent a 0.5°C reduction in rumen temperature (to its biological limit).

There was a 1 to 2 h lag between maximum and minimum rumen temperature and maximum and minimum HLI. This suggests that there is some buffering of the rumen against external heat load, although similar lags have been reported for body temperature. In the current HLI model (Gaughan et al. 2008a) the reduction in body heat content occurs when the HLI is 77 units or less. The data from the current study suggests that this value is suitable for un-shaded Angus but is too low for shaded cattle, and un-shaded and shaded Brahman and Charolais.

Suggested adjustments are: Brahman – heat dissipation commences when HLI is 92 (assuming it has reached a maximum above the 96 unit threshold); Angus – 77 unit threshold if no access to shade and for shaded cattle 84 (when the 91 thresholds has been reached [assume 2 – 3 m^2 of shade]); Charolais – 84 unit threshold (assuming the 89 threshold has been reached). The changes for Angus and Brahman are modelled in Figure 18.

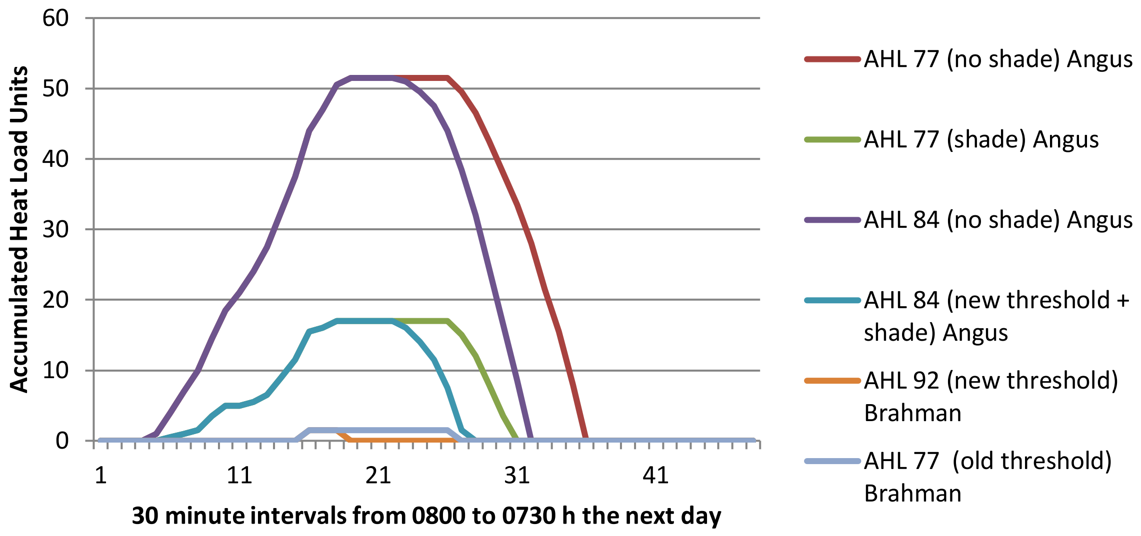

Figure 18 Modelling exercise to show differences in new heat loss thresholds

The new threshold values for heat loss do not reduce the maximum heat load value but increase the rate of heat dissipation. Therefore the AHLU values will decrease at a quicker rate.

Outcomes from these data:

1. ***Rumen temperature is a useful indictor of the thermal status of an individual***
2. ***Rumen temperature can be used to determine the thermal tolerance of cattle***
3. ***The increase in rumen temperature in relation to the time of the day and HLI was not breed dependent (this was an unexpected finding, and further investigation is warranted)***
4. ***The change in rumen temperature over time, particularly at night is a useful tool for determining heat loss***
5. ***Suggested adjustments to HLI thresholds are: Brahman – heat dissipation commences when HLI is 92 (assuming it has reached a maximum above the 96 unit threshold); Angus –***

77 unit threshold if no access to shade and for shaded cattle 84 (when the 86 thresholds has been reached); Charolais – 84 unit threshold (assuming the 89 threshold has been reached)

6. ***Provision of shade reduces the thermal stress on Bos taurus cattle, but has minimal impact on Bos indicus (100%) cattle***

4.8 Mean Panting Score

The change in panting scores i.e. from 0 to 4.5 as the animal is heat challenged is a good indicator of the changing heat load status of the animal (Mader et al., 2006; Gaughan and Mader 2013). When groups of cattle are assessed for PS, the mean panting score (MPS) is used (Brown-Brandl et al., 2006; Gaughan et al., 2008a). The MPS can be used as an indicator of the severity of climatic induced stress: 0 to 0.4 minimal heat load – no stress; 0.4 to 0.8 moderate heat load – slight stress; 0.8 to 1.2 high heat load – moderate heat load; >1.2 extreme heat load cattle highly stressed (Gaughan et al., 2008b).

Mean panting score was affected ($P < 0.05$) by treatment, treatment × hour, breed and breed × treatment. The Angus steers had the highest MPS within both the shade and un-shaded treatments, followed by the Charolais and Brahmans (Table 6). The ranking by breed was similar to breed differences reported by Gaughan et al. (2010b).

At 0600 h the un-shaded Angus had a greater ($P < 0.05$) MPS (1.06 ± 0.04) compared with the un-shade Brahman (0.10 ± 0.02) and un-shaded Charolais (0.90 ± 0.04). The MPS of the Angus was further affected by night time conditions. The MPS of un-shaded Angus was 1.44 at 0600 h on heat wave days (maximum 0600 h MPS was 1.60 on 12th January), especially when morning (0500 to 0600 h) conditions are warm (≥ 22 ^{o}C) and humid (≥ 60%). There is a strong indication that elevated MPS at 0600 h is a reliable indicator that cattle have not had sufficient night time cooling. However, there may also be instances where cattle attempt to dissipate heat in the morning by increased respiratory activity, especially when the morning is hot. Both of these ideas are supported by Gaughan and Mader (2013) who reported that elevated 0600 h panting scores of Angus steers occur at lower body temperatures compared with steers showing the same panting score in the afternoon. It is likely that if there is an accumulated heat load overnight then the elevated respiratory response is directly related to the animal's inability to dissipate sufficient heat during the night. This is obviously a critical factor in the heat load susceptibility of the animal coming into a new day. Therefore, managers need to assess animals in the context of not just how hot today will be but also need to consider how much carry over heat the animals may have. Although not completely defined it would appear from this study that if there is an AHL ≥ 25 at 0300 h then cattle will probably not have been able to reduce body temperature sufficiently. Furthermore, the data is suggesting that Angus cattle need to have at least 6 h of 0 heat load (i.e. AHLU = 0 for 6 h) at night in order for there to be sufficient relief. Unfortunately, this is somewhat confounded by night time feed intake. If cattle are consuming the bulk of their feed at night, they may still have carry over heat even where weather conditions suggest that there has been sufficient cooling. This will be discussed further below.

As expected the maximum heat load was experienced between 1200 and 1600 h (Table 6). It is clear from the data presented here that the Angus cattle were under high to extreme heat load conditions from 0800 to 1600. The Charolais were under moderate to high heat load, whereas the Brahmans were under minimal to moderate heat load between 0600 and 1800 h. It is worth noting that the Brahmans did exhibit an increase in respiration as heat load increased, albeit from a low base.

When examined on a percentage basis the percentage increase in PS (from 0600 to 1400 h) of un-shaded Brahmans was 87%, and 97% for those with access to shade; for Angus the increase was 40% (47% shaded) and the increase for Charolais was 34% for un-shaded and 41% for shaded. For all breeds the greater % increase in PS for shaded cattle suggests that the provision of shade allows cattle to more effectively use shade for thermo regulation. Having a lower PS at 0600 h appears to be an important factor in the animal's capacity to use respiration rate as a means of containing body temperature. The greater percentage rise in PS of the Brahmans indicates that this breed does use increased respiratory dynamics in thermo regulation.

The provision of shade reduced the impact of solar load by reducing the amount of time cattle were exposed to extreme conditions, but did not completely remove the impact. Similar findings have previously been reported (Sullivan et al. 2011; Gaughan et al. 2010a). However, in this study the differences between the breeds used have been quantified and it is clear that shade will improve thermo regulatory capacity of the breeds used.

Outcomes from these data:

1. ***Supports the new HLI thresholds for Bos indicus and Bos taurus steers***
2. ***Supports the new HLI threshold for European steers***
3. ***Recommend that the White Coat threshold be increased to + 4***
4. ***Highlights the importance of early morning panting score observation of Bos taurus (Angus) cattle, especially when AHLU ≥ 25 at 0300 h or there has been less than 6 h of 0 AHLU overnight***
5. ***Suggests that a modification to the HLI recovery threshold is required to account for the early morning respiratory dynamics – more analysis is required on this point***
6. ***Suggest that night time feeding behaviour may influence cattle heat load status***

4.9 Activity and Posture

There were a few breed x treatment effects ($P < 0.05$) and time of day effects ($P < 0.05$) on the number of animals eating, drinking, standing and lying at a given time. The data for each of the breeds are presented in Tables 7, 8 and 9. The data for all breeds is presented in Table 10.

The biggest treatment effect was for the percentage of Angus lying at 1600 h; 16.1% of shaded cattle and 29.6% of un-shaded cattle (Table 7). A similar response was seen for the Charolais (Table 8) but not for the Brahman (Table 9). Unexpectedly there was a trend for more of the shaded Angus and Charolais to be standing at each observation time. For Brahman steers it was less equivocal. A greater percentage of shaded Angus and Charolais were eating at 1600 h compared with their un-shaded counterparts. Between 1200 and 1800 h more ($P<0.05$) of the shaded Angus were observed drinking compared with the un-shaded Angus. This supports some anecdotal evidence that *Bos taurus* cattle with access to shade drink more often.

Rumination (Table 11) was largely time dependent ($P<0.05$). However, there was a Brahman × treatment effect with more ($P<0.05$) rumination observed in the un-shaded Brahmans. There is probably not much that can be determined from this due to feed being offered late in the afternoon. It is likely that a greater number of animals would be ruminating at night when observations were not made.

There were breed, breed × time and time effects for shade usage (Table 12 and Figure 18). Angus used the shade in greater numbers (P<0.05) for all times except at 0600 h. For all breeds less than 1% was under shade at 0600 h. For Angus maximum shade usage occurred at 1200 h (81.5%), for Charolais and Brahman maximum shade usage occurred at 1400 h (39.4% and 24.6% respectively). Two very interesting outcomes from shade usage observations were the higher than expected use of shade by Brahmans and lower than expected use by Charolais.

Outcomes from these data:

1. ***Shade usage is the best behavioural measure (apart from panting) of thermal stress***
2. ***Supports the previous recommend that the White Coat threshold be increased to + 4***
3. ***Shows that Brahmans will use shade if it is available***

4.10 Thermal Images

The use of thermal imaging as a tool to determine heat flow from animals is relatively new. It is important to remember that the values seen are not an absolute measure of body temperature, but are a measure of heat flow from the animal. The higher the value the greater the heat flow from the animal to the environment. The images shown in Figure 19 demonstrate variations in heat flow between an Angus and a Brahman steer during a coll night. The average heat flow from the Brahman is 2 °C lower than from the Angus. Clear difference in heat flow via the ears is also evident.

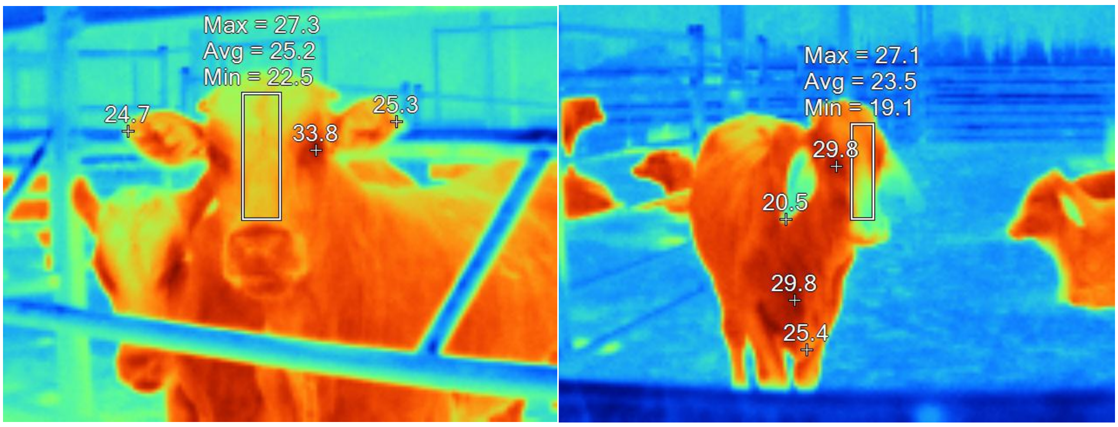

Figure 19 Heat flow from Charolais and Brahman steers at approximately 0220 h on the 7th January 2013

Variations in heat flow between breed and animals within breed are evident (Figure 20). It is also clear that heat flow is not consistent on the body. An interesting preliminary result was the greater heat flow from Brahmans at night and early evening when conditions were hot (Figure 20 and 21).

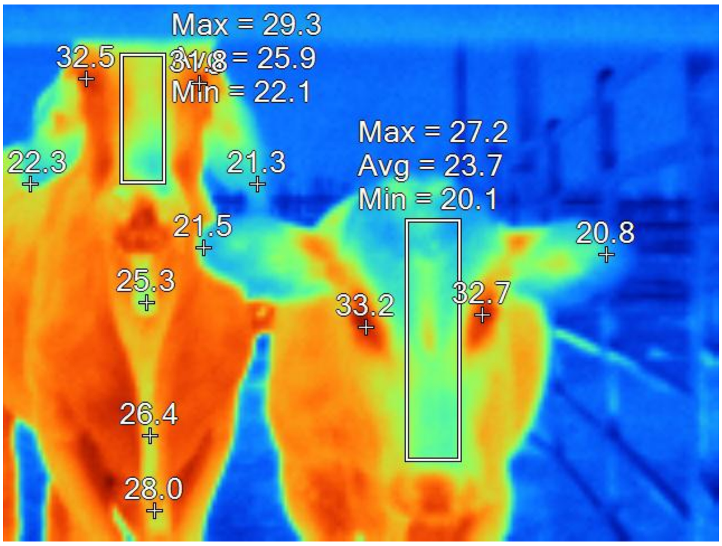

Figure 20 Breed differences in heat flow on a hot night

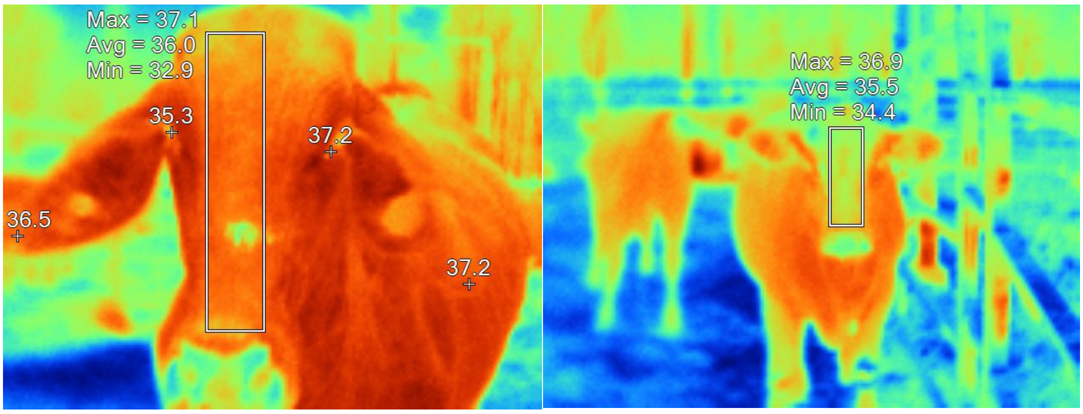

Figure 21 Differences between Brahman and Angus at approximately 1830 h on 13th January, 2013 (heat wave)

The use of this technology as a scientific tool will require further investigation. There is some evidence from this study of a relationship between heat flow and rumen temperature. However, there is a considerable amount of data that is still being investigated from this study.

4.11 Night Time Feeding Activity

Although not fully analysed inspection of video footage has shown the following.

Brahman cattle appear to have more frequent meals (determined by visits to feedbunk with head in bunk) compared with the Angus and Charolais. This trend was noticed during the day and at night, and during high heat load events the frequency of meals by Brahmans increased. Angus and Charolais made fewer night time visits to the feedbunk, but also tended to stay longer. The greater frequency of small meals may be useful in reducing heat build-up due to the heat of fermentation in the rumen. The Brahman cattle did not appear to have an early evening spike in rumen temperature seen by the other breeds (Figure 20), which was assumed to be a result of high feed intake from 1800 h.

There was on average an increase in eating behaviour between 0200 h and 0400 h most nights in the un-shaded pens especially when there was little night time relief. The video data will continue to be analysed.

Outcomes from these data:

1. ***Eating behaviour of Brahmans differs to Angus and Charolais ~ Brahmans eat 'little and often'***
2. ***Eating behaviour of Angus and to a lesser extent Charolais changes during periods of hot weather ~more night time eating***

Table 6 Changes in mean panting score (means ± SE) for shaded (SH) and un-shaded (US) Angus (AA), Brahman (BH) and Charolais (CH) steers from 0600 to 1800 h, and mean (± SE) heat load index (HLI).

	Panting score at different times (h) of the day						
	0600	0800	1000	1200	1400	1600	1800
SH							
AA	0.81^{d2} ± 0.05	1.25^{b12} ± 0.03	1.29^{b1} ± 0.03	1.37^{ab2} ± 0.04	1.52^{a2} ± 0.04	1.30^{b12} ± 0.04	1.01^{c1} ± 0.05
BH	0.02^{d3} ± 0.01	0.05^{d5} ± 0.02	0.22^{bc4} ± 0.04	0.29^{b5} ± 0.05	0.69^{a4} ± 0.06	0.34^{b4} ± 0.05	0.08^{cd4} ± 0.03
CH	0.77^{c2} ± 0.04	0.84^{bc3} ± 0.04	0.84^{bc3} ± 0.05	1.03^{b3} ± 0.05	1.31^{a3} ± 0.04	0.93^{bc3} ± 0.06	0.49^{d23} ± 0.07
US							
AA	1.06^{c1} ± 0.04	1.36^{b1} ± 0.04	1.42^{b1} ± 0.05	1.59^{ab1} ± 0.07	1.77^{a1} ± 0.07	1.51^{b1} ± 0.07	1.11^{c1} ± 0.06
BH	0.10^{d3} ±0.02	0.26^{cd4} ± 0.07	0.38^{bc4} ± 0.06	0.53^{ab4} ± 0.07	0.78^{a4} ± 0.08	0.50^{bc4} ± 0.07	0.33^{bcd3} ± 0.06
CH	0.90^{cd12} ± 0.04	1.13^{abc1} ± 0.04	1.04^{bc2} ± 0.06	1.23^{ab23} ± 0.06	1.37^{a23} ± 0.06	1.12^{abc23} ± 0.07	0.65^{d2} ± 0.08
HLI	68.48 ± 0.60	85.30 ± 0.30	85.66 ± 0.25	85.70 ± 0.26	84.89 ± 0.31	83.38 ± 0.27	79.01 ± 0.32

$^{a-d}$ Means in a row with the different superscript letters were different (P<0.05).

$^{1-5}$ Means in a column with the different superscript numbers were different (P<0.05).

Table 7 The effect of having access to shade, or no shade on: activity (eating, drinking), posture (standing or lying) of Angus steers at two hourly intervals from 0600 to 1800 h.

	Time of day (h)						
	0600	0800	1000	1200	1400	1600	1800
Eating,%							
Shaded	3.65^{c}	7.83^{c}	0.49^{c}	0.23^{c}	1.32^{c}	25.22^{b}	35.76^{a}
Un-shaded	5.21^{c}	8.60^{bc}	0.33^{c}	0.69^{c}	4.95^{c}	17.80^{b}	34.96^{a}
Drinking,%							
Shaded	5.09^{ab}	1.64^{b}	2.13^{b}	1.89^{b1}	3.76^{b1}	9.75^{a1}	9.32^{a1}
Un-shaded	2.78^{ab}	4.65^{a}	0.65^{ab}	0.00^{b2}	0.90^{ab2}	4.17^{ab2}	4.45^{a2}
Standing,%							
Shaded	52.75^{ab}	59.79^{a1}	44.07^{bc}	33.33^{c}	48.41^{ab}	48.91^{ab}	41.88^{bc2}
Un-shaded	45.14^{ab}	46.05^{ab2}	37.91^{ab}	34.38^{b}	37.84^{ab}	48.48^{ab}	52.81^{a1}
Lying,%							
Shaded	38.51^{cd}	30.74^{d}	53.31^{ab}	64.55^{a}	46.51^{bc}	16.12^{e2}	13.04^{e}
Un-shaded	46.87^{bc}	40.70^{cd}	61.11^{ab}	64.93^{a}	56.31^{abc}	29.55^{d1}	7.78^{e}

$^{a-c}$ Means in a row with the different superscript letters were different (P<0.05).

$^{1-2}$ Means in a column within each behaviour with the different superscript numbers were different (P<0.05).

Table 8 The effect of having access to shade, or no shade on: activity (eating, drinking), posture (standing or lying) of Charolais steers at two hourly intervals from 0600 to 1800 h.

Behaviour	Times of a day (h)						
(% of animals)	0600	0800	1000	1200	1400	1600	1800
Eating							
Shaded	4.95^{b}	6.09^{b}	2.22^{b}	1.80^{b}	3.44^{b}	34.33^{a}	34.10^{a}
Un-shaded	7.92^{c}	11.47^{c}	4.32^{c}	2.50^{c}	4.32^{c}	29.55^{b}	43.78^{a}
Drinking							
Shaded	1.35^{c}	6.35^{a}	2.67^{abc}	1.13^{c}	1.85^{bc}	1.99^{bc}	5.28^{ab1}
Un-shaded	1.25^{a}	3.96^{a}	1.57^{a}	0.83^{a}	2.16^{a}	1.82^{a}	1.33^{a2}
Standing							
Shaded	59.46^{a1}	46.03^{ab}	29.20^{c}	22.97^{c}	45.24^{b}	44.53^{b}	48.86^{ab}
Un-shaded	33.54^{ab2}	37.79^{a}	29.80^{ab}	21.25^{b}	35.14^{ab}	35.90^{ab}	45.00^{a}
Lying							
Shaded	34.24^{c2}	41.53^{bc}	65.91^{a}	74.10^{a}	49.47^{b}	19.15^{d2}	11.76^{d}
Un-shaded	57.29^{bc1}	46.78^{cd}	64.31^{ab}	75.42^{a}	58.38^{bc}	32.73^{d1}	9.89^{e}

$^{a-d}$ Means in a row with the different superscript letters were different ($P<0.05$).
$^{1-2}$ Means in a column within each behaviour with the different superscript numbers were different ($P<0.05$).

Table 9 The effect of having access to shade, or no shade on: activity (eating, drinking), posture (standing or lying) of Brahman steers at two hourly intervals from 0600 to 1800 h.

Behaviour	Time of a day (h)						
(% of animals)	0600	0800	1000	1200	1400	1600	1800
Eating							
Shaded	1.89^{bc}	8.62^{b}	2.09^{bc}	0.00^{c}	1.27^{bc}	24.48^{a}	27.58^{a}
Un-shaded	2.78^{c}	11.42^{bc}	1.31^{c}	0.69^{c}	0.90^{c}	23.48^{ab}	29.26^{a}
Drinking							
Shaded	1.49^{a}	4.32^{a}	2.62^{a}	2.30^{a1}	3.97^{a}	1.59^{a}	5.32^{a1}
Un-shaded	0.00^{a}	2.33^{a}	0.65^{a}	0.00^{a2}	2.70^{a}	0.76^{a}	0.74^{a2}
Standing							
Shaded	74.82^{a1}	57.42^{b}	40.49^{cd2}	28.51^{d}	50.95^{bc}	50.30^{bc}	58.02^{b}
Un-shaded	57.64^{a2}	66.09^{a}	53.59^{a1}	27.78^{b}	44.15^{ab}	51.52^{a}	65.19^{a}
Lying							
Shaded	21.80^{cd2}	29.64^{c}	54.80^{b}	69.19^{a}	43.81^{b}	23.63^{c}	9.08^{d}
Un-shaded	39.58^{bc1}	20.16^{de}	44.45^{b}	71.53^{a}	52.25^{ab}	24.24^{cd}	4.81^{e}

$^{a-d}$ Means in a row with the different superscript letters were different (P<0.05).
$^{1-2}$ Means in a column within each behaviour with the different superscript numbers were different (P<0.05).

Table 10 Comparison of standing and lying behaviours between breeds when shade is available

Posture	Time of day (h)						
(% of animals)	0600	0800	1000	1200	1400	1600	1800
Standing - shade							
Angus	0.00^{b1}	30.42^{a1}	36.44^{a1}	27.75^{a1}	35.98^{a1}	27.81^{a1}	2.17^{b1}
Brahman	0.00^{c1}	5.42^{bc2}	6.84^{bc2}	5.68^{bc2}	14.29^{a2}	10.65^{ab2}	1.79^{c1}
Charolais	0.45^{c1}	3.97^{bc2}	11.60^{ab2}	12.84^{a2}	19.05^{a2}	12.19^{ab2}	1.67^{c1}
Lying - shade							
Angus	0.23^{d1}	6.88^{cd1}	37.09^{b1}	53.78^{a1}	35.29^{b1}	11.59^{c1}	1.21^{d1}
Brahman	0.50^{c1}	1.35^{bc2}	8.18^{ab2}	12.16^{a2}	10.32^{a3}	8.46^{ab1}	0.48^{c1}
Charolais	0.23^{b1}	2.38^{b2}	15.56^{a2}	20.72^{a2}	20.37^{a2}	5.47^{b1}	0.71^{b1}
Standing – no shade							
Angus	52.75^{a2}	29.37^{bc2}	7.62^{e3}	5.59^{e2}	12.43^{de3}	21.09^{cd2}	39.71^{b2}
Brahman	74.82^{a1}	52.01^{bc1}	33.64^{de1}	22.84^{e1}	36.67^{d1}	39.65^{cd1}	56.23^{b1}
Charolais	59.01^{a2}	42.06^{bc1}	17.60^{ef2}	10.14^{f2}	26.19^{de2}	32.34^{cd12}	46.90^{ab12}
Lying – no shade							
Angus	38.29^{a1}	23.86^{b2}	16.22^{bc2}	10.77^{cd2}	11.22^{cd2}	4.53^{d2}	11.84^{cd1}
Brahman	21.31^{bcd2}	28.28^{bc12}	46.62^{a1}	57.03^{a1}	33.49^{b1}	15.17^{cd1}	8.60^{d1}
Charolais	34.01^{c1}	39.15^{bc1}	50.36^{ab1}	53.38^{a1}	29.10^{c1}	13.68^{d1}	10.48^{d1}

$^{a-d}$Means in a row with the different superscript letters were different (P<0.05)

$^{1-3}$Means in a column within each behaviour with the different superscript numbers were different (P<0.05)

These data do not include cattle eating or drinking at the scheduled observation times.

Table 11 The effect of having access to shade, or no shade on the ruminating behaviour of Angus, Brahman and Charolais steers at two hourly intervals from 0600 to 1800 h.

	Time of a day (h)						
(% of animals)	0600	0800	1000	1200	1400	1600	1800
Ruminating Angus,%							
Shaded	3.24^{c}	4.29^{bc}	9.33^{ab}	10.90^{a}	14.66^{a1}	2.59^{c}	2.03^{c}
Un-shaded	3.13^{b}	3.49^{b}	5.56^{b}	11.81^{a}	6.76^{ab2}	3.41^{b}	1.48^{b}
Ruminating Brahman,%							
Shaded	1.62^{d2}	3.39^{cd}	7.69^{bc2}	14.14^{a2}	9.63^{ab2}	2.49^{cd}	1.16^{d2}
Un-shaded	4.86^{c1}	6.78^{bc}	17.65^{ab1}	24.31^{a1}	24.32^{a1}	6.06^{bc}	4.44^{c1}
Ruminating Charolais, %							
Shaded	4.05^{cde}	7.14^{cd}	10.22^{bc}	18.15^{a1}	14.55^{ab}	3.23^{de}	0.52^{e}
Un-shaded	5.00^{abc}	6.51^{abc}	9.02^{ab}	11.25^{a2}	9.10^{abc}	3.64^{bc}	1.78^{c}

Animals all locations in pen, standing and lying

Table 12 Comparison of shade usage (% ± SE) of Angus, Charolais and Brahman steers at 0600, 0800, 1000, 1200, 1400, 1600 and 1800 h.

Breed	Shade usage (%) at different times of the day						
	0600	0800	1000	1200	1400	1600	1800
Angus	$0.23^{c1} \pm 0.23$	$37.30^{b1} \pm 4.72$	$73.53^{a1} \pm 3.61$	$81.53^{a1} \pm 2.94$	$71.27^{a1} \pm 4.09$	$39.40^{b1} \pm 4.41$	$3.38^{c1} \pm 1.07$
Charolais	$0.68^{e1} \pm 0.50$	$6.35^{de2} \pm 1.62$	$27.16^{bc2} \pm 3.52$	$33.56^{ab2} \pm 3.87$	$39.42^{a2} \pm 4.14$	$17.66^{cd2} \pm 3.05$	$2.38^{e1} \pm 0.78$
Brahman	$0.50^{c1} \pm 0.35$	$6.77^{bc2} \pm 2.01$	$15.02^{ab3} \pm 3.01$	$17.84^{a3} \pm 2.55$	$24.60^{a3} \pm 3.00$	$19.10^{a2} \pm 3.44$	$2.27^{c1} \pm 1.02$

$^{a-e}$Means in a row with the different superscript letters were different ($P<0.05$)
$^{1-3}$Means in a column with the different superscript numbers were different ($P<0.05$)

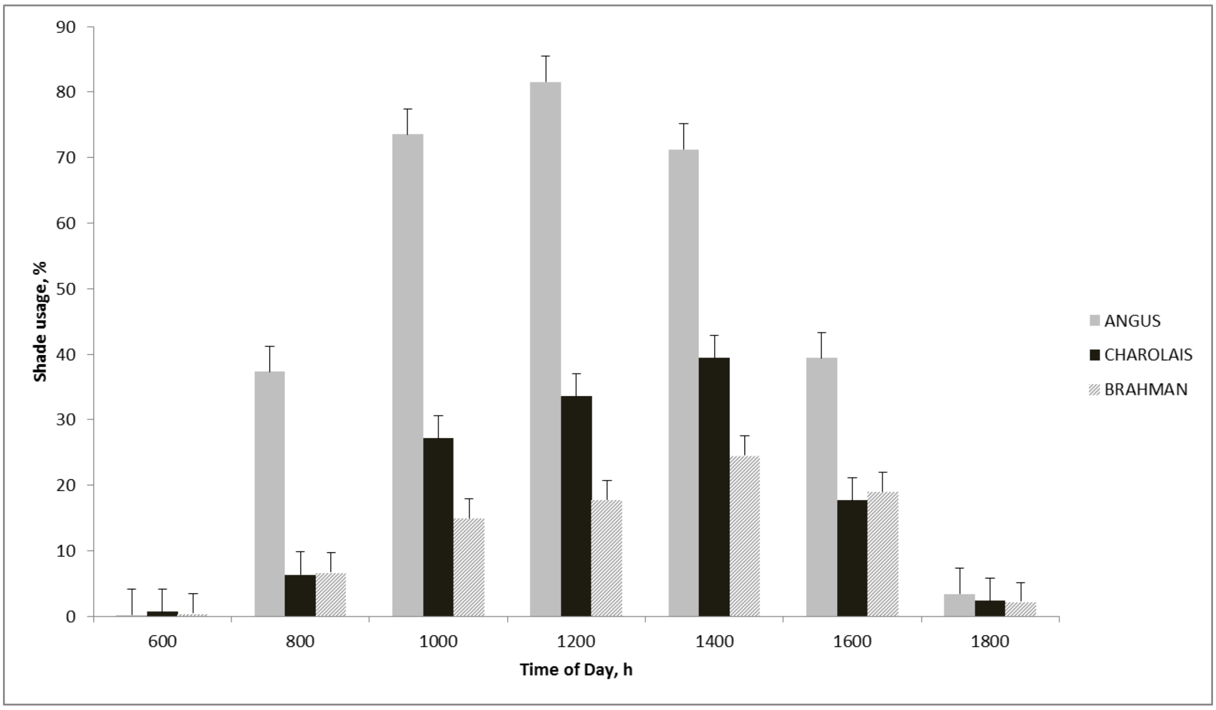

Figure 18 The percentage of Angus, Charolais and Brahman steers that were using shade at 0600, 0800, 1000, 1200, 1400 and 1600 h

4.12 Blood Metabolites

Limitations have prevented the completion of the assay analysis of cytokine (Interleukin 6) samples and the final statistical analysis of heat shock protein 70 (hsp70).

A summary of the blood analysis follows:

- Breed and sample date had an effect on potassium concentration with Charolais (4.9 mmol/L) having higher levels than Brahmans (4.6 mmol/L) ($P < 0.05$). Angus (4.7 mmol/L) were similar to Charolais and Brahman steers ($P > 0.05$) (Figure 19).
- Shaded cattle (100.9 mEq/L) had lower plasma chloride concentration compared to the un-shaded group (100.0 mEq/L) ($P < 0.05$) (Figure 20).
- Breed × treatment and sample date had an effect on bicarbonate concentration with shaded Charolais (22.6 mEq/L) being higher than shaded Angus (20.7 mEq/L) ($P < 0.05$) (Figure 21).
- There were no differences detected for plasma sodium concentration of breed and breed × treatment groups (Figure 22).
- Breed and sample date had an effect on cholesterol concentration with Brahmans (2.4 mg/dL) having higher levels than Charolais (1.7 mg/dL) and Angus (1.9 mg/dL) ($P < 0.05$) (Figure 23).
- There were no differences detected in the plasma triglyceride concentration of breed and breed × treatment groups (Figure 24).
- Breed had an effect ($P < 0.05$) on glucose concentration: Angus (4.6 mmol/L), Charolais (5.0 mmol/L) and Brahmans (5.3 mmol/L) (Figure 25).
- Shaded cattle (177.2 IU/L) had a higher plasma creatine kinase chloride concentration compared to the un-shaded cattle (151.5 IU/L) ($P < 0.05$) (Figure 27).

- Breed had an effect on plasma insulin concentration with Angus steers (8.0 µIU/L) having higher levels than Brahmans (5.3 µIU/L) ($P < 0.05$). Charolais (6.4 µIU/L) were similar to both Angus and Brahman steers ($P > 0.05$) (Figure 26).
- There were no between breed or treatment differences ($P > 0.05$) for plasma haptoglobin (Figure 28).

Outcomes from these data:

1. ***There were some changes in blood metabolites that suggest a breed effect (e.g. higher cholesterol in Brahmans) but it is not clear if the differences are biologically important***
2. ***The inability to detect significant and consistent differences between treatment and breed × treatment may be a reflection of the frequency of blood collection***
3. ***Further analysis of the blood data is being undertaken***

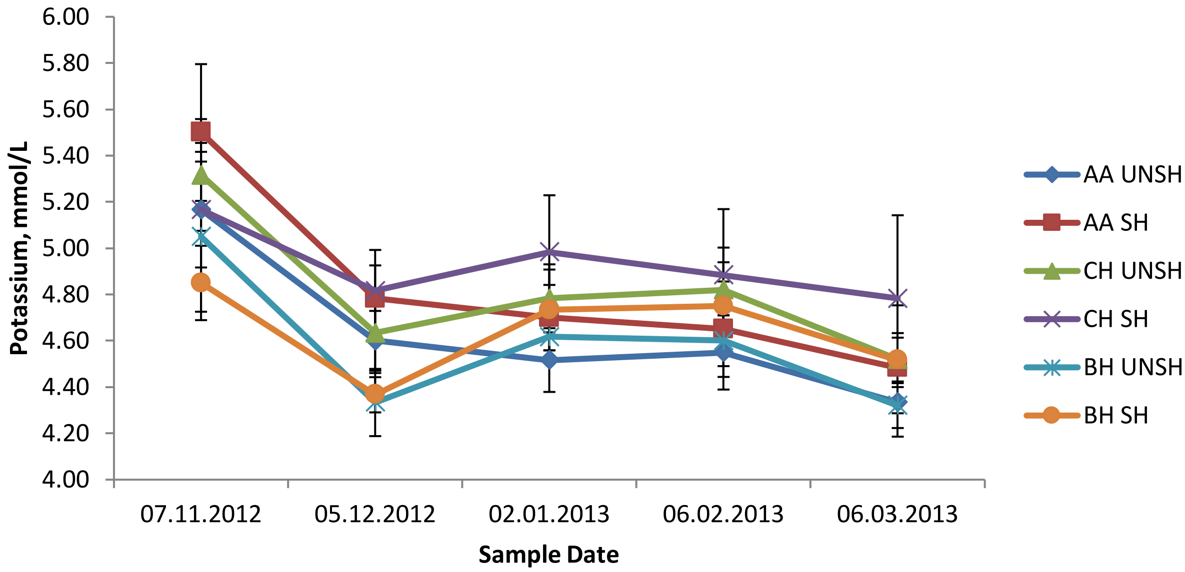

Figure 19 Plasma potassium level (mmol/L) in un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

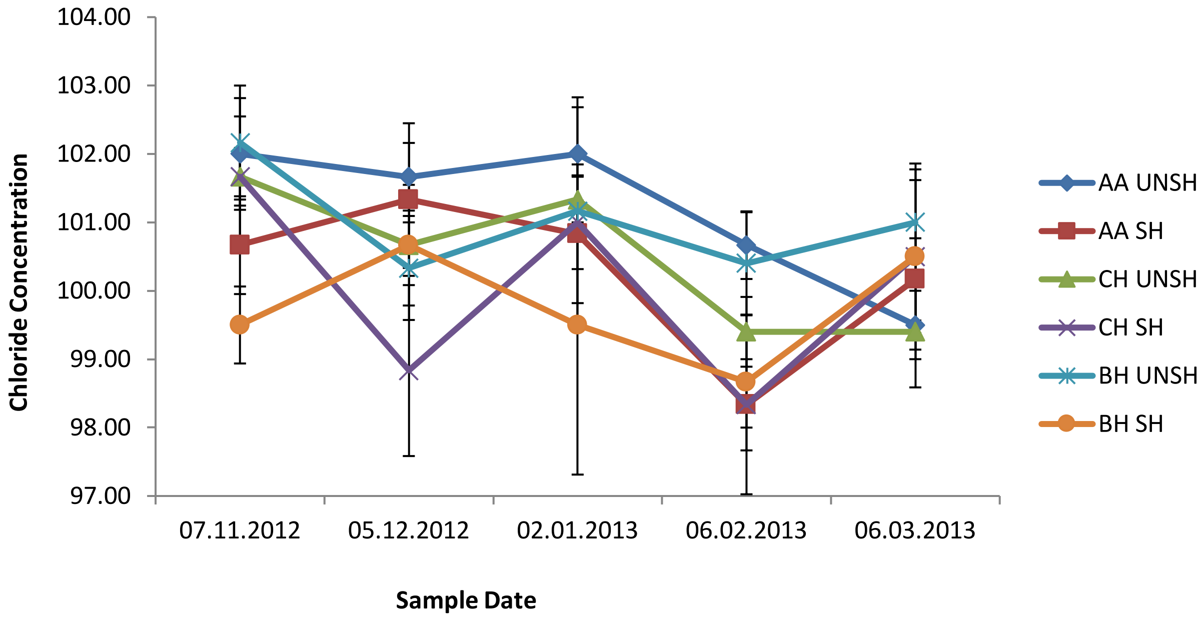

Figure 20 Plasma chloride concentrations from un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

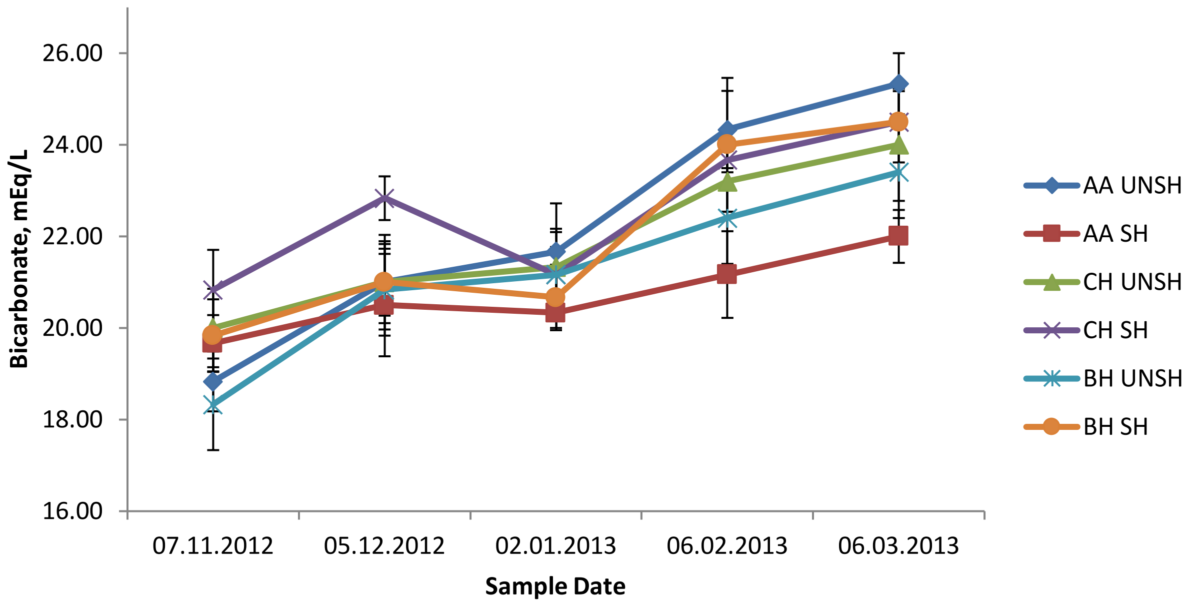

Figure 21 Plasma bicarbonate level (mEq/L) in un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

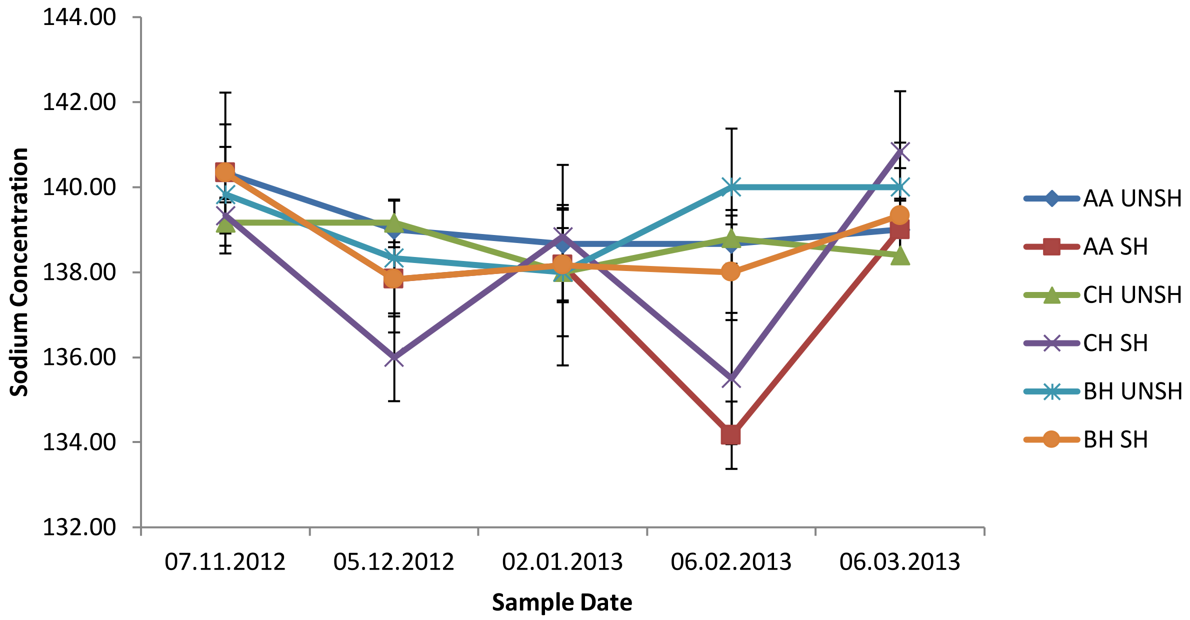

Figure 22 Plasma sodium concentrations from un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

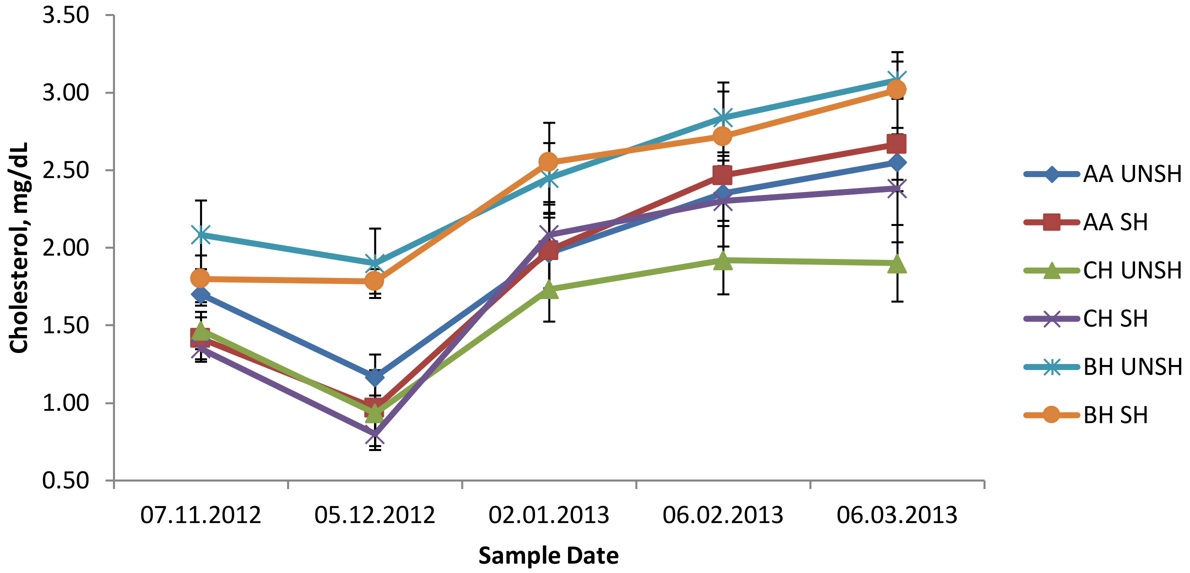

Figure 23 Plasma cholesterol (mg/dL) for un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

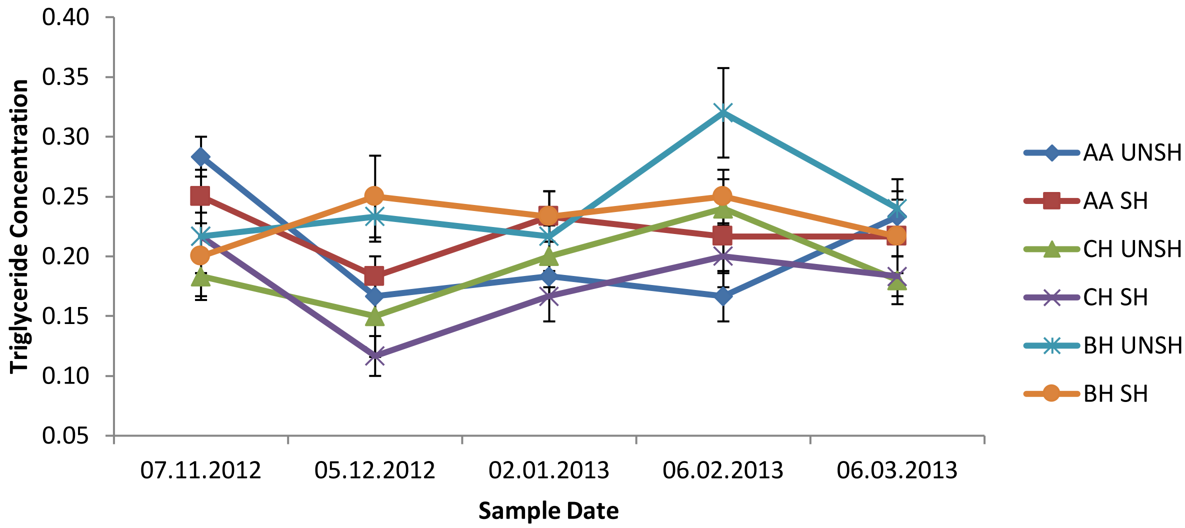

Figure 24 Plasma triglyceride concentrations from un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

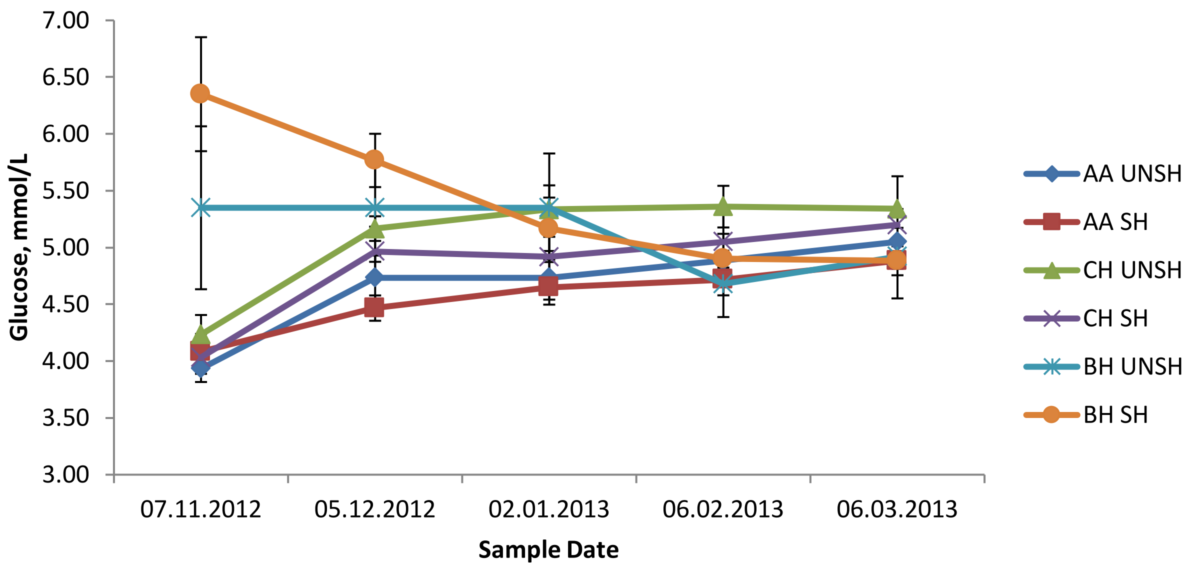

Figure 25 Plasma glucose (mmol/L) in un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

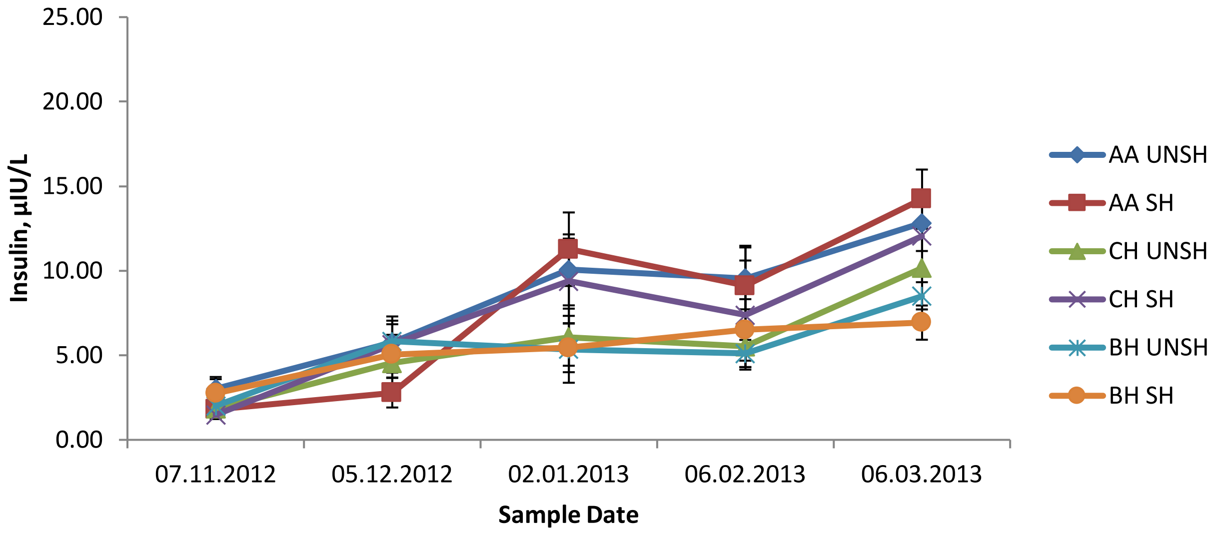

Figure 26 Plasma insulin (µIU/L) in un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

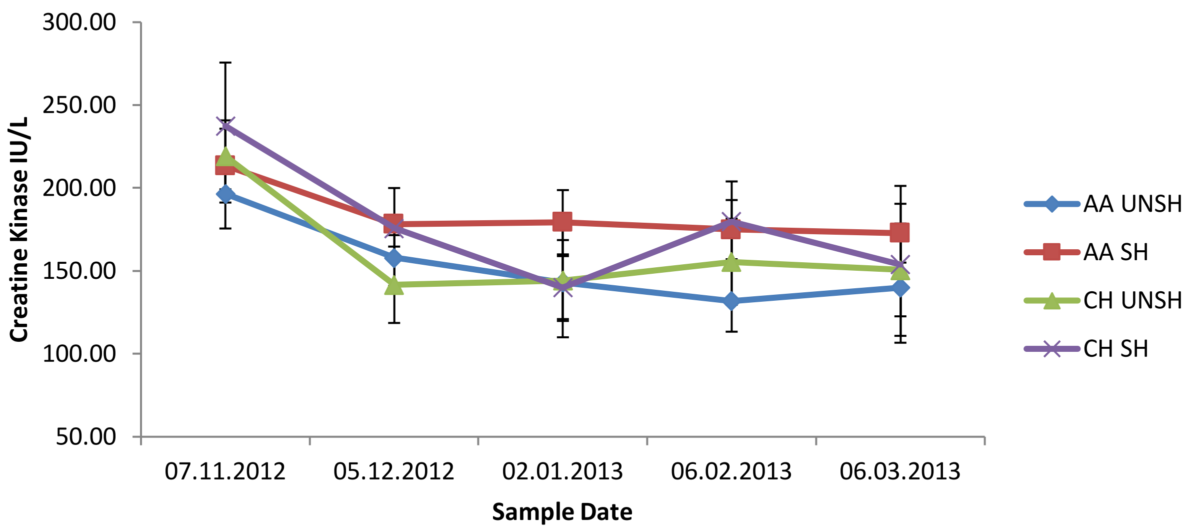

Figure 27 Plasma creatine kinase (IU/L) in un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

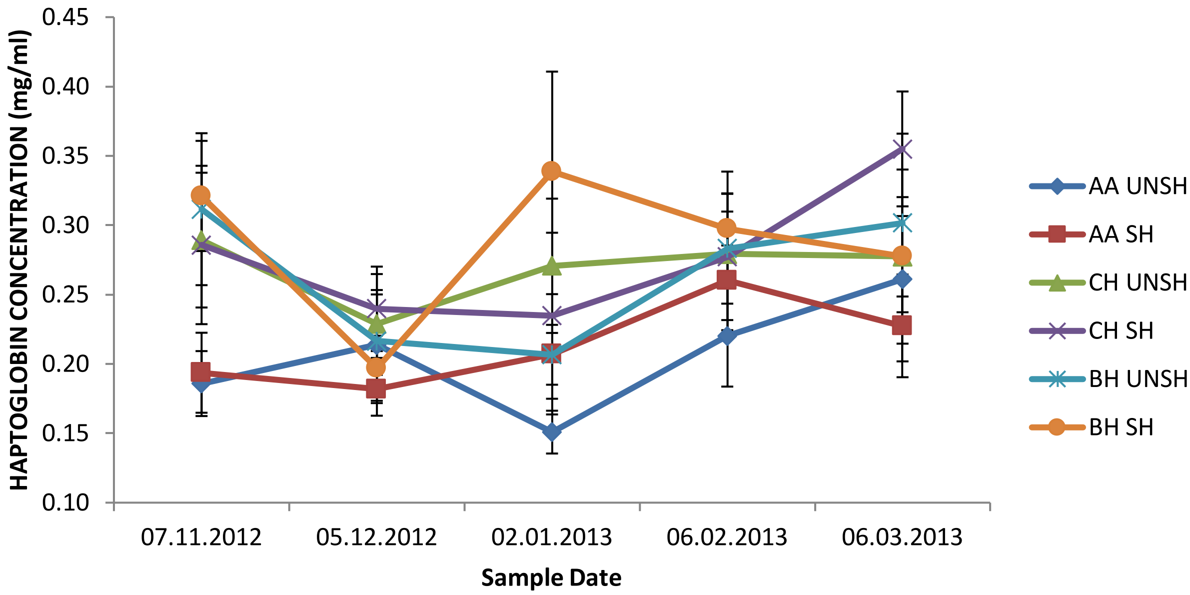

Figure 28 Plasma haptoglobin concentrations from un-shaded Angus (AA UNSH), Charolais (CH UNSH), and Brahman (BH UNSH) steers. And for shaded Angus (AA SH), Charolais (CH SH) and Brahman (BH SH) steers.

5 Results and Discussion – Southern Feedlot Data

5.1 Weather

Unfortunately, the weather data was not as robust as expected due to some technical issues. However, there is sufficient data to determine day, month and year variations in climatic variables. The mean maximum temperatures for; October, November and December were 26.2, 28.3 and 27.0°C (2011) and 26.9, 29.6, 31.3°C (2012). The mean minimum temperatures were 8.3, 13.0, 14.6°C (2011) and 9.1, 12.9 and 14.2°C (2012). During the period October to December 2011 rainfall exceeded 245 mm, and during the same period in 2012 rainfall was approximately 125 mm.

5.2 Panting Score

There was a significant (P<0.05) year and month effect on panting score. Panting scores were generally greater in 2011 compared to 2012. The primary cause of this appears to be related to the higher rainfall in 2011, rather than the ambient heat *per se*.

Panting scores were higher (P<0.05) in un-shaded pens (Table 14). There was a major heat event on 28 November 2011 which resulted in 8% of un-shaded cattle with a PS of 2.5. However, over the two years of the study panting scores greater than 2 were rarely observed, and these mostly occurred in un-shaded cattle when pens were muddy.

There was observation period (MO) effect on PS (P<0.001). For both shaded and un-shaded cattle PS were greater during the first two observation periods (days 0 – 20 and days 21 to 40). There was a trend for more of the elevated panting scores to occur between days 21 to 30 in MO 2. The differences between shaded and un-shaded cattle were only seen for the midday observation (PER

2) during observation periods MO 1 and MO 2. By the third observation period (days 41 to 60) the previously observed differences were not seen. Overall heat load was greater during the third observation period. These data suggest that cattle are acclimating to the increasing heat load over the first 60 days of summer.

Panting score was not affected by DOF in either year or month. However, there was a trend in 2011 (P>0.10) for panting score to be greater with increased DOF. Again this may be related to the wetter conditions in that year.

5.3 Activity and Posture

Eating activity (Table 14) was largely a reflection of feeding time with a greater percentage of cattle eating in the morning. However, there were observation period and shade effects on the percentage of cattle eating. There were more (P<0.05) shaded cattle observed eating during PER 1 and 3 during the first observation period (MO 1). No differences (P>0.05) were seen for MO2 and MO3. More (P<0.05) of the shaded cattle there observed standing in the shade at midday (PER 2) during the first 20 days of observation (MO 1). During PER 1 and PER 3 more cattle were in full sun than under shade. For the un-shaded cattle more cattle were observed standing during each PER within each observation period (MO), except for MO 3 PER 3 when the percentages were 34% each for standing and lying.

Outcomes from these data:

1. ***There is a trend for cattle to have a greater heat load response (assessed by elevated panting score) in the early summer period (mid-October to mid-November) compared with the period mid-November to mid-December ~ this could due to acclimation occurring over a 40 day period***
2. ***Cattle with access to shade had lower midday panting scores over the first 40 days of observation compared with those that do not***
3. ***Recommendation that the acclimation threshold (currently -5 for non-acclimated cattle) be maintained, and applied to Southern cattle for at least the first 40 days of 'summer' i.e. from when maximum HLI is expected to exceed 81***

Table 14 Mean values (%) for cattle activity (eating or drinking), location in pen (shade or sun), posture (standing or lying) and panting score (PS = 0, 1, 2 or >2), over three 20 day periods (MO) and three daily periods (PER)

MO[A]	PER[B]	DOF[C]	Eating	At Feed Bunk (not eating)	Drinking	Lying at Water Trough	Standing in Shade	Lying in Shade (shaded pens)	Standing in Sun (shaded pens)	Lying in Sun (shaded pens)	Standing in Sun (un-shaded pens)	Lying in Sun (un-shaded pens)	PS 0	PS 1	PS 2	PS >2
Shade																
1	1	56	26^{a1}	<1	6^{a}	$<1^{a}$	13^{a}	12^{aA}	29^{aA}	14^{aA}	.	.	226^{a}	$<1^{a1}$	$<1^{a1}$	<1
1	2	57	11^{b1}	<1	7^{a}	$<1^{a}$	37^{bA}	27^{bA}	9^{bA}	9^{bA}	.	.	198^{b}	23^{b1}	6^{b1}	<1
1	3	55	16^{b1}	<1	13^{b}	2^{b}	19^{a}	17^{a}	25^{aA}	8^{bA}	.	.	219^{a}	$<1^{a1}$	5^{b1}	<1
2	1	72	23^{a1}	<1	4^{a}	$<1^{a}$	14^{a}	11^{aA}	34^{aAB}	15^{aA}	.	.	219^{a}	$<1^{a1}$	$<1^{a1}$	<1
2	2	75	8^{b1}	<1	6^{a}	$<1^{a}$	29^{aB}	20^{bB}	15^{bA}	21^{bB}	.	.	211^{a}	9^{b1}	2^{b1}	<1
2	3	73	18^{a1}	<1	11^{b}	1^{a}	12^{b}	16^{b}	30^{aB}	12^{aB}	.	.	187^{b}	36^{c1}	1^{b1}	<1
3	1	41	16^{a1}	<1	3^{a}	$<1^{a}$	12^{a}	11^{aA}	38^{aA}	19^{aA}	.	.	231^{a}	$<1^{a1}$	<1	<1
3	2	42	9^{b1}	<1	6^{a}	$<1^{a}$	31^{bA}	26^{bA}	14^{bA}	13^{bB}	.	.	221^{a}	9^{b1}	<1	<1
3	3	42	16^{a1}	<1	8^{a}	2^{b}	12^{a}	28^{bB}	21^{cA}	14^{bB}	.	.	230^{a}	$<1^{a1}$	<1	<1
No Shade																
1	1	52	32^{a2}	<1	8^{a}	$<1^{a}$	.	.	.	.	40^{a}	21^{a}	231^{a}	3^{a2}	$<1^{a1}$	<1
1	2	50	12^{b1}	<1	9^{ab}	$<1^{a}$	.	.	.	.	48^{a}	31^{b}	185^{b}	39^{b2}	7^{b1}	<1
1	3	53	23^{c2}	1	14^{b}	3^{b}	.	.	.	.	40^{a}	19^{a}	225^{a}	3^{a2}	4^{b1}	<1
2	1	62	24^{a1}	<1	5^{a}	$<1^{a}$	.	.	.	.	50^{a}	21^{a}	237^{a}	1^{a2}	$<1^{a1}$	<1
2	2	60	10^{b1}	<1	8^{a}	$<1^{a}$	.	.	.	.	54^{a}	27^{b}	202^{b}	23^{b2}	7^{b2}	<1
2	3	59	17^{c1}	<1	8^{a}	4^{b}	.	.	.	.	47^{a}	23^{a}	189^{c}	42^{c1}	1^{a1}	<1
3	1	61	18^{a1}	<1	4^{a}	$<1^{a}$	.	.	.	.	48^{a}	30^{a}	238^{a}	$<1^{a1}$	<1	<1
3	2	61	10^{b1}	<1	6^{a}	$<1^{a}$	.	.	.	.	44^{a}	39^{b}	226^{b}	11^{b1}	<1	<1
3	3	62	18^{a1}	<1	8^{a}	6^{b}	.	.	.	.	34^{b}	34^{ab}	233^{a}	4^{c2}	<1	<1

[A]MO 1 = days 0 – 20 in feedlot, MO 2 = 21 to 40 days in feedlot; MO 3 = 41 to 60 days in feedlot. [B]PER 1 = morning observation (approx. 0630 h); PER 2 = midday observation (approx. 1200 h); PER 3 = afternoon observation (approx. 1630 h). [C]DOF = average days on feed (all observed cattle). Means within a column (within in shade group) with different superscripts (a,b,c) differ (P<0.05). Means within a column with different superscripts (1,2) differ (P<0.05) – these are the differences between shaded and un-shaded cattle.

Means within a column with different superscripts (A,B) differ (P<0.05) – these are the differences for the variable between MO 1, 2 and 3.

6 Updating the Heat Load Index

The final component of the current study was to assess the existing heat load index and ascertain whether any adjustments are required. To this end data from the Gatton phase of the study, primarily changes in morning rumen temperature and panting score were used in conjunction with weather parameters (specifically the current HLI and AHLU). The data was analysed using the same methodology as Gaughan et al. (2008a) except that rumen temperature was used in place of tympanic temperature. The current study was specifically designed to assess early morning temperature and humidity effects on feedlot cattle. Therefore, the data analysis focused on the periods 0400 to 0900 h (but all times were included). Analysis of the panting score data determined that there were two new black globe temperature thresholds (21^{o}C and 25^{o}C) compared with the original HLI which had a single threshold at 25^{o}C. The new HLI model (HLI_2) has a three step function.

When BGT<21: $HLI_2 = 6.5 + 0.58 \times RH + 0.9 \times BGT - WS$,

When BGT>21 <25: $HLI_2 = 8.2 + 0.42 \times RH + 1.22 \times BGT – 0.2 \times WS$

When BGT >25 <60: $HLI_2 = 5.92 + 0.48 \times RH + 1.52 \times BGT – 0.4 \times WS + WS^{e(2.6-WS)}$

The HLI_2 model has slightly higher minimum values (approximately 5 units higher when BGT < 21. There is little difference between the two models in the HLI values obtained when BGT >25 ^{o}C (Figure 28).

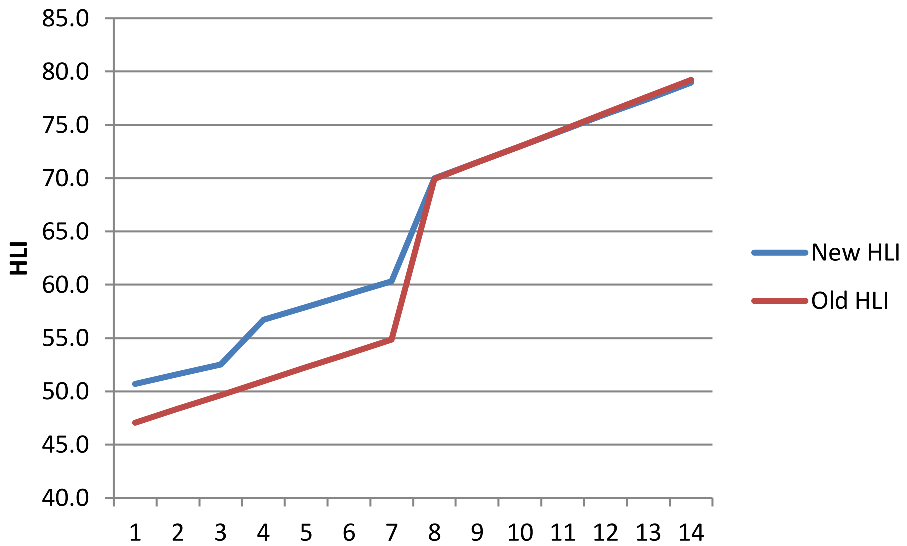

Figure 28 The current HLI and the new HLI modelled at a constant wind speed (1 m/s) and relative humidity (50%). Black globe temperature ranged from 18 to 31^{o}C.

The new HLI was developed with small number of animals (although there was considerable data) and at a single location (Gatton) therefore the model will need to be field tested. The new model will be tested at Gatton over the summer 2013/14 summer within an existing MLA funded study. However, a much more robust assessment will be required. The HLI_2 is obviously more complex that the previous model. The model will need to be rigorously evaluated to determine if it a better predictor of heat load than the existing HLI and if swill need to be simplified into a single algorithm

Outcomes from these data:

1. ***A new version of the HLI has been developed***
2. ***The new HLI (HLI2) will need to be field tested to determine whether it is a better predictor of heat load than the current HLI***
3. ***Recommendation that the new HLI be field tested at Gatton over the summer of 2013/14, and if it proves reliable a larger assessment be undertaken (multiple sit analysis using existing data)***

7 Success in Achieving Objectives

The initial start date of the project was delayed to contractual issues between MLA and UQ when these were overcome the project ran fairly smoothly. The climatic conditions which prevailed over the data collection period were sufficient to induce heat stress in the cattle selected for this study, particularly un-shaded Angus (Gatton and Southern feedlot), although there were only a couple of events during which the cattle were exposed to extreme heat load. Overall, the climatic conditions were harsh enough to elicit a response from the cattle. Clear welfare and performance differences were seen between shaded and un-shaded cattle. The rumen boluses worked well and there was little technical difficulty with the equipment. The statistical analysis of the rumen data was problematic and delayed statistical analysis by some weeks; however, a robust statistical model has been developed. There were some delays at the start of the project in regards to the organisation of the southern cattle component of the study but these were overcome and there was only a slight delay in data collection. The project has been able to achieve the objectives as set out in Section 2 of this report.

8 Impact on Meat and Livestock Industry – Now and In Five Years' Time

The findings from this study (B.FLT.0150) have provided further insights into the use of shade as an alleviation strategy in feedlots during summer, and further demonstrated the usefulness of panting score as an indicator of thermal stress. There have been a number of clear positive, measurable welfare and production outcomes e.g. reduction in rumen temperature and reduction in mean panting score and better efficiency.

Furthermore, the data from this study will be used to improve the robustness of the HLI and AHLU models which will improve management response to heat load events.

9 Conclusions and Recommendations

9.1 Conclusions

The weather conditions experienced over the summer of 2012/13 were sufficient to elicit a heat stress response in the cattle. The provision of shade reduced the impact of ambient heat load but did not entirely remove the effects. A useful thermal response indicator in cattle is the feed to gain ratio. Over the study period the feed to gain was higher (P = 0.10) for the un-shaded cattle (10.1:1) compared with the shaded cattle (9.4:1). In comparison feed:gain of 6:1 was obtained using similar feed, and similar cattle over the winter months (not part of this trial).

Rumen temperature is a useful indictor of the thermal status of an individual and can be used determine the thermal tolerance of cattle. The increase in rumen temperature in relation to the time of the day and HLI was not breed dependent. The change in rumen temperature over time, particularly at night is a useful tool for determining heat loss. The provision of shade reduced the thermal stress on *Bos taurus* cattle, but had minimal impact on *Bos indicus* (100%) cattle.

The panting score data supports the recommended changes in the HLI thresholds for *Bos indicus* and *Bos taurus* steers (see Recommendation 2). The data further highlights the importance of early morning panting score observation of *Bos taurus* (Angus) cattle, especially when AHLU ≥ 25 at 0300 h or there has been less than 6 h of 0 AHLU overnight. Furthermore, there is a trend in the data that suggest that night time feeding behaviour may influence cattle heat load status.

Shade usage is probably the best behavioural measure (apart from panting) of thermal stress. The shade usage by the Charolais supports the Recommendation 3. The use of thermal imaging has potential and least a scientific tool to assess heat flow from cattle. Further analysis of data collected from this study is underway.

Differences in eating behaviour between Brahman, Angus and Charolais steers especially during periods of hot weather may explain some of the differences in thermal tolerance.

There were some changes in blood metabolites that suggest a breed effect but it is not clear if the differences are biologically important. The timing of blood collection relative to thermal stress may need to be further refined.

There is a strong indication that Southern *Bos taurus* cattle take approximately 40 days to acclimate to summer weather conditions. However, this may be somewhat skewed by high rainfall events. Shade ameliorates the effects of early summer conditions at midday, over the first 40 days. There is not sufficient data to state that Southern *Bos taurus* cattle are physiologically different to northern *Bos taurus* cattle. However, it would be worthwhile ensuring that the -5 threshold for non-acclimated animals is used, at least for the first 6 weeks of summer.

The data presented strongly suggested that there was a need to look at the HLI and determine if changes were required. Based on the Gatton data a new version of the HLI has been developed. The new model will need to be field tested to determine whether it is a better predictor of heat load than the current HLI.

Overall the project met its goals, and while some questions have not been fully answered there is sufficient data for on-going analysis. The development of a new HLI is a start in the process of further developing heat load tools for livestock managers. However, it will need to be robustly field tested before any firm recommendations can be made on its use. The recommended adjustments to the existing HLI thresholds will strengthen the existing AHLU and RAP.

9.2 Recommendations

Based on the production and welfare findings from this study, the type of cattle used, the stocking density, the dietary treatments and shade area used the following recommendations are made.

Recommendation 1: ***Shade should be considered as the primary method to alleviate heat load for black Bos taurus feedlot cattle in areas were high heat load is expected***

Recommendation 2: ***Suggested adjustments to HLI thresholds are: Brahman – heat dissipation commences when HLI is 92 (assuming it has reached a maximum above the 96 unit threshold); Angus – 77 unit threshold if no access to shade and for shaded cattle 84 (when the 86 thresholds has been reached); Charolais – 84 unit threshold (assuming the 89 threshold has been reached)***

Recommendation 3: ***The White Coat threshold be increased to + 4***

Recommendation 4: ***Further investigation to determine the effect of early morning relative humidity on heat load coming into a 'new' day (NB this will be done in conjunction with FLOT 1057 over summer 2013/14)***

Recommendation 5: ***Further investigation to quantify and revise climatic predictors of heat stress as identified in the project data, specifically in relation to Recommendation 2. (NB this will be done in conjunction with FLOT 1057 over summer 2013/14)***

Recommendation 6: ***Angus and Charolais consumed a larger portion of feed at night; therefore, it is recommended that a study be undertaken to specifically look at night time feeding behaviour during the summer, and relate this to changes in body temperature and heat dissipation***

Recommendation 7: The threshold for non-acclimated Bos taurus cattle be maintained at -5: However, there is a need for more data to be collected in southern and northern feedlots for the period mid-September to mid-December in order to further refine the acclimation threshold

Recommendation 8: the new HLI be field tested at Gatton over the summer of 2013/14, and if it proves reliable a larger assessment be undertaken (multiple sit analysis using existing data)

10 Project Personnel

The following personnel from UQ Gatton were involved in the project:

Dr John Gaughan, Mrs Angela Lees, Dr Megan Sullivan, Mr Bob Englebright, Mr Edward Qualischefski, Mr Scott Kershaw, Mr Jarrod Lees, Mr Daniel Keter, Mrs Andrea Baldwin, Mr Ngoc Bang Nguyen, Mr Allan Lisle.

11 Acknowledgements

The research team would like to thank the staff from the Queensland Animal Science Precinct (QASP) for their support over the course of the study. Thanks also go to Dr Robert Lawrence for his guidance and assistance with the feeding strategies used during the study.

12 References

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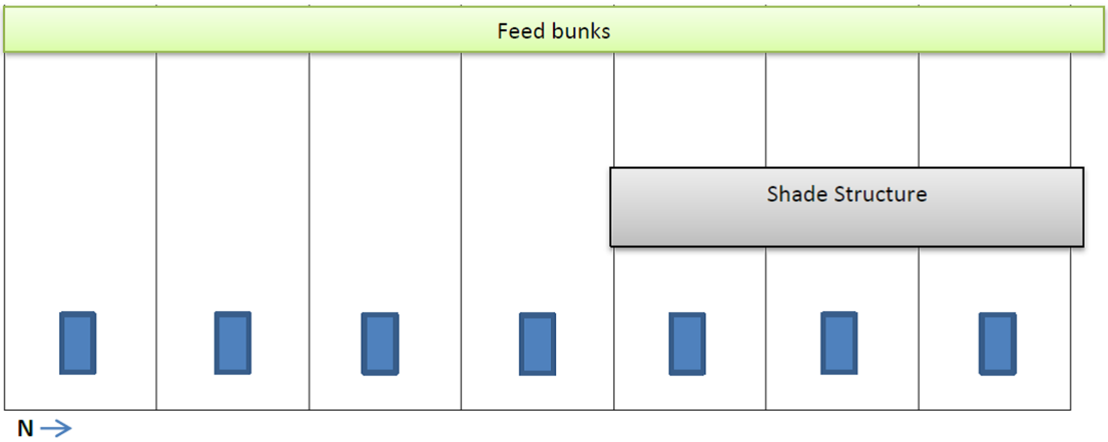
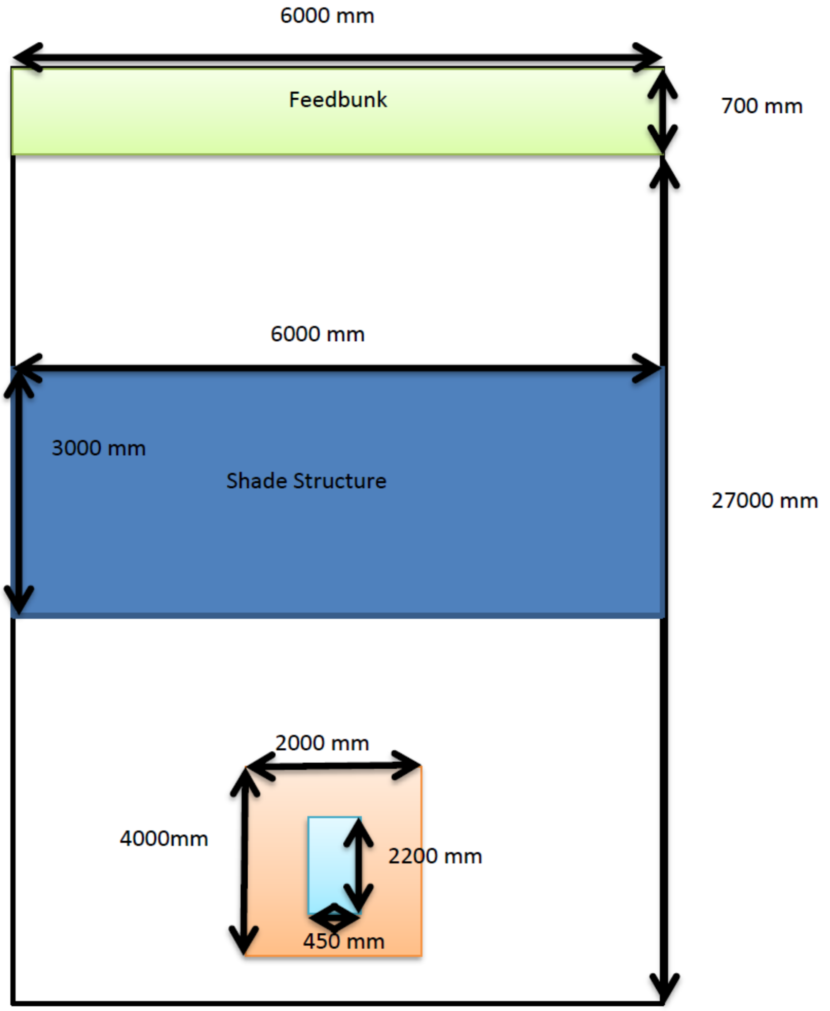
13 Appendices

13.1 Appendix 1 Feedlot Layout



Layout of feedlot pens

Note: This symbol  is used to represent the location of water troughs within the pen. The first 3 pens without shade were used for the un-shaded treatment. The fourth un-shaded pen was not used.



Layout of individual pens (not to scale) – the un-shaded pens did not have the shade structure

13.2 Appendix 2 Project Schedule

DAY/ DATE/ TIME	ALLOCATION/ TREATMENT
Monday 15.10.2012	Cattle arrive (36); induction of cattle (including weighing CAAS ID tags and vaccinations); allocated into groups of 6; cattle settled into pens; Begin backgrounding process (to be completed by 01.12.2012)
Wednesday 24.10.2012 @ 0700h	Weighting
Monday 29.10.2012	Start cattle on grain
Wednesday 31.10.2012 @ 0700h	Weighing
Wednesday 07.11.2012 @0700h	Blood Collection (18 animals), BCS, Height Measurements & Weighing
Thursday 08.11.2012 @ 0700h	Blood Collection (18 animals) & Weighing
Wednesday 14.11.2012 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 21.11.2012 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 28.11.2012 @0700h	Blood Collection (18 animals) & Weighing
Saturday 01.12.2012	Backgrounding process complete animals will be on a full feedlot starter ration
Wednesday 05.12.2012 @0700h	Blood Collection (18 animals), BCS, Height Measurements & Weighing
Thursday 06.12.2012 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 12.12.2012 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 19.12.2012 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 26.12.2012 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 02.01.2013 @0700h	Blood Collection (18 animals), BCS, Height Measurements & Weighing
Thursday 03.01.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 09.01.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 16.01.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 23.01.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 30.01.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 06.02.2013 @0700h	Blood Collection (18 animals), BCS, Height Measurements & Weighing
Thursday 07.02.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 13.02.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 20.02.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 27.02.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 06.03.2013 @0700h	Blood Collection (18 animals), BCS, Height Measurements & Weighing
Thursday 07.03.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 13.03.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 20.03.2013 @0700h	Blood Collection (18 animals) & Weighing
Wednesday 27.03.2013 @0700h	Blood Collection (18 animals) & Weighing
Saturday 02.04.2013	Completion of trial work
Saturday 31.03.2013 to Wednesday 03.04.2013	Cattle to be sold on consignment – some cattle will be eligible for MSA grading
Sunday 14.04.2013	Cattle Transported to Kilcoy Pastoral Company

13.3 Appendix 3 Heat Load Management Action plan

Feedlot:	The University of Queensland Gatton Feedlot - CAAS		Page No:	
Map Reference:	QA Systems	No. 1	Date:	15 OCT 12
Procedure:	Heat Load Management	No.	Author (s):	John Gaughan

Who: ALL research staff, CAAS staff and students Where: CAAS Feedlot When: At all times (research)	Reference to Industry Standards
Actions: 1. High heat load can occur from Nov to Mar. Risk Assessment – update RAP printout each year (October). Daily Nov – Mar access Katestone Site www.katestone.com.au/MLA at 0700 and 1500 h. 2. Check previous night's AHL. If greater than 60 – extra daytime vigilance is required. 3. All cattle to be assessed daily at 0600, 0800 h, 1200 h, 1600 h & 1800 h on days when the HLI > 86 units. All cattle inspected at 0600 each day (Nov – Mar) if PS ≥ 2 at 0600 – report same to contact persons (see below). 4. If distressed (PS 4 any time; or PS 3.5 for prolonged periods) cattle can be sprayed with water (if pens are not wet), or removed from feedlot to nearby shaded paddock or shed. Do not forcibly remove cattle. Under these conditions cattle will be inspected at least hourly. 5. PS for individual animals to be recorded, HLI and AHL to be recorded, optimally every 10 minutes, minimally every 60 minutes. Weather station to be checked daily, and weather data to be downloaded daily. 6. Contact Persons – All Times: John Gaughan 0419664380: Ange Lees 0407570373 7. Do not move or handle cattle when AHL > 60 and/or HLI > 86 (trials may preclude this). 8. Feeding – if a heat wave is predicted (AHL > 30 units over 3 days and does not return to 0 at night and/or max HLI > 90, reduce feed offered to 95% of previous 5 day mean intake. Or feed 'storm' ration. 9. Check water troughs twice each day and clean out at least 3 times each week.	MLA Managing heat load manual. RAP software Panting Score (PS) photo guide

13.4 Appendix 4 Heat Load Management Action Plan Implementation

13.4.1 Step 1 – Katestone forecasting

Friday, 11 Jan 2013																						
	12 AM	3 AM			6 AM			9 AM			12 PM			3 PM			6 PM			9 PM		
HLI			64	66	79	90	90	90	90	90	90	91	92	91	90	88	83	69	67	66	66	66
BGT			20	21	25	31	34	36	38	40	42	43	43	41	41	37	32	26	25	24	23	23
T			21	23	23	25	27	28	30	32	33	34	34	33	33	30	29	27	26	25	25	24
RH			100	98	99	87	75	66	59	53	46	43	49	56	54	64	70	73	75	78	82	86
WD			NE	NE	NE	NE	NE	N	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
WS			12	6	4	7	11	10	11	12	14	13	17	21	18	20	15	16	14	12	8	8
Rain			0	0	0	0	0	0	0	0	0	0	1	1	0	2	1	0	0	0	0	0
AHLU 80			0	0	0	10	20	30	40	50	60	71	83	94	105	159	162	158	153	148	142	137
AHLU 83			0	0	0	7	14	21	28	35	42	50	59	67	75	76	76	72	68	62	57	51
AHLU 86			0	0	0	4	8	12	16	20	24	29	35	40	45	43	43	40	34	29	24	18
AHLU 89			0	0	0	1	2	3	4	5	6	8	11	13	15	17	17	13	8	3	0	0
AHLU 92			0	0	0	0	0	0	0	0	0	0	0	0	0	7	7	3	0	0	0	0
AHLU 95			0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0

Katestone Forecast of Saturday January 12th 2013

13.4.2 Step 2 – Cattle observation and monitoring

Normal daily observations of the cattle occurred at 2 hourly intervals between 0600 and 1800 h. Due to the forecasted heat wave conditions the cattle in the yards for heat wave blood sample collection between 0630 and 0930 h. After the cattle were returned to the feedlot pens two Angus steers were observed at a PS3 (ID 2082) and PS 3.5 (ID 2081) from the shaded treatment group. The observations of these high PS scores were contributed to the climatic conditions and the heat production associated with locomotion. With the observation of high (≥ 3) during early morning hours (prior to 1000 h) the heat load management action plan was implemented. Initial implementation of the action plan involved increasing observations to hourly to ensure animal welfare was maintained. All cattle in the unshaded pens had a panting score ≥ 1 for all observations proceeding 1000 h.

Panting scores at each treatment from observation made between 1100 and 1500 h on Saturday January 12th 2013

Treatment	PS	Time (h)				
		1100	1200	1300	1400	1500
Un-shaded	1	6 BH	1 BH	-	1 BH	6 BH
Shaded		3 BH; 1 CH	2 CH	4 BH; 1 CH	5 BH	6 BH
Un-shaded	1.5	4CH	5 BH	6 BH; 1 CH	5 BH; 3 CH	5 CH; 2 AA
Shaded		2BH, 4CH+2AA	4 CH; 2 AA	2 BH; 5 CH; 4 AA	4 CH; 1 BH	5 CH; 3AA
Un-shaded	2	2 CH; 4 AA	5 CH	4 CH; 1 AA	3 AA; 1 CH	4 AA; 1 CH
Shaded		4AA	2 AA; 1 CH	2 AA	6 AA; 2 CH	3 AA; 1 CH
Un-shaded	2.5	-	1 CH	1 CH	2 CH; 1 AA	-
Shaded		-	1 AA	-	-	-
Un-shaded	3	2 AA	1 AA	2 AA	1 AA	-
Shaded		-	-	-	-	-
Un-shaded	3.5	-	4 AA	2 AA	1 AA	-
Shaded		-	-	-	-	-
Un-shaded	4	-	1 AA	1 AA	-	-
Shaded		-	-	-	-	-
Un-shaded	4.5	-	-	-	-	-
Shaded		-	-	-	-	-

PS = panting score. BH= Brahman, AA = Angus, CH = Charolais

After the 1300 h (approximately 1330 h) observation both two un-shaded Angus steers were observed at a PS 4 verging on a PS 4.5. Both animals were standing at the water trough placing their whole heads under the water then pulling them out and panting quite hard with their tongues fully extended (plate 1). At this time it was also observed that another Angus steer PS had increased to a PS 4, and two Charolais steers had increased to a PS 3/3.5. At this point I went and checked the latest rumen temperature data.

Plate 1: Angus steers exhibiting excessive heat load behaviours

After observing a number of animal's PS increasing the most recent rumen temperature log was obtained. At this time there were 13 animals that had a rumen temperature of 40°C or above (see table below)

Rumen temperature data of animal greater than 40°C at 1345 h on Saturday January 12th 2013

Animal	Breed	Pen	Temperature (°C)
2073	AA	1B	43.0
2067	AA	1B	42.7
2074	AA	4A	42.0
2066	AA	2A	42.2
2081	AA	3B	41.2
2075	AA	3A	41.0
2082	AA	3B	40.5
2092	CH	3A	40.0
2072	AA	2A	42.0
2091	CH	2A	40.2
2069	CH	1B	40.7
2086	AA	3A	40.5

BH= Brahman, AA = Angus, CH = Charolais; Pens 1A, 1B and 2A were un-shaded. Pens 3A, 3B and 4 A were shaded.

13.4.3 Step 3 – Movement of Cattle

After observing the behaviour and monitoring rumen temperature the decision was made to relocate the unshaded cattle to shaded pens. This was done in quiet manner allowing the cattle to move at their own pace. Once the cattle were in the shaded pens they were continually monitored to ensure that they animals were adequately recovering.

13.5 Appendix 5 Starter and Finisher Diets – Ingredients and Nutrient Specifications

Table 3.1. Ingredients and nutrient compositions of the diets

Item	Starter (d 1-28)	Finisher (d 29 -105)
Ingredients (kg per 2000kg feed)		
Barley	330.00	500.00
Sorghum	798.02	678.56
Wheat	165.00	-
Millrun	200.00	200.00
Peanut hulls	320.00	-
Cottonseed meal	35.00	-
Free flow molasses	40.00	40.00
Limestone	22.00	28.90
Sodium bicarbonate	16.00	16.00
Potassium chloride	6.84	-
Urea	14.00	13.90
Sulphur (dusting)	0.94	0.45
Moneco 200	0.20	0.20
Sodium bentonite gra	50.00	50.00
Beef/sheep premix	2.00	2.00
Chick pea shell	-	400.00
Sunflower meal	-	70.00
Nutrient compositions[a]		
Dry matter (%)	89.30	89.20
Protein (%)	11.90	12.01
Rumen degradable protein (UDP) (%)	8.49	8.39
Un-degradable dietary protein (UDP) (%)	3.62	3.58
Crude fiber (%)	14.73	10.05
Neutral detergent fiber (NDF) (%)	23.74	24.16
acid detergent fiber (ADF) (%)	14.62	13.31
ME (MJ/kg)	11.20	12.27
Calcium (%)	0.50	0.70
Phosphorus (%)	0.36	0.33
Sodium (%)	0.25	0.25
Salt (%)	0.00	0.01
Potassium (%)	0.60	0.67
Magnesium (%)	0.20	0.24
Sulphur mg/kg	1400.16	1400.60
Fat/Ether extract (%)	2.25	2.29
Monensin mg/kg	20.00	20.00

[a]Dry matter is in percent fresh weight, and other nutrients are expressed in percent dry matter. ME is metabolic energy.

Adapted from Nguyen (2013)

13.6 Appendix 6 Blood Analysis Procedures

13.6.1 Insulin

The procedure for the Insulin (SIEMENS) Radioactive immunoassay was:

- All samples, diluents and pre-coated antibody tubes were brought to room temperature before use.
- Pipette 200 µl of each calibrator along with quality controls and samples, induplicate, to the pre-coated antibody tubes.
- Add 100 µl of Insulin to each pre-coated antibody tube and vortex.
- Incubate at room temperature for 18 – 24 hours.
- After incubation, decant thoroughly removing all visible moisture from the pre-coated antibody tubes.
- Count for one minute using a Gamma counter.

13.6.2 Creatine Kinase

The procedure for the Creatine Kinase (BIOO Scientific Corporation) assay was:

- All samples, diluents and buffers were brought to room temperature before use.
- Transfer 5 µl of each calibrator along with quality controls and samples, induplicate, to the blank microplate.
- Add 250 µl of Reagent solution to each microwell.
- Incubate for 5 minutes at room temperature.
- Read immediately at 5 minutes at an absorbance wavelength of 340 nm.

13.6.3 Haptoglobin

The procedure for the Haptoglobin (PHASE, tridelta) assay was:

- All samples, diluents and buffers were brought to room temperature before use.
- Transfer 7.5 µl of each calibrator along with quality controls and samples, induplicate, to the blank microplate.
- Add 100 µl of Reagent 1 to each microwell. Place on a microplate shaker for 1 minute at 650 rpm.
- Add 200 µl of Reagent 1 to each microwell. Incubate for 5 minutes at room temperature.
- Read immediately at 5 minutes at an absorbance wavelength of 600 nm.

13.6.4 Cytokine

The procedure for the Cytokine IL-6 (Thermo Scientific) assay was:

- Bring Coating Antibody to room temperature and dilute 1:100 with Carbonate Bicarbonate buffer (110 µl of Coating Antibody in 10.89 ml of Carbonate Bicarbonate buffer).
- Add 100 µl of Coating Antibody solution into each microwell.

- Cover with a plate sealer and incubate at room temperature for 12-16 hours on a microplate shaker at 300 rpm.
- Bring all samples, diluents and buffers to room temperature before use.
- Aspirate the Coating Antibody solution and add 300 µl of blocking buffer to each well.
- Cover with a plate sealer and incubate at room temperature for 1 hour on a microplate shaker at 300 rpm.
- Aspirate blocking buffer and add 100 µl of standards, quality controls and samples, in duplicate, into the prepared antibody coated microplate.
- Cover with a plate sealer and incubate at room temperature for 1.5 hours on a microplate shaker at 750 rpm.
- Bring Detection Antibody to room temperature and dilute 1:100 with Reagent Diluent (110 µl of Detection Antibody in 10.89 ml of Reagent Diluent).
- Aspirate standards, quality controls and samples and wash each microwell with 300 µl of wash buffer three times.
- Add 100 µl of Detection Antibody solution into each microwell.
- Cover with a plate sealer and incubate at room temperature for 1 hour on a microplate shaker at 750 rpm.
- Bring to Streptavidin-horseradish peroxidase (SA-HRP) to room temperature and dilute 1:400 with Reagent Diluent (30 µl of Detection Antibody in 12 ml of Reagent Diluent)
- Aspirate Detection antibody solution and wash each microwell with 300 µl of wash buffer three times
- Cover with a plate sealer and incubate at room temperature for 30 minutes on a microplate shaker at 750 rpm.
- Aspirate SA-HRP solution and wash each microwell with 300 µl of wash buffer three times.
- Add 100 µl of Substrate Solution to each microwell and incubate in the dark, at room temperature for 30 minutes.
- Stop the reaction by adding 100 µl of Stop solution to each microwell.
- Measure the absorbance at a wavelength of 450 nm with a reference wavelength of 550 nm.

13.6.5 Heat Shock Protein 70

The procedure for the heat shock protein 70 (EIAab) assay was:

- Bring all samples, diluents and buffers to room temperature before use.
- Add 100 µl of standards and samples, in duplicate, into each microwell.
- Cover with a plate sealer and incubate at 37 °C for 2 hours.
- Aspirate standards and samples from microplate and add 100 µl of Detection Reagent A in to each well.
- Cover with a plate sealer and incubate at 37 °C for 1 hour.
- Aspirate Detection Reagent A and wash each microwell with approximately 400 µl of wash buffer 3 times.
- Add 100 µl of Detection Reagent B into each microwell.
- Cover with a plate sealer and incubate at 37 °C for 1 hour.
- Aspirate Detection Reagent B and wash each microwell with approximately 400 µl of wash buffer 3 times

- Add 90 µl of Substrate solution into each microwell; incubate in the dark at 37 °C for 1 hour.
- Add 50 µl of Stop solution into each microwell.
- Measure the optical density (absorbance) at a wavelength of 450 nm.

13.7 Appendix 7 Mean weather Conditions for January, February and March 2013

Table 4.2. Mean (±SE), maximum (max), and minimum (min) for ambient temperature (TA, °C), black globe temperature (BGT, °C), solar radiation (SR, W/m²), wind speed (WS, m/s), relative humidity (RH, %), heat load index (HLI), and HLI categories at different times (h) of a day in February.

Climatic data		Time of a day (h)						
		600	800	1000	1200	1400	1600	1800
TA, °C	Mean ± SE	19.83 ± 83	22.81 ± 0.28	25.23 ± 0.28	26.58 ± 0.43	26.95 ± 0.52	26.81 ± 0.57	25.40 ± 0.51
	Max	23.10	25.45	27.90	31.13	31.80	33.10	31.80
	Min	16.20	19.50	21.88	22.10	21.50	21.20	21.00
BGT, °C	Mean ± SE	22.54 ± 0.31	29.10 ± 0.39	32.33 ± 0.46	33.90 ± 0.62	34.14 ± 0.71	33.32 ± 0.77	29.22 ± 0.67
	Max	26.32	31.96	35.44	39.65	40.50	41.24	36.68
	Min	19.17	25.33	29.19	25.94	26.35	25.28	22.40
SR, W/m²	Mean ± SE	24.13 ± 1.73	330.70 ± 28.10	561.20 ± 56.70	606.40 ± 60.20	533.10 ± 54.80	338.00 ± 36.20	53.99 ± 7.38
	Max	44.00	522.00	1081.00	1175.00	1055.00	702.00	146.00
	Min	11.00	23.80	43.70	25.90	68.80	55.60	8.00
WS, m/s	Mean ± SE	0.87 ± 0.13	1.81 ± 0.15	2.40 ± 0.19	2.37 ± 0.18	2.50 ± 0.19	2.36 ± 0.19	1.68 ± 0.16
	Max	2.70	3.60	4.50	4.50	4.50	4.50	3.60
	Min	0.00	0.40	0.40	0.90	0.40	0.40	0.40
RH, %	Mean ± SE	88.09 ± 1.05	77.98 ± 1.63	68.16 ± 2.28	63.74 ± 2.85	62.01 ± 3.19	62.47 ± 3.03	67.29 ± 2.98
	Max	95.67	94.62	95.73	95.00	94.93	94.77	94.32
	Min	73.00	63.00	53.00	43.00	37.00	35.00	33.00
HLI[1]	Mean ± SE	65.73 ± 1.43	83.97 ± 0.79	83.77 ± 0.79	84.53 ± 0.78	84.04 ± 0.93	83.31 ± 0.75	78.92 ± 1.27
	Max	91.37	92.80	95.89	94.24	94.61	93.05	88.04
	Min	57.92	77.05	78.01	76.60	74.68	74.89	63.59
HLI categories[2]		Cool	Hot	Hot	Hot	Hot	Hot	Hot

[1,2]See footnotes to Table 4.1

Table 4.1. Mean (±SE), maximum (max), and minimum (min) for ambient temperature (TA, °C), black globe temperature (BGT, °C), solar radiation (SR, W/m²), wind speed (WS, m/s), relative humidity (RH, %), heat load index (HLI), and HLI categories at different times (h) of a day in January.

Climatic data		Time of a day (h)						
		600	800	1000	1200	1400	1600	1800
TA, °C	Mean ± SE	22.20 ± 0.29	25.17 ± 0.27	27.89 ± 0.43	30.00 ± 0.65	31.54 ± 0.78	31.32 ± 0.81	28.77 ± 0.72
	Max	25.80	28.80	32.40	35.70	38.70	40.00	37.80
	Min	19.10	22.50	23.30	23.40	22.60	23.30	22.80
BGT, °C	Mean ± SE	26.13 ± 0.33	31.77 ± 0.41	35.50 ± 0.58	37.94 ± 0.82	38.42 ± 1.00	38.40 ± 1.00	33.11 ± 0.94
	Max	30.44	36.34	40.93	44.99	47.96	48.79	44.35
	Min	21.54	26.68	27.65	28.01	26.72	27.63	24.80
SR, W/m²	Mean ± SE	67.74 ± 6.57	373.70 ± 30.90	640.30 ± 47.10	730.30 ± 60.70	650.60 ± 54.70	366.70 ± 32.80	70.84 ± 9.16
	Max	152.00	574.00	951.00	1167.00	996.00	593.00	173.00
	Min	36.59	36.00	68.00	82.00	59.00	67.00	9.00
WS, m/s	Mean ± SE	0.95 ± 0.23	1.78 ± 0.24	2.09 ± 0.22	2.08 ± 0.22	2.42 ± 0.22	2.71 ± 0.24	2.64 ± 0.17
	Max	5.80	6.30	6.70	6.30	7.20	5.80	4.50
	Min	0.00	0.40	0.40	0.90	0.90	0.40	0.90
RH, %	Mean ± SE	86.26 ± 1.20	75.19 ± 1.82	64.71 ± 2.35	57.55 ± 3.26	51.90 ± 3.38	52.65 ± 3.54	61.90 ± 3.44
	Max	99.00	94.00	95.00	95.00	94.00	95.00	26.00
	Min	74.00	59.00	50.00	37.00	25.00	24.00	96.00
HLI[1]	Mean ± SE	82.29 ± 2.22	87.80 ± 0.88	88.24 ± 0.81	89.31 ± 0.93	88.52 ± 0.96	86.94 ± 0.90	81.61 ± 0.98
	Max	99.02	96.02	94.96	98.58	100.57	101.50	90.59
	Min	59.18	77.92	79.17	78.62	78.00	79.26	66.40
HLI categories[2]		Hot	Very hot	Very hot	Very hot	Very hot	Very hot	Hot

[1]HLI: HLI (BGT<25°C) = $10.66 + 0.28 \times RH + 1.30 \times BGT - WS$; HLI (BGT> 25°C) = $8.62 + 0.38 \times RH + 1.55 \times BGT - 0.5 \times WS + e^{(2.4 - WS)}$ ($e \approx 2.71828$).

[2]HLI categories: Cool, if HLI<=70; Moderate, if 70 < HLI ≤77; Hot, if 77 < HLI ≤ 86; Very hot, if HLI > 86 (Gaughan et al. 2008b).

From Nguyen (2013)

Table 4.3. Mean (±SE), maximum (max), and minimum (min) for ambient temperature (TA, °C), black globe temperature (BGT, °C), solar radiation (SR, W/m²), wind speed (WS, m/s), relative humidity (RH, %), heat load index (HLI), and HLI categories at different times (h) of a day in March.

Climatic data		Time of a day (h)						
		600	800	1000	1200	1400	1600	1800
TA, °C	Mean ± SE	19.10 ± 0.34	21.58 ± 0.22	24.83 ± 0.29	26.61 ± 0.46	27.61 ± 0.53	26.94 ± 0.60	24.61 ± 0.45
	Max	22.94	24.35	28.38	33.62	34.85	33.84	29.21
	Min	15.04	19.30	20.96	21.56	21.35	21.30	19.47
BGT, °C	Mean ± SE	20.83 ± 0.37	27.41 ± 0.29	31.84 ± 0.39	34.04 ± 0.60	34.79 ± 0.68	33.07 ± 0.76	27.28 ± 0.53
	Max	25.01	30.51	36.32	42.41	43.54	41.57	32.49
	Min	16.66	23.51	26.24	27.32	26.11	24.37	21.00
SR, W/m²	Mean ± SE	11.06 ± 0.46	241.70 ± 18.80	475.00 ± 34.50	612.90 ± 49.10	487.80 ± 42.80	256.00 ± 26.20	19.49 ± 1.31
	Max	18.92	406.90	782.80	957.50	863.70	501.10	39.75
	Min	8.00	29.00	144.30	79.70	92.60	11.50	9.25
WS, m/s	Mean ± SE	0.68 ± 0.08	1.29 ± 0.11	1.70 ± 0.12	2.06 ± 0.14	2.14 ± 0.16	2.14 ± 0.13	1.54 ± 0.12
	Max	1.57	2.44	2.98	4.28	4.56	3.64	3.23
	Min	0.00	0.35	0.63	0.72	0.85	0.72	0.00
RH, %	Mean ± SE	90.70 ± 1.24	85.07 ± 1.41	72.07 ± 1.75	64.37 ± 2.34	58.06 ± 2.80	61.16 ± 2.94	68.66 ± 2.57
	Max	96.55	95.93	95.97	94.50	94.85	94.62	93.57
	Min	63.13	58.60	54.83	43.20	29.15	22.70	30.17
HLI[1]	Mean ± SE	63.15 ± 1.04	84.49 ± 1.16	86.13 ± 0.80	85.59 ± 0.83	84.26 ± 0.78	82.14 ± 0.97	75.48 ± 1.34
	Max	89.91	95.06	95.36	94.12	93.14	65.18	88.23
	Min	54.72	67.13	78.75	75.74	74.96	91.68	58.87
HLI categories[2]		Cool	Hot	Verry hot	Hot	Hot	Hot	Moderate

[1,2]See footnotes to Table 4.1

From Nguyen (2013)