RUMEN TEMPERATURE AS A BIOMARKER FOR HEAT STRESS

By

CATHERINE HAVILAND

Bachelor of Science in Animal Science

Oklahoma State University

Stillwater, Oklahoma

2013

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2016

RUMEN TEMPERATURE AS A BIOMARKER FOR HEAT STRESS

Thesis Approved:

Dr. Christopher J. Richards

Thesis Adviser

Dr. Clinton R. Krehbiel

Dr. Sara E. Place

ACKNOWLEDGEMENTS

First and foremost, I would like to like to extend my gratitude to Dr. Chris Richards for taking a chance on me when I was the random undergraduate student that knocked on his door. You have devoted endless amount of time and patience to me while perusing my MS degree. I defiantly would not be where I am in my graduate career without your knowledge and support. You have always been patient with me, believed in me, and encouraging me to challenge myself to push my academic career even further. I look forward to what the future holds and greatly appreciate everything you have done for me!

I would like to extend a huge thank you to Dr. Clint Krehbiel! You believed in me and my abilities when I could not always see them, your encouragement, patience, and support has been greatly appreciated! I want to especially thank you for allowing me to take on the Holstein trial and helping me along the way. It will not be the same around the department without you being around!

Dr. Sarah Place, you have played a very large part in my MS career and I greatly appreciate all of the extended help and support you have given me over the last 3 years. I greatly appreciate the endless support you have shown me during my time at the feedlot, in classes, and also during my Holstein trial. The department is not going to be the same without you around, I want to wish you nothing but the best for your new career chapter!

Dr. D. L. Step, I greatly appreciate your positive personality and attitude on a daily basis, it always brightens my day! I always look forward to your daily challenges and your ability to teach and share your knowledge. The feedlot just has not been the same without you around but I know you are enjoying your new job!

I would like to personally thank Caleb Lockard for being my endless support and putting up with me on a daily basis. You are added support through the good and bad times and I could not see anyone else being there for me. You are always encouraging me to push myself above and beyond and always know how to put a smile on my face! Justin Lyles, you were my first friend in graduate school and my endless support! You have always believed in me more than anyone! I could never repay you for everything you have done for me, if it wasn't for rumen fluid, I'm not sure we would have found each other! I miss you dearly and cannot wait to see what the future holds for you! I would extend an appreciation to everyone in my family for their endless support and help through my never-ending college career. I greatly appreciate the support from each one of you and definitely would not be where I am if you did not believe in me abilities and brains.

I would like to extend an extra thank you towards the other graduate students! Especially to Casey Maxwell, Blake Wilson, Charlotte O'Neil, Sara Linneen, and Bryan Bernhard for installing a hidden passion for research and pushing me to pursue my PhD degree. I greatly appreciate your time and support!!

Name: CATHERINE LEE HAVILAND

Date of Degree: DECEMBER, 2016

Title of Study: RUMEN TEMPERATURE AS A BIOMARKER FOR HEAT STRESS

Major Field: ANIMAL SCIENCE

Abstract: Steers were randomized to 1 of 3 production systems, natural (NAT; did not received growth promoting technologies), conventional (CONV; received an implant on arrival and daily supplemented monensin and tylosin), and conventional with zilpaterol hydrochloride (ZH; CONVZ; fed ZH for the last 20 d of the feeding period). For the first experiment of 2 experiments; Experiment 1 (n = 108; initial BW 377kg) and Experiment 2 (n = 33; initial BW 357 kg) and all data was broken into 3 periods based on ZH period, PRE (7 d before), ZHF (20 d ZH feeding), and POST (3 d withdrawal). Steers received rumen temperature (T_{rum}) boluses when sorted to production system pens. Respiration (RR) and panting scores (PANT) were taken during the ZHF and POST periods at 1000h and 1700h. Natural steers had lower average and maximum T_{rum}, RES, and PANT; CONV and CONVZ steers had similar average and maximum T_{rum} in the PRE and ZHF, but CONVZ steers increased in the POST. Conventional steers had increased ADG and BW over the NAT steers in both experiments. Overall, ZH did not have an effect on T_{rum} until it was removed from the diet in both experiments. In the second experiment, NAT and CONV were used to determine the effect of housing on T_{rum}, performance and carcass characteristics over an 84 d period. In the second experiment, production system (NAT vs CONV) steers (n = 54; initial BW 384 ± 2 kg) were housed in outdoor/indoor facility (SHADE) and steers (n = 54; initial BW 392 ± 2kg) were housed in open air pens (NOSHADE) for comparison. In the beginning of the feeding period, NAT NOSHADE had lower average and maximum T_{rum} and CONV NOSHADE had the highest. For number of drinks daily, NAT NOSHADE steers had the most followed by NOSHADE CONV having the least. Performance were similar for SHADE and NOSHADE steers but BW was greater for NOSHADE; CONV steers had improved BW and ADG over the NAT steers. Back fat thickness, HCW, dressing percentage, LM area and marbling was effected by production system, but not housing.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

- Literature Cited 3

II. REVIEW OF LITERATURE..........5

- Introduction..........5
- Factors that Influence Heat Stress..........7
  - Animal Factors and Behaviors..........7
  - Environmental Factors..........11
  - Comprehensive Climate Index..........13
- Feeding Strategies..........15
- Heat Mitigation Strategies..........17
  - Shade and Sprinkling..........17
  - Methods of Heat Transfer..........20
- Body Temperature..........22

Mode of Action of Growth Promoting Technologies..........26
Rumen Temperature..........27
Conclusion..........30
Literature Cited..........31

III. THE EFFECTS OF GROWTH PROMOTING TECHNOLOGIES AND ENVIRONMENTAL TEMPERATURE ON RUMEN TEMPERATURE, PANTING SCORES, AND RESPIRATION RATES OF BLACK-HIDED CROSSBRED FEEDLOT STEERS 37

- Abstract..........37
- Introduction..........39
- Materials and Methods..........40
  - Experiment 1..........40
  - Experiment 2..........41
  - Cattle Management..........41
  - Rumen Temperature Collection..........42
  - Respiration Rates and Panting Scores..........42
  - Environmental Data Collection..........44
  - Statistical Analysis..........45
- Results..........46

Experiment 1……………………………………………………...........................46
Experiment 2…………………………………………………………………….48
Discussion…………………………………………………………………………48
Literature Cited……………………………………………………………………52

Chapter Page

IV. EFFECTS OF HOUSING AND GROWTH PROMOTING TECHNOLOGIES ON RUMEN TEMPERATURE, FEEDLOT PERFORMANCE, AND CARCASS CHARACTERISTICS OF BLACK-HIDED CROSSBRED FEEDLOT STEERS ..……………………………………………………………………………….74

Abstract 74
Introduction 75
Materials and Methods 77
Cattle Management 77
Feedlot Performance and Carcass Characteristics ....…79
Rumen Temperature Collection…………………………………….…….…79
Environmental Data Collection…………………………………..…….…81
Statistical Analysis……………………………………………...……......81
Results………………………………………………………………...….....82
Rumen Temperature………………………………………………….…….82
Feedlot Performance…………………………………………………...83
Carcass Characteristics……………………………………………..…83
Discussion………………………………………………………………….…84
Literature Cited……………...……………………………………………...89

LIST OF TABLES

Table Page

3.1 Arbitrary comprehensive climate index thermal stress threshold......................57

3.2 Environmental measurements for Stillwater, Oklahoma from Oklahoma Mesonet archives for Experiment 1and Experiment 2……………………..…………….58

3.3 Average and maximum rumen temperature and area under the curve for steers in 3 production systems (PS) in Experiment 1 ……………………………………..62

3.4 Average and maximum AM and PM panting scores and respiration rates by production system for Experiment 1……………………………………………65

3.5 Average and maximum period rumen temperature (ºC) and calculated area under the curve by production system in Experiment 2……………..…………..……..69

3.6 Average and maximum AM and PM panting scores and respiration rates by production system for Experiment 2 .. …………………………..…………..72

3.7 Feedlot performance for by production system for Experiment 1 and Experiment 2 ……………………………………………………………………….……73

3.8 Ingredient composition (% DM basis) of diets fed……………………………...74

4.1 Ingredient composition (% DM basis) of diets fed…………….……………….…92

4.2 Arbitrary comprehensive climate index thermal stress threshold……………………………………………………………………...93

4.3 Monthly environmental conditions for Stillwater, Oklahoma from Oklahoma Mesonet……………………………………………………………………..….94

4.4 Monthly average and maximum rumen temperatures (ºC), area under the curve, and daily drinks for production systems (PS) housed in shade and no shade…..……..95

4.5 Effects of production system (PS) and housing on performance and carcass characteristics. …………………………………………………………………...99

LIST OF FIGURES

Figure Page

3.1 Average and maximum comprehensive climate index (CCI) values for Stillwater Oklahoma from Oklahoma for Experiment 1..59

3.2 Average daily rumen temperature by production system for Experiment 1……...60

3.3 Maximum daily rumen temperature by production system for Experiment 1……61

3.4 Period average and maximum rumen temperature for steers in Experiment 1 thirty days before harvest…………………………………………….…..…………..63

3.5 Production system average and maximum rumen temperatures for steers in Experiment 1 thirty days before harvest……………………………….………64

3.6 Average and maximum comprehensive climate index values for Stillwater Oklahoma from Oklahoma Mesonet for Experiment 2 ………………………………………66

3.7 Average daily rumen temperatures by production system in Experiment 2……..…67

3.8 Maximum daily rumen temperatures by production system in Experiment 2………68

3.9 Period average and maximum rumen temperatures for Experiment 2 thirty days before harvest…………………………………………………………...………..70

3.10 Production system average and maximum rumen temperatures for treatments in Experiment 2 thirty days before harvest……………………………………………71

4.1 Period average rumen temperatures for shade and no shade housing........................97

4.2 Period maximum rumen temperatures for shade and no shade housing….…………98

CHAPTER I

INTRODUCTION

Annually, heat waves and/or periods of extreme weather cause significant loss in profitability of feedlot cattle in several regions of the United States. In the past decade, the negative impacts have taken a $10 to $20 million a year loss for the beef industry (Mader et al., 2003). Extreme summer conditions can contribute to an animal's heat load and ability to dissipate excessive body heat (Mader et al., 2006 and Mader et al., 2010). Environmental factors that can contribute to cattle heat load include increased air temperature, solar radiation, and humidity, decreased rain fall and wind speed.

Heat stress can be defined as when the animal loses its ability to effectively control their own body heat load and their body temperature increases to dangerous levels (Mader et al., 2003; Mader 2006; Mader et al., 2006a). The exposure to extreme heat causes a decrease in DMI, profitability, and the overall well-being of feedlot cattle. Previous research has found that when cattle are exposed to high heat conditions, thyroid gland activity decreases causing a decrease in metabolic rates, muscle activity, rumen passage rates, and overall diet digestibility (Kamal and Ibrahim, 1969; Mader and Kreikemeier, 2006b).

Previous research has shown that cattle exposed to severe heat conditions have increased respiration rates and panting scores (Gaughan et al., 2008 and Mader et al., 2006). The addition of shade to open air feedlot pens has been shown to decrease direct solar radiation up to 30% and can improve feed intake, ADG, and BW. Shade has been shown to be the most immediate and cost-effective approach for increasing productivity and well-being of feedlot cattle (Mader et al., 1999).

The addition of growth promoting technologies such as implants, ionophores, feed-grade antibiotics, and β-agonists at the end of the feeding period improve feedlot performance, decrease feed intake, and enhance efficiency (Maxwell et al., 2015, and Arp et al., 2014). Previous research has shown that with the addition of the β-agonist, zilpaterol hydrochloride at the end of the feeding period did not have an effect on core body temperature until the product was removed from the diet (Wahrmund; 2008). Limited research has been done to examine the effects of growth promoting technologies and housing on core body temperature throughout a feeding period during summer conditions. The objective of these experiments is to 1) determine the effect of growth promoting technologies on body temperature, respiration rates, and panting scores and 2) determine the effect of housing, outdoor/indoor or outdoor, and production system on body temperature, performance, and carcass characteristics of black-hided feedlot steers.

LITERATURE CITED

Arp, T. S., S. T. Howard, D. R. Woerner, J. A. Scanga, D. R. McKenna, W. H. Kolath, P. L. Chapman, J. D. Tatum, and K. E. Belk. 2014. Effects of dietary ractopamine hydrochloride and zilpaterol hydrochloride supplementation on performance, carcass traits, and carcass cutability in beef steers. J. Anim. Sci. 92:836-843.

Kamal, T. H., I. I. Ibrahim. 1969. The effect of the natural climate of the Sahara and controlled climate on the thyroid gland activity in Friesian cattle and water buffaloes. Int. J. Biometeorol. 13:275-285.

Mader, T. L. 2003. Environmental stress in confined beef cattle. J. Anim. Sci. 81(E. Suppl. 2): E110-E119.

Mader, T. L., M. S. Davis, and J. B. Gaughan. 2006. Effect of sprinkling on feedlot microclimate and cattle behavior. Int J Biometerorol. 51:541-551.

Mader, T. L., M. S. Davis, and T. Brown-Brandl. 2006a. Environmental factors influencing heat stress in feedlot cattle. J. Anim. Sci. 84:712-719.

Mader, T. L., J. M. Dahlquist, G. L. Hahn, and J. B. Gaughan. 1999. Shade and wind barrier effects on summertime feedlot cattle performance. J. Anim. Sci. 77:2065-2072.

Mader, T. L., W. M. Kreikemeier. 2006b. Effects of growth-promoting agents and season on blood metabolites and body temperature in heifers. J. Anim. Sci. 84:1030-1037.

Maxwell, C. L., B. C. Bernhard, C. F. O'Neill, B. K. Wilson, C. G. Hixon, C. L. Haviland, A. N. Grimes, M. S. Calvo-Lorenzo, D. L. VanOverbeke. G. G. Mafi, C. J. Richards, D. L. Step, B. P. Holland, and C. R. Krehbiel. 2015. The effects of technology use in feedlot production systems on feedlot performance and carcass characteristics. J. Anim. Sci. 93:1340-1349.

Wahrmund, J. L. 2008. Zilpaterol hydrochloride impact on core body temperature in feedlot cattle. PhD Dissertation. Oklahoma State Univ., Stillwater OK

CHAPTER II

REVIEW OF LITERATURE

EFFECTS OF HEAT STRESS ON RUMEN TEMPERATURE

INTRODUCTION

Environmental temperature change has a wide range of impacts on feedlot cattle performance, daily intakes, and well-being. Annually, heat waves and/or periods of severe weather cause significant losses in feedlots in the several regions of the United States. According to Mader (2003), in the past 10 years' economic losses in the feedlot industry averaged between $10 million to $20 million/year as a result of adverse environmental conditions. Cattle discomfort increases with increasing environmental temperatures and increasing temperatures are particularly harmful to cattle when over a couple of days. West (2003) stated that during heat stress (**HS**) cattle may exhibit reduced feed intake (**DMI**), decreased activity and performance, increased water intake (**DWI**), respiratory rate (**RR**), and peripheral blood flow.

The term HS can be used widely and may have several definitions. Heat stress occurs when the animal cannot effectively control their body heat load and core body temperature increases to dangerous levels that can occur over a period of several days. A definition of stress often used by physiologists, denotes the magnitude of forces external to the bodily system which tend to displace that system from its resting or ground state and is the internal displacement from the resting or ground state brought about by the application of the stress. Environmental factors that can aid in inducing HS conditions include high humidity and air temperatures, decreased wind speeds, and increased solar radiation exposure.

Without heat stress mitigation techniques such as the addition of shade or sprinklers that aid in body temperature (**T_B**) regulation, can be an increase in discomfort and decrease in well-being of cattle.

Mader (2003) estimated yearly losses in live weight gain of feedlot cattle to be approximately 10 kg/year and can be equivalent to an additional 7 days on feed, assuming an average daily gain of 1.6 kg. In previous years, feedlot cattle productivity has seen 5-10% decrease because of environmental factors. Corresponding losses from severe HS and death could approach $5,000 due to associated live animal performance losses (Mader, 2003). With the addition of mitigation techniques, the goal is to not to completely eliminate environmental stress, but to decrease the severity of the environmental factors and aid cattle in decreased their core T_B and adaptation.

Body temperature can be an excellent indicator of cattle's susceptibility to high environmental factors based on their daily heat load. When monitoring rumen temperatures (**T_{rum}**), it has been determined that the rumen produces temperatures that are highly correlated with T_B and have potential to be a viable means of detecting illness and HS. Remote monitoring of T_{rum} could eliminate the need for rectal temperature measurements and also decrease stress and labor associated with movement of cattle if they are not ill. Furthermore, with remote detection of T_B, it is possible that the onset of disease occurrence could be identified earlier than by observing visual symptoms (Dye et al, 2007). Constant monitoring of T_B of feedlot steers may also aid with adapting management techniques that aid cattle when their biological temperatures are highest throughout the day.

FACTORS THAT INFLUENCE HEAT STRESS

Animal and Behaviors

Animal factors may decrease the ability of cattle to cope with their heat load, hide color, BW, and fat, and previous exposure are just a few of the factors. It has been previously found that black hided steers had body surface temperatures as much as 21ºC greater than lighter hided cattle and would reach their peak daily T_B quicker than light hided cattle (Mader et al., 2006a; Mader et al., 2002). Dark hair coats tend to absorb more solar radiation than the light hided cattle and maybe at an increased risk of experiencing HS throughout the day when the environmental factors are at their highest. The degree at which the heat is reflected from the hair coat may be considered as having some importance when evaluated the cattle's ability to cope with high heat.

Throughout the feeding period, as the light hided cattle increased their body condition, they acted similar to dark hided cattle when the climatic conditions increased, suggesting that with an increase in BW there is an increase in HS susceptibility. Mader and others (2002) found that at the end of the feeding period when feedlot cattle have an increased BW, body fat, and surface area. Previous research has found that heavier cattle begin to exhibit signs of HS sooner than lighter cattle. In a study with Holstein steers by Dikmen et al (2011), compared light and heavy steers in a high heat environment, found that there was an increase in the HS behaviors of heavier steers, indicating heavier cattle may have an increased susceptible to HS.

Mader et al (2002) found when comparing dark to light hided feedlot steers, climatic influences have less effects on the light hided cattle and their responses could be contributed to their feed intake. When comparing the daily increases in body temperatures, dark cattle hit their peak temperatures between 1700 and 1900 and light hided between 2000 and 2100. Heavier feedlot cattle carry a higher percentage of BW and fat may act as an insulation and hold metabolic heat in, decreasing their ability to dissipate the extra heat load. Cattle with greater body condition begin displaying signs of HS sooner than those with less body condition (Mader, 2003).

Dikmen and others (2012) found that feedlot cattle on a high-energy diet, exhibit superior body condition, carry high amounts of body fat, and dark hided, may have increased vulnerability to excess heat load. While experiencing HS, there is a decrease in performance resulting mainly from a decrease in feed intake which over time, which leads to a decrease in live weight gains, efficiency, and carcass characteristics. An increase in NEm requirements is found in cattle exposed to hot conditions which is largely dependent on the level and intensity of panting.

Respiratory rates increase when the evaporative heat loss is inadequate and the body temperature increases and they can change from closed-mouth to open-mouth panting to further aid in heat loss. Panting scores have been used to evaluate the heat load status of feedlot cattle under commercial and research conditions and maybe a reliable indicator of heat load status (Gaughan et al., 2008). Evaporation of moisture from the respiratory tract or panting maybe the primary mechanism for cattle to dissipate their excess body heat.

Mader and others (2006) compiled a panting scoring (**PS**) system to be utilized to determine the severity of HS of cattle. This scoring system ranges from 0 to 4, normal to severe open-mouthed breathing. With the first phase of increased respiration will be short and shallow, reducing tidal volume. With a shift to the second phase, there is a change to slower and deeper breathing and increased tidal volume, there will be a decrease in RR. A switch to the second phase and the increase in RR due to increasing body heat load. Phase one breathing is a PANT between 0 and 2.5 and the second is a PANT between 3.0 and 4.0.

Gaughan et al. (2000) found that effect of ambient temperature on respiratory rate is influenced by age, sex, and genotype, level of performance, nutrition, body condition and previous exposure to hot conditions. In a study conducted to determine the relationship between changing environmental conditions and RR, the results were not constant and were influenced by many additional factors. They found an increase in breaths per minute (**bpm**) under hot conditions and 2.8 to 3.3 bpm increase per 1°C. Gaughan et al. (2000) found that larger cattle had an increase in panting rates, even with prior exposure to hot conditions. A decreased respiratory rate and change from rapid open mouth to deep open mouth breathing, does not always indicate a decrease in HS but indicates the animal may be starting to fail to cope with raising environmental and T_B. In a study mentioned earlier, Mader et al (2002) found that dark hided cattle had the greatest percentage of cattle showing moderate to severe panting rates and light hided cattle showed the least.

Beatty et al. (2006) found that when steers were exposed to high heat and humidity over a long period of time that there are also renal adjustments to help maintain the blood pH while there is an increase in respiration rates. With the increase in respiration rates, there is an increase in CO_2 production beyond its production within the body. With an increase in pCO_2 and HCO_3^- may suggest that the animal maybe experiencing respiratory alkalosis. The acid-base balance within the body during HS conditions has been studied and it was observed that the respiratory alkalosis occurred only when HS was present during the day. During the nighttime hours, lower urine pH and greater urine ammonia was recorded. With the recorded changes in blood gases this may indicate that during HS, there is a large turnover of HCO_3- to maintain a homeostatic blood pH after a heating period as well as after prolonged and continuous HS periods.

Nighttime cooling may be beneficial to decreasing overall heat load for following day. Feedlot cattle were able to cope with HS by storing heat during the day and dissipating it at night but only with decreased environmental temperatures with the addition of an increased respiratory rate may also help dissipate body heat load. Nighttime cooling is only beneficial to decreasing body heat load when the environmental temperature is cooler than the daytime temperatures. Mader (2003) found that the ability for cattle to lose body heat at night is also dependent on moisture levels or relative humidity. If this does not occur, then the heat load is likely to carry over to the next day, especially if higher temperatures are expected the following day creating an accumulative heat load for the cattle.

Before and during HS events, cattle behaviors may change. Including increase in DWI, decreased DMI, increased standing, and increased RR. In high heat environments, pen stocking density becomes critical, waterer space available and water intake per animal becomes very important. Mader (2003) found that during summer conditions, that it is recommended to increase the amount of water space by three times the normal space per animal may be needed to allow for sufficient room for all animals to access and benefit from the available water this maybe dependent on the severity of the climate conditions. Cattle not only use the waterer as a source of dietary DWI but they will also use it to splash their tongue or stand over the cool water as another potential source of cooling.

Feed intake habits may also change as cattle are experiencing HS. Blaine and Nsahlai (2000) found that animals in hot environments had frequent meals of smaller sizes, this may help to decrease the increase in metabolic heat load. A simple change in feeding times may help delay the peak in metabolic heat load to a cooler part of the day. It was found that a peak feeding period at 1400 hours for shaded animals as opposed to 1600 hours for non-shaded cattle can be recommended to offset temperature highs and encouraged feeding activity. Shaded animals displayed strong feeding behavior mainly at 0800 and 1400 hours whereas non-shaded animals delayed most of their peak eating to later in the day and evening hours (Blaine and Nshlai, 2000).

Environmental Factors

Solar radiation contributes significantly to overall heat load of the animal; this is particularly evident in black-haired cattle (Mader, 2006a). Excessive heat load has been used to describe HS in feedlot cattle, the combination of environmental factors may have a large influence. These factors can include humidity, wind speed, air temperature, and solar radiation. The prolonged exposure to environmental heat and humidity can cause an increase in T_B of cattle which can indicate that the animal's heat-loss mechanism cannot compensate fully for the excessive heat load.

Summer conditions with above normal ambient temperatures, high humidity, high solar radiation and low wind speed can contribute to an animal's heat load and result in discomfort and decreased performance. When studying the effects of environmental factors on feedlot cattle, Mader et al. (2006a) found that increased PANT can be correlated with low wind speed, low relative humidity, and high ambient temperatures. With an increased wind speed, feedlot cattle may be able to use the air movement for an evaporative cooling to dissipate heat. There was a negative relationship with wind speed and PANT the increased air movement results in a disruption in the air space closest to the skin. This allows the removal of the hot air and replace it with cooler air and creates a convection heat exchange. With the increase in PANT being correlated with the relative humidity, this could be a result of the decreased ability of the animal to fully utilize evaporative heat exchange.

The ability of cattle be able to utilize environmental factors to aid in their cooling or air movement is dependent on the ambient temperature being cooler than the body temperatures. Mader et al. (2006a) found that is the ambient temperature exceeded the body temperature of the cattle, than the effects were uncertain. Under conditions that the relative humidity is low, wind speed could still have an effect, but when there is high humidity evaporative cooling is limited. High humidity coupled with high wind speed could result in increasing body temperature at a faster rate. As long as the cattle's core temperature remains greater than the environmental temperatures, than as the gradient decreases overnight than wind speed will become important in the cooling process.

Solar radiation contributes greatly to the overall heat load of feedlot cattle, especially true for dark hided cattle. When studying the relationship between maximum air temperature and solar radiation, Bristow and Campbell (1983) found that with increased solar radiation load, there was an increased in air temperature. They found a positive correlation with an increased solar radiation influencing the increased air temperature. Considering this correlation, this would explain the increased heat load for feedlot cattle with increased solar radiation and air temperature. Providing a protective method from solar radiation, especially for black hided cattle will help them cope with high climatic factors.

Brosh et al. (1998) found that with the influenced of increased solar radiation there was an increase in RR during the hottest parts of the day. With the increase in RR, there was not an increase in energy expenditure by those cattle. This allows the animal to pant with little internal heat production from their metabolism. There is an increase in energy expenditure needed by respiratory muscles could be accompanied by a decrease in the metabolism of other tissues.

Comprehensive Climate Index

Ambient temperatures are altered based on the influence of several environmental factors like the effects of humidity, wind speed, and solar radiation. The characteristic effect these factors have on the ‘real-feel’ air temperature has been combined into one comprehensive climate index. Mader et al. (2010) have summarized several models to characterize the effect of environmental factors on the comfort of cattle. For the heat index, the relationship between the effects of ambient temperatures and humidity. A previous index can be used for moderate to hot conditions called the temperature-humidity index but it only includes temperature and humidity.

Radiation had an effect on the animal from two different sources, direct solar radiation from the sun as well as the surface radiation from the pen surface. Two equations were developed and included in the overall equation, direct solar radiation and surface solar radiation. The surface equation was developed to determine if there was an additional influence from the surface temperature of the pen and can be determined from direct radiation or surface temperatures. Under hot conditions, radiant heat from the ground contributes to the heat load of the animal whereas, during cold conditions heat is transferred from the body to the ground. Animal efficiency differs based on hot and cold conditions and the amount of solar radiation. Direct solar radiation has a positive relationship with increasing ambient temperatures.

The relationship between WS and temperature adjustments was determined to be exponential with a logarithmic adjustment to define appropriate declines in apparent temperature as WS increases. Based on the existing wind chill and heat indices, the effect of WS on apparent temperature is sufficiently similar to allow one equation to be utilized under hot or cold conditions. Wind speed resulted in the greatest change in temperature per unit of wind speed regardless to whether it is hot or cold conditions. Heat loss due to wind is proportional to the surface area of the animal exposed to the wind, but not the entire surface area of the animal.

The relationship with ambient temperature and humidity includes an exponential relationship with temperature changing up and down around 30% humidity. Mader et al. (2010) found that for humidity above 30% and ambient temperature about 5°C there is a downward or negative adjustment in the temperature. In hot conditions with an increase in ambient temperatures paired with increased humidity, will decrease the ability of the animal to dissipate excess body heat. In cattle housed in outside pens, pen surfaces act as a radiation source and can act as heat emitters or heat sinks in both hot and cold conditions.

The CCI in summer conditions can be used to determine a maximum threshold for cattle for hot or cold conditions with a normal range between 25 to 40, for feedlot cattle on a high-energy diet, the lower end of temperature for HS is 20. In hot conditions, Mader et al (2010) found that a CCI above 40 can be considered to be the critical threshold and listed as extreme and there is a higher probability that cattle housed in outside pens there is extreme discomfort or death. Other CCI thresholds are designed to be aligned with similar thresholds and do not take into consideration cattle susceptibility to environmental conditions. The CCI is designed to and distinguish stress based on climatic conditions.

FEEDING STRATEGIES

When managing HS conditions, changes to feeding strategies may be least expensive and a beneficial strategy. It has been discovered that decreasing energy intake by either increased roughage intake or restricting feed intake during times of high climatic heats have been shown to be beneficial in reducing the susceptibility of feedlot cattle to HS. Mader (2003) found that keeping an empty bunk 4 to 6 hours of the day may beneficial in delaying the peak metabolic heat load to bypass the climatic peak heat load. This change in feeding will force the cattle to eat late at night, and decreases contribution to increasing T_B, compared to feeding during the hottest part of the day. In a study done to evaluate the effects of feeding times on body heat load, heifers were either exposed to solar radiation or had a shade protection. Brosh et al. (1998) found that feeding in the morning increased the heat load during the late morning to early afternoon, but they did not have an increase in T_B when fed the heifers were fed in the afternoon.

Another feed management system that can aid with HS can include changing the composition of the diets being fed. In a study by Mader (2002), feedlot steers were restricted 75% of their normal DMI for a period of time and compared to steers that were fed ad libitum the feeding period, all steers were fed at the same time daily. Dark hided steers fed the full feed, responded to rises in climatic temperatures quicker than the restricted production system groups and cattle that were restricted during the hot periods, found to have lower T_B than cattle on full feed. During nighttime observations, it was noticed that the restricted cattle stayed cooler overnight than non-restricted cattle. Restricted feed intake management techniques may be a form of dietary manipulation that help to increase efficiency of cattle, decrease their heat load, and also increase their welfare.

Mader et al. (2002) also stated that with restricted feed could have also contributed to a decreased organ size. A lower temperature in the periods after restricted feed may indicate a change in organ mass or a lowered metabolic activity due to the restricted intake. Cattle will benefit because as their organ size decreases, this may also indicate a decrease in metabolic heat production especially on days with high climatic temperatures. A change in feeding times and restricted feed intakes may be a beneficial approach to decreasing the effects of the high heat environments. These management practices paired with facility changes may decrease the discomfort of the cattle as well as increase performance and efficiency.

HEAT MITIGATIONS STRATEGIES

Shade and Sprinklers

The most common technique includes sprinklers, shade, and wetting the pen surfaces. Using sprinkling as a means of decreasing heat load of feedlot cattle can be beneficial, as stated earlier, especially when cattle are experiencing HS from high environmental temperatures coupled with high relative humidity, solar radiation, and low wind speed. Providing shade for feedlot cattle can decrease the effects of direct solar radiation decrease the solar radiation exposure from the direct sunlight and pen surfaces and can improve performance of cattle, especially cattle that have not acclimated to hot conditions and have higher BW.

According to Mader et al. (2006) as the water is evaporated from the air surrounding the animal, the ambient air temperature will be lowered increasing the heat gradient and allowing for heat flow away from the animal allowing a greater dissipation of their heat load. Although, in climates with consistent high relative humidity, sprinkling cattle may not be beneficial because the humidity does not allow evaporative cooling. Brown-Brandl et al. (2009) stated that the evaporation of 1 g of water removes 2.45 KJ of energy proving that evaporative cooling can be an effective means of cooling cattle but can be compromised by high relative humidity which impedes evaporation, making it difficult to cool the animal.

Thermal conductivity of soil is very poor. When cooling the pen’s surface and decreasing the temperature of the soil, this allows for some conductivity heat exchange between the animal and the soil and will provide a mechanism efficient heat transfer. The addition of water on a hot soil surface, allows for conductivity to increase and greatly enhances the dissipation of heat exchange off cattle. There may be a lowering of T_B when sprinkling is applied to cattle, but this heat exchange and transfer can also continue after sprinkling because of the increased thermal conductivity of the soil.

When comparing dry pens to sprinkled pens, Mader et al. (2006) found that with the addition of sprinkling to HS pens, there was a decreased soil temperature more than dry pens. With the addition of water, there was a range of 3.21 to 7.19ºC difference in the top soil up to 1.0 meter below the surface. When measuring the relative humidity of the two treatments, the dry pens had higher humidity during the sprinkling time period, but it switched to the wet pens having an increased humidity. Earlier in the day, cattle in wet and dry pens had similar PANT, but as the sprinkling progressed through the feeding period, there was a decrease in PANT. There were little differences observed when sprinkling occurred in the morning hours versus during the afternoon hours when the climatic factors were at their peaks.

Comparing the effects of shade and misting on feedlot cattle, Mitlöhner et al. (2001) found that misting cattle did not contribute to their heat load dissipation but providing shade did. The cattle that were provided shade had lower RR and the cattle with neither misting nor shade had the higher RR. Cattle that were provided shade reached their target BW as much as 19 d earlier than cattle in misting and non-misting treatments. Misting only provided small water droplets to cling on the outer hair of the cattle, it was not able to reach the skin and prevented evaporative cooling from occurring. The shade helped cattle cope with the high heat environment by decreasing the influence of the direct solar radiation and increased productivity, decreased discomfort, and increase carcass characteristics.

The primary purpose of shade is to protect feedlot cattle from intense direct solar radiation and can reduce heat load by up to 30% (Mader, et al., 1999). When comparing the effective cooling means of wind barrier to shade, Mader and et al. (1999) found that by provided shade over the feeding period increased DMI, ADG, and fat thickness. Shade can be the most immediate and cost-effective approach for increasing productivity in feedlot cattle. The disadvantage of shade is the structure, if the shade is solid it may run the risk of holding the heat underneath and increase the humidity under the shade and may decrease its effectiveness. In pens without wind barriers, there was an increase in air movement through the shaded area, decreasing humidity and air temperature, when compared to pens with a wind barrier.

When looking at the T_B of cattle in shaded areas, cattle housed in shaded areas had lower T_B than non-shaded cattle. Gaughan et al. (2010) found that the magnitude of change between maximum and minimum temperature was greater for non-shaded cattle than shaded cattle. When the ambient temperature was highest at 35°C, the non-shaded cattle had 1.32°C higher T_B then the shaded cattle. With the addition of shade in high heat environments, the reduction in T_B, RR, and open mouth breathing has been seen in several studies.

When looking at shade vs non-shaded housed cattle with RR as the primary response by Eigenberg et al. (2004) found that the non-shaded cattle had higher RR than shade cattle and the opposite occurred during the nighttime periods. Shade seemed to be effective with reducing RR during the hottest parts of the day making it more evident. When there was a climatic temperature increased, there was an increase in RR with non-shaded cattle, which was observed three times higher than shaded cattle. Shade decreased the observed number of open mouth breathing cattle during the hottest part of the day, whereas the non-shaded cattle had an increased number of observed open-mouth breathers.

Shade and sprinkling contribute to the dissipation of heat with different heat transfer mechanisms, when comparing the two against each other in dairy Holsteins there was an increased with the addition of shade. Domingos et al. (2013) found that with the addition of sprinkling to shade reduced heat accumulation and can be considered to be the best combination to increase the production of milk as well as aiding cattle with body heat load. Cows that were not provided shade or sprinkling, there was a 10ºC increase in temperature when looking at the hair coat surface temperature compared to shade and sprinkling being provided. When comparing RR, non-shaded cattle had RR at 75 bpm when compared to the shaded cows at 57 bpm. The milk production levels of the shade/sprinkled cows were improved when compared to the non-shade/sprinkled cows which had decreased milk production. With the addition of sprinkling to shade, cattle were able to dissipate excess heat load, non-shaded cattle were not able to dissipate that heat and had to resort to increased RR.

Methods of Heat Transfer

The four main methods of heat transfer include evaporation, convection, conduction, and radiation. Heat exchange is a two-way process, going from the environment to the animal and vice versa. When the environmental temperatures are higher than the animals hide temperature, the heat exchange is not beneficial for the animal but may be increasing temperatures instead. If these heat transfer methods can occur, they will be a beneficial aid in cooling HS cattle by moving heat away from cattle and decreasing T_B, RR, and PANT.

Evaporation occurs with the removal of water droplets either in the form of moisture off of the animal's skin or expelled out of the lungs. With the addition of sprinkling water on HS cattle, a wet hide has the ability to move heat away from the body but may also have a disadvantage with the addition of water adding to the heat load by holding the heated water against the surface until it is vaporized into the environment. Humidity can also damper the movement of water from the hide into the environment, with a higher humidity, there will be less movement.

Convection occurs with the transfer of heat from one place to another through the movement of fluids and gases or movement of heat from the body through into the air. If the air temperature is hotter than the hide of the animal, movement of air around the animal does not act as cooling effect. For convection to be beneficial for cooling the animal, the air around the animal must be cooler than the animals hide. With the increase of air speed, there is an increase in air movement off of the hide and cooling. Convection can be most beneficial for cattle when fans are provided or when wind movement is not restricted through holding pens.

Conduction heat transfer occurs with the transfer of heat through physical contact or when objects of different temperatures come in contact. This can occur through hooves, while laying down, or in standing water. The addition of mud in the pen will provide cattle an ideal place to lay and allow heat to transfer to the cooler area around them. There can be two different methods for heat transfer through conduction, passive and forced. Passive exchange occurs with the are near the skin is cooled or heated and is similar to the method of convection. Forced exchange is the physical exchange of heat from one object to another, which also occurs within the lungs with respiration or internal heat movement.

Radiation is the form of heat loss or gain through one object to another without actually physical contact. For example, the sun being able to transfer heat to the surface by solar radiation. Radiation in cattle works in a reverse direction when the ambient temperature is cooler than the body temperature of the cattle, heat is going from the animal into the environment. When the ambient temperature is higher than the temperature of the body temperature, than heat is going from the environment into the animal creating a heat load situation. With the addition of heat from the environment and the animal's metabolic heat, may overload the animals coping mechanisms causing discomfort.

With the understanding all of the heat transfer methods it is beneficial to the comfort of the animal in any setting. Combining several transfer methods into one mitigation technique will provide to be most beneficial and increase performance and profitability of the cattle.

BODY TEMPERATURE

Body temperature can be used as an indicator of health complications, diseases, and HS. Beatty et al. (2007) stated that it has been observed that with hot environmental temperatures there will be a rise in T_B, if it rises too much, it may indicate that the animals' heat loss mechanisms are unable to cope with increasingly hot environmental conditions. With increasing T_B, there is an increase in RR which may be an indicator of another method to dissipating heat load. Body temperature of feedlot cattle can be influenced by several factors including movement, handling, health, environmental, and metabolic.

Mader (2002) compared daily feeding times, feeding patterns, and T_B of feedlot cattle during HS events. In this study, cattle were also processed and moved during the high heat events, the process of moving cattle seemed to have an effect on increasing T_B immediately due to an increase in muscle activity, regardless of the season. For summer months, cattle moved double the distance had T_B almost doubled of short moved cattle, although the cattle moved had increased temperatures while they were being moved, after they were returned to their home pens they had a decrease in T_B greater than the cattle not moved out of pens.

It was found that the movement of cattle out of pens during high heat events, for either additional processing or health issues increased their T_B by up to 1.4°C than cattle that were left in pens (Mader, 2002). For cattle moved short distances, peak T_B did not occur till they were returned to their home pens and was short lived, but for cattle moved long distances their peak T_B occurred while they were in the working facilities. After movement, the behaviors of cattle were different, there was an increase in laying and an increase in DWI and cattle standing at the water (Mader, 2002). Movement of cattle experiencing HS may increase the detrimental effects of HS and decrease the performance and productivity of feedlot cattle. It is advised to only move cattle early morning or while environmental temperatures are lower.

With a change in feeding times and the addition of sprinklers maybe have the largest impact on decreasing T_B during high heat events. Davis et al. (2003) compared T_B between treatments of different feeding management and regimens and coat color. It was found that alternating feeding time had a limited effect on T_B, but it was found to be more beneficial the longer the cattle were on the program. During severe environmental conditions, bunk management and limit-feeding programs had an effect on T_B. The only concern with a change in feed management is that the animal effects may not be noticeable immediately.

Late afternoon and evening feeding did alter the T_B and allowed the animal to cope with the high heat of the following day and also allows the animal to utilize metabolizable energy more efficiently. Manipulation of feeding time or amount of feed consumed can improve cattle's ability to balance their heat load under period of severe HS and may result in an increase in cattle comfort. When providing these cattle sprinklers during severe HS, T_B of the wet hided cattle were cooler than dry hided cattle throughout the hottest part of the day. With the addition of sprinklers and AM feeding regimen during severe HS, cattle had the lowest T_B during the hottest part of the day. With the addition of the wet hide, there was an increase in dissipation of heat by way of evaporation.

Coat color has been observed to have an influence on T_B during high heat events. When comparing black hided and light hided cattle during HS, Davis et al. (2003) found that dark hided cattle had higher T_B. When comparing the hottest part of the day, 1000 to 1900, black hided steers had an increased T_B of 0.16°C and increased nighttime T_B of 0.14°C. Mader (2002) found similar results in a previous study when comparing the T_B of white hided cattle to black hided cattle during HS and processing. Black hided are more susceptible to experiencing HS conditions in high heat environments then lighter hided cattle because, as stated before, the solar absorbency of the black hide is higher than with lighter hide colors. It may be recommended for management practices to sort black hided feedlot cattle into a separate pen and provide them with additional mitigation aid in dissipating heat load to decrease their discomfort and increase productivity.

During the end of the feeding period, the addition of zilpaterol hydrochloride adds additional weight to the cattle BW as well as carcass characteristics (Montgomery et al., 2009; Reinhardt et al., 2014). When adding zilpaterol hydrochloride during cooler months of the year, Wahrmund et al (2008) found that there was a higher percentage of cattle reaching their maximum T_B during 0000 to 0300, indicating that as the feeding period progressed maximum daily T_B occurred during the night instead of during the day. With the feeding of zilpaterol hydrochloride, there was a decrease in T_B during the day and an increased T_B during the night. With the cooler environmental temperatures, there was not an influence from ambient temperatures on increasing T_B.

As stated earlier, RR increase with high heat climatic temperatures and as HS conditions increase. When looking the relationship of T_B and RR, there was an increase in RR with the increase in T_B. Gaughan and Mader (2013) found that there was a positive correlation between PANT and T_B. Within each time of day that PANT were taken, there was an increase in PANT with the increased T_B. With a PANT of 1, T_B was 39.8°C and RR were 53.1 bpm and at a PANT of 3.5 there was a T_B of 41.5°C and 123 bpm. Body temperature monitoring can be a beneficial addition to indicating heat load of feedlot cattle but can hard to monitor daily. With the addition of RR and PANT may be an additional management technique. Morning observations after a high heat day, may help to understand the correct management for decreasing the discomfort of those cattle for the following day. Understanding the relationship between PANT and T_B can help to monitor and manage feedlot cattle without individual T_B monitors.

MODE OF ACTION OF GROWTH PROMOTING TECHNOLOGIES

Feeding of a β-agonist (β-AG) has been proven to increase weight gain, increase efficiency, and decrease the feed intake of feedlot steers as well as finishing pigs (Maxwell et al., 2015; Arp et al., 2014; and Montgomery et al., 2009). A protein kinase is activated by the β-AG which is responsible for changes in protein synthesis and degradation in skeletal muscle. It has been previously studied that with the oral application of a β-agonist, there is modification of the blood flow, release of hormones, or central nervous system. With the study of the complex mode of action on the cell wall, it is still unclear about how the feeding of a β-agonist effects the natural heat regulation mechanism of the animal (Mersmann, 1998).

There are β-andrenergic receptors (β-AR) on the surface of almost all mammalian cells. Mersmann (1998) stated that with the activation of the β-AR, there is an activation of the G_s protein within the cell wall. The activation of this protein leads to the activation of adenylyl cyclase to produce cyclic adenosine monophosphate (cAMP). Cyclic adenosine monophosphate is used as a second messenger that's concentration is influence by hormones, including epinephrine and norepinephrine. Epinephrine and norepinephrine act as physiological β-agonists, and they are released form the adrenal medulla and have a direct effect on the sympathetic nervous system.

With the universal distribution of β-AR on all of mammalian cell types, provides for a complex mechanism of action to understand. With the activation of the β-AR and the increase in cAMP, there is a list of hormonal and physiological responses from numerous tissues. With the feeding of a β-AG, the desired response is an increase in muscle mass. It has been studied that there is an expected increase in protein synthesis and decrease in protein degradation. Although, protein degradation is hard to directly measure the rates there is a way to measure proteases within the muscle. Proteases are the enzyme that performs protein catabolism or degradation within tissues. With the feeding of a β-AG there is a decrease in protease activity within the tissues or there is an increase in the concentration of protease inhibitors.

Previous research by Kamal and Ibrahim (1969) reported that with increasing environmental temperatures, there was a decrease in thyroid activing gland. Cattle fed in summer months had a 16% decrease in thyroid and metabolic rates when compared to cattle finished in winter months. With increasing heat load, increase blood urea nitrogen has also been reported which may appear to be a result of reabsorption from the blood to the rumen to compensate for the decrease in ruminal ammonia due to reduced feed intakes. In summer months, there is a decrease in diet digestibility, ruminal passage rates, muscle activity, and metabolism to aid in decreasing overall heat load of the animal (Kamal and Ibrahim, 1969; Mader and Kreikmeier, 2006).

RUMEN TEMPERATURE

Rumen temperature has been correlated to be closely correlated with core T_B of feedlot cattle. Heat production within the rumen can be influenced by environmental temperatures and metabolic temperature, heat is removed from the rumen by direct conduction to overlaying tissues and convection to surrounding blood flow. Rumen blood flows increases during feeding and decreases during HS conditions when DMI is decreased. The decreased would theoretically increase T_{rum} because of the decrease in heat transfer away from the rumen. With the monitoring of T_{rum} may eliminate the need for movement of cattle for a rectal T_B measurement. Also, with the aid or T_{rum} boluses, maybe useful in determining DWI and also the extent of ruminations.

Dye and others (2007) found that with remote T_{rum} monitoring the onset of several common feedlot diseases was sooner than the visual observations. Steers were challenged with bovine respiratory disease and M. *haemolytica,* cattle exposed had increased T_{rum} on days 1 and 2 after exposure to the diseases. With the comparison of T_{rum} and rectal T_B; T_B was 0.24°C higher than T_{rum} but they were positively correlated. Improved detection of adverse health effects can help to decrease necessary or unnecessary movement of cattle and detection of diseases earlier.

The act of feeding raises the metabolic rate of an animal, known as the heat increment of feeding which includes the heat of fermentation and energy expenditure in the digestive process, as well as heat produced as a result of nutrient metabolism (Beatty et al., 2007). The decreased amplitude and frequency of the rumen contractions as the result of 5 days exposed at 38°C suggested that high ambient temperatures have a direct effect on rumen motility, and is not mediated indirectly through a reduction of the feed intake (Atteberry et al, 1956). The relationship between acidosis and T_{rum} has been previously studied and indicate that there is a negative correlation between T_{rum} and pH, therefore providing a means to detect ruminal acidosis episodes earlier (Wahrmund et al., 2012).

Temperature difference between the T_{rum} and the T_B is remarkably constant despite changes in heat load and feed and DWI. The position that the bolus settles in the rumen could potentially influence the results. Temperature gradients could occur with stratification of rumen contents when newly eaten, actively fermenting material responsible for high temperature settle at the top of the rumen, the ingesta at the bottom of the rumen might be the site of the greatest heat loss and the reason for the lower recorded T_{rum} (Beatty et al., 2007). Wahrmund and others (2012) found a highly correlated relationship between T_{rum} and rectal temperatures on feedlot steers over a 72 hour period.

Rumen temperatures between 38 and 40°C are optimal for rumen microbial fermentation and peak microbial fermentation occurs after feeding, and T_{rum} may rise as high as 41°C. Rumen temperatures of 41°C were reached and at that time feed intakes were reduced and T_B were increased due to hot environmental conditions (Beatty et al., 2007). It has not been previously studied whether prolonged periods of T_{rum} above 41°C would cause changes to rumen microbial populations and subsequently affect the rate of rumen fermentation but it is known that rumen protozoa do not survive T_{rum} above 40°C for extended periods of time (Beatty et al., 2007).

CONCLUSION

Monitoring T_{rum} in cattle has been a difficult task in the past but with new technologies, it is becoming readily used by more producers. Rumen temperature can be a useful way of keeping track of HS events within cattle and may also prevent illness and death. By understanding how and when to feed cattle and providing them shade, sprinklers, or access to wind, we can help to manage the HS and keep it at a minimum for the cattle's' welfare and increase comfort, performance, and profitability. The flux in T_{rum} at different time periods throughout the day will be helpful in determining ideal management techniques to decrease T_B during high heat events over a period of time.

Rumen temperature can be influenced by several factors including environmental, ration compositions, DWI, physical attributions, and feeding management. Several of the influences can be managed to decrease T_{rum} and cattle discomfort. Rumen temperature monitoring has the potential to provide a number of different observational opportunities that can help with illness, HS, DWI, DMI, and many more factors that have not been discovered. With the addition of T_{rum} monitoring in a research setting, we can observe the T_B and relay our findings back to industry settings to correctly manage cattle and increase profitability of cattle.

LITERATURE CITED

Arp, T. S., S. T. Howard, D. R. Woerner, J. A. Scanga, D. R. McKenna, W. H. Kolath, P. L. Chapman, J. D. Tatum, and K. E. Belk. 2014. Effects of dietary ractopamine hydrochloride and zilpaterol hydrochloride supplementation on performance, carcass traits, and carcass cutability in beef steers. J. Anim. Sci. 92:836-843.

Arias, R. A. and T. L. Mader. 2011. Environmental factors affecting daily water intake of cattle finished in feedlots. J. Anim. Sci 89:245-251.

Argyle, J. L. and R. L. Baldwin. 1987. Modeling of rumen water kinetics and effect of rumen pH changes. J. Dairy Sci. 71:1178-1198.

Attebery, John T., and Harold D. Johnson. 1969. Effects of environmental temperature, controlled feeding and fasting on rumen motility. J. Anim. Sci. 29:734-737.

Beatty, D. T., A. Barnes, E. Taylor, and S. K. Maloney. 2007. Do changes in feed intake or ambient temperature cause changes in cattle rumen temperature relative to core temperature. Journal of Thermal Biology. 33.1:12-19.

Blaine, B. L. and I. V. Nsahlai. 2010. The effects of shade on performance, carcass classes, and behavior of heat-stressed feedlot cattle at the finisher phase. Trop Anim Health Pro. 43:609-615.

Bristow. K. L. and G. S. Campbell. 1983. The relationship between incoming solar radiation and daily maximum and minimum temperature. Agricultural and Forest Meteorology. 31.2:159-166.

Brown-Brandl, T. M., R. A. Eigenberg, and J. A. Nienaber. 2009. Water spray cooling during handling of feedlot cattle. IntJ Biometeorol. 54:609-616.

Brown-Brandl, T.M., R.A. Eigenberg, and J.A. Nienaber. 2010. Benefits of providing shade to feedlot cattle of different breeds. Trop. Anim. Health. Prod. 43:609-615.

Calamari, L., F. Petrera, L. Stefanini, and F. Abeni. 2012. Effects of different feeding time and frequency on metabolic conditions and milk production in heat-stressed dairy cows. Int J Biometeorol. 57:785-796.

Davis, M. S., T. L Mader, S. M. Holt, and A. M. Parkhurst. 2003. Strategies to reduce feedlot cattle heat stress: Effects on tympanic temperature. J. Anim. Sci. 81:649-661.

Dikmen, S., H. Ustuner, and A. Orman. 2012. The effect of body weight on some welfare indicators in feedlot cattle in a hot environment. Int J Biometeorol. 56:297-303.

Domingos H. G. T., A. S. C. Maia, J.B.F. Souza Jr., R. B. Silva, F. M. C. Vieira, R. G. Silva. 2013. Effect of shade and water sprinkling on physiological responses and milk yields of Holstein cows in a semi-arid region. Livestock Science 154:169-174.

Dye, E. K., C. J. Richards, L. O. Burciaga-Robles, C. R. Krehbial, D. L. Step, R. W. Fulton, and A. W. Confer. 2007. Rumen temperature boluses for monitoring health of feedlot cattle. Proquest.

Eigenberg, R. A., T. M. Brown-Brandl, J. A. Nienaber, and G. L. Hahn. 2005. Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, part 2: predictive relationships. Bio systems Engineer Sci. 35:871-876.

Gaughan, J. B., S. Bonner, I. Loxton, T. L. Mader, A. Lisle, and R. Lawrence. 2010a. Effect of shade on body temperature and performance of feedlot steers. J.Anim. Sci. 88:4056-4067.

Gaughan, J. B., S. M. Holt, G. L. Hahn, T. L. Mader, and R. Eigenberg. 2000. Respiration rate- Is it a good measure of heat stress in cattle? J. Anim. Sci. C: 329-332.

Gaughan, J. B., and T. L. Mader. 2013. Body Temperature and respiratory dynamics in un-shaded beef cattle. Int. J. Biometeorol.

Gaughan, J.B., T.L. Mader, S.M. Holt, and A. Lisle. 2008. A new heat load index for feedlot cattle. J. Anim. Sci. 86:226-234.

Gaughan, J. B., T. L. Mader, S. M. Holt, M. L. Sullivan, and G. L Hahn. 2010. Assessing the heat tolerance of 17 beef cattle genotypes. Int. J. Biometeorol. 54:617-627.

Hoffman, M. P. and H. L. Self. 1972. Factors affecting water consumption by feedlot cattle. J. Anim. 4:871-876.

Ittner, N. R., Kelly, C. F., and Bond, T. E. 1957. Cooling cattle by mechanically increasing air movement. , J. Anim. Sci. 3:732-738.

Lefcourt, A. M., and W. R. Adams. 1996. Radiotelemetry measurement of body temperatures of feedlot steers during summer. J. Anim. Sci. 74:2633-2640.

Lofgreen, G. P., R. L. Givens, S. R. Morrison, and T. E. Bond. 1975. Effect of drinking water temperature on beef cattle performance. J. Anim. Sci. 40:223-229.

Lemenager, R. P., F. N. Owens, B. J. Shockey, K. S. Lusby, and R. Totusek. 1978. Monensin effects on rumen turnover rate, twenty-four hour VFA pattern, nitrogen components, and cellulose disappearance. J. Anim. Sci. Vol. 47, No. 1. 1978.

Macia-Cruz, U., F. D. Alvarez-Valenzuela, N. G. Torrentera-Olivera, J. V. Velazquez-Morales, A. Correa-Calderon, P.H. Robinson, L. Avendano-Reyes. 2010. Effect of zilpaterol hydrochloride on feedlot performance and carcass characteristics of ewe lambs during heat-stress conditions. Animal Production Science. 50,10: 983-989.

Mader, T. L. 2002. Body Temperature in feedlot cattle. J.Anim. Sci, 81(E. Suppl. 2):E110-E119.

Mader, T. L. 2003. Environmental stress in confined beef cattle. J. Anim. Sci. 81(E. Suppl. 2): E110-E119.

Mader, T. L., J. M. Dahlquist, G. L. Hahn, and J. B. Gaughan. 1999. Shade and wind barrier effects on summertime feedlot cattle performance. J. Anim. Sci. 77:2065-2072.

Mader, T. L. and M. S. Davis. 2004. Effect of management strategies on reducing heat stress of feedlot cattle: Feed and water intake. J. Anim. Sci. 82:3077-3087.

Mader, T. L., M. S. Davis, and J. B. Gaughan. 2006. Effect of sprinkling on feedlot microclimate and cattle behavior. Int J Biometerorol. 51:541-551.

Mader, T. L., M. S. Davis, and T. Brown-Brandl. 2006a. Environmental factors influencing heat stress in feedlot cattle. J. Anim. Sci. 84:712-719.

Mader, T. L., S. M. Holt, G. L. Hahn, M. S. Davis, and D. E. Spiers. 2002a. Feeding strategies for managing heat load in feedlot cattle. J. Anim Sci. 80:2373-2382.

Mader, T. L., W. M. Kreikemeier. 2006. Effects of growth-promoting agents and season on blood metabolites and body temperature in heifers. J. Anim. Sci. 84:1030-1037.

Mader, T. L., L. J. Johnson, and J. B. Gaughan. 2010. A comprehensive index for assessing environmental stress in animals. J.Anim. Sci. 88.6: 2153-2165.

Mersmann. H. J., 1998. Overview of the effects of β-andrenergic receptor agonists on animal growth including mechanisms of action. J. Anim. Sci. 1998. 76:160-172.

Mitlöhner F. M, J. L Morrow, J. W. Dailey, S. C Wilson, M. L Galyean, M. F. Miller, and J. J. McGlone. 2001. Shade and water misting effect on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. J. Anim. Sci. 79:2327-2335.

Montgomery, S. P., J. S. Drouillard, J. J. Sindt, T. B. Farran, H. J. Labruen, and R. D. Hunter. 2003. Effects of monensin and tylosin concentrations in limit-fed, high energy growing diets for beef cattle. Prof. Anim. Sci. 244-250.

Montgomery, J. L., C. R. Krehbiel, J. J. Cranston, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. N. Streeter, D. T. Bechtol, E. Johnson, T. TerHune, and T. H. Montgomery. Dietary zilpaterol hydrochloride I. Feedlot performance and carcass traits of steers and heifers. 2009. J. Anim. Sci. 87:1374-1383.

Reinhardt, C. D., C. I. Vahl, B. E. Depenbusch, J. P. Hutcheson, and D. U. Thomson. Feeding zilpaterol hydrochloride is associated with decreased dry matter intake shortly after initiation of feeding dependent on season and previous intake. 2014. J. Anim. 92:4751-4760.

Rhoad, A. O. 1940. Absorption and reflection of solar radiation in relation to coat color in cattle. J. Anim. Sci. 1:291-293.

Roberston, D. 2006. Mechanism for the control of respiratory evaporative heat loss in panting animals. J. Appl. Physiol. 101:664-668.

Senft, R. L., and L. R. Rittenhouse. 1985. A model of thermal acclimation in cattle. J. Anim. Sci. 61:297-306.

Sullivan, M. L., A. J. Cawdell-Smith, T. L. Mader, and J. B. Gaughan. 2011. Effect of shade area on performance and welfare of short-fed feedlot cattle. J. Anim. Sci. 89:2911-2925.

Wahrmund, J. L. 2008. Zilpaterol hydrochloride impact on core body temperature in feedlot cattle. PhD Dissertation. Oklahoma State Univ., Stillwater OK.

Wahrmund, J. L., J. R. Ronchesel, C. R. Krehbiel, C. L. Goad, S. M. Trost, and C. J. Richards. 2012. Ruminal acidosis challenge impact on ruminal temperature in feedlot cattle. J. Anim. Sci. 90:2794-2801.

West, J. W. 2003. Effects of heat-stress on production of dairy cattle. J. Dairy Sci. 86:2131-2144.

Winchester, C. F., and M. J. Morris. 1956. Water intake rates of cattle. J. Anim. Sci. 3:722-74

CHAPTER III

EFFECTS OF GROWTH PROMOTING TECHNOLOGIES ON BODY TEMPERATURE, PANTING SCORE, AND RESPIRATION RATES OF BLACK-HIDED CROSSBREED FEEDLOT STEERS

Abstract:

Two experiments were conducted to determine the effects of growth promoting technologies on the rumen temperature (**T_{rum}**), respiration rates, and panting scores of black-hided feedlot steers. Experiment 1 (**EXP1**) 108 steers (6 blocks, 377 ± 9 kg) and Experiment 2 (**EXP2**) 33 steers (2 blocks, 357 ± 9 kg). Steers were randomized to 1 of 3 production systems (**PS**); natural (**NAT**; did not receive growth promoting technologies), conventional (**CONV**; received an implant on arrival and were fed monensin and tylosin daily), and conventional with zilpaterol hydrochloride (**ZH; CONVZ**; fed ZH during the last 23 days of the feeding period). Data from both experiments was broken into 3 periods based on the ZH feeding; 1) 7 d before ZH (**PRE**), 2) 20 d ZH feeding (**ZHF**), and 3) 3 d withdrawal (**POST**). Panting scores (**PANT**) and respiration rates (**BPM**) were recorded at 1000 h and 1700 h every other day during the ZHF and POST. Six steers in each pen were selected based on pen median BW to monitor rumen temperatures. Maximum environmental conditions for EXP1 ranged from extreme danger to severe (CCI = 39.29); EXP2 ranged from moderate to no stress (CCI = 25.59), based on the Comprehensive Climate Index. For EXP1, NAT had the lowest average and maximum T_{rum} and CONVZ steers had the highest production system ($P < 0.001$); ZHF and PRE had the lowest average and maximum ($P < 0.001$). Average PANT was greater during the ZHF than the POST period ($P = 0.01$). Average and maximum BPM during the PM measurements were higher in the POST than ZHF period ($P < 0.001$). Average and maximum BPM were the highest for the CONV steers ($P < 0.001$). For EXP2, there was a production system effect for average T_{rum} with the CONVZ having the highest ($P < 0.001$). There was a effect for average and maximum T_{rum} with CONVZ having higher and NAT having the lowest average and maximum T_{rum} ($P < 0.001$). There was a period effect on AM average and maximum BPM being higher in ZHF period ($P < 0.001$). The CONV and CONVZ steers had improved weight gain and ADG when compared to NAT steers ($P < 0.001$). With the addition of ZH there was not an effect on T_{rum}, BPM, or PANT until the product was removed from the diet, which was seen in both experiments. Steers that were fed in higher CCI tended to have decreased performance and had higher T_{rum} than steers in cooler CCI.

Key words

bovine, environmental, heat stress, panting score, zilpaterol hydrochloride, rumen temperature

Introduction

With increasing climatic temperatures, an increase in discomfort of finishing cattle is seen. This discomfort can lead to increased respiration rates, decreased feed intakes, decreased performance, and in severe cases, death. With increased environmental temperatures over an extended period, heat stress occurs when an animal cannot effectively control their body heat load and their core body temperature raises to dangerous temperatures.

The exposure to high heat can lead to decreased feed intake and performance of finishing feedlot steers (Dikmen et al., 2012; Sullivan et al., 2011). Kamal and Ibrahim (1969) found that when cattle were exposed to high heat conditions, thyroid gland activity decreased causing a decrease in metabolic rates and muscle activity to help reduce overall heat load. Mader and Kreikemeier (2006b) had similar results with a dramatic decrease in thyroid activity, digesta passage rates, and diet digestibility when heifers were exposed to high heat conditions.

The addition of growth-promoting technologies such as implants, ionophores, low-dose antibiotics, and β-agonists impact feedlot performance, feed intake, and efficiency (Maxwell et al, 2015; Arp et al., 2014; Montgomery et al., 2009). Zilpaterol hydrochloride (**ZH**) is a synthetic β-adrenergic receptor agonist approved for use in the last 20 d and has shown an improvement in live and carcass weight gain (Zilmax product label, Merck Animal Health, DeSoto, KS). Little is known about the effects of feeding growth-promoting technologies on the core body temperature in high heat conditions. Previous research by Wahrmund (2008), found that there is not an effect on core body temperature while feeding ZH but reported an increase in temperatures when the product was removed from the diet. With the addition of implants, Mader and Kreikemeier (2006b) reported an increase in heat stress susceptibility with the addition of estrogenic or trenbolone acetate implants to finishing heifers in a high heat environment.

The ability to monitor body temperatures continuously and remotely throughout the feeding period is beneficial for the assessment of animal status. The objective of this study is to determine the effect of implants, ionophores, and feed antibiotic with or without a β-agonist on rumen temperature (**T_{rum}**), respiration rates, and panting scores.

Materials and Methods

Experiment 1

One-hundred and sixty-eight cross-bred, black-hided, certified natural steers (initial BW = 396 ± 9 kg) from Willow Lake, SD and eighty-four steers from Cedar Rapids, NE (initial BW = 414 ± 10 kg) arrived at Willard Sparks Beef Research Center in Stillwater OK, on April 26, 2013. Steers were used in a randomized complete block design with 3 production systems (**PS**); natural (**NAT**), conventional (**CONV**), and conventional with ZH (**CONVZ**). On d 0, steers were sorted based on their d -1 BW, source, hide score and chute score (Bernhard et al., 2014) and randomly assigned to their experiment pens (6 blocks, 3 pens/block, 14 steers/pen). Of the 252 steers, 6 steers from each pens (**EXP1**; 108 steers, initial BW =377 ± 9kg) were selected based on pen median BW to assess rumen temperature (**T_{rum}**), panting score (**PANT**), and respiration rates (**BPM**).

Experiment 2

Eighty-four cross-bred, black-hided, certified natural steers (**EXP2**; initial BW = 374 ± 8 kg) from Willow Lake, SD arrived at Willard Sparks Beef Research Center in Stillwater OK, on April 26, 2013. Steers were used in a randomized complete block design with 3 PS; NAT, CONV, and CONVZ. On d 0, steers were sorted based on their d -1 BW, source, hide score and chute score (Bernhard et al., 2014) and randomly assigned to their experiment pens (2 blocks, 3 pens/block, 14 steers/pen). Of the 84 steers, 6 steers form each pen (**EXP2**; 33 steers, initial BW 357 ± 9 kg) were selected based on pen median BW to asses T_{rum}, PANT, and BPM. Three steers (1 CONVZ and 2 CONV) were removed from the analysis due to malfunctioning boluses.

Cattle Management

The morning following arrival, steers were weighed and individually identified with visual numbered tag and electronic identification tags. All steers were vaccinated with clostridial toxins (Vision 7, Merck Animal Health, DeSoto, KS), infectious bovine rhinotracheitis, parainfluenza-3 virus, bovine respiratory syncytial virus, and bovine viral diarrhea virus type I and II, *Manheimia haemolytica* and *Pasteurella multocida* (Vista Once, Merck Animal Health, Desoto, KS), and treated for internal parasites (Safeguard, Merck Animal Health, Desoto, KS), and external parasites (Ivomec Plus, Merial Animal Health, Duluth, GA). After allocation to PS, all steers were housed in 24 uncovered 12.2

x 30.5 m, open air, soil surfaced feedlot pens, with 12.16 m concrete bunk lines, and 76 L concrete fence line waterers.

All steers were fed at approximately 0700h and 1300h daily in the following order NAT, CONV, and CONVZ. All steers received the same ration with different supplementation. Conventional and CONVZ steers received 33 mg/kg of monensin and 9 mg/kg tylosin (DM basis; Rumensin® and Tylan®, Elanco Animal Health, Greenfield, IN) in their ration and CONVZ steers received ZH (Zilmax®, Merck Animal Health, DeSoto, KS) at a calculated rate of 87.6 mg $\cdot \mathrm{steer}^{-1} \cdot \mathrm{d}^{-1}$ the last 20 d on feed with a 3 d withdrawal period before steers were harvested. The NAT steers received a supplement without ionophore, antibiotic, or beta agonist. All steers received a direct fed microbial daily by mixing 2.26 kg of ground corn with 1 g/hd of Bovamine (Bovamine, Nutrition Physiology Company, Guymon OK) with the morning feeding. The finishing ration consisted of 48% DRC, 15% DDG, 15% wet corn gluten, 15% supplement (liquid and dry) and 7% switch grass hay. The ration and supplement were formulated to meet 2000 NRC requirements (National Research Council 2000; Maxwell, 2014; Table 3.10).

Further feedlot performance and carcass characteristic analysis and results can be found in Maxwell (2014).

The ZH feeding period analysis was broken into 3 periods, pre-ZH (**PRE;** d -7 to -1), ZH feeding (**ZHF;** d 0 to 21), and post-ZH (**POST;** d 22 to 23). Experiment 1 steers started, PRE on August 12, 2013, ZHF on August 18, 2013, and POST on September 9,

2013. The CONV and CONVZ steers were harvested on September 12 and NAT on September 13, 2013. Experiment 2 started PRE on October 1, 2013, ZHF on October 8, 2013, and POST on October 28, 2013. The CONV and CONVZ steers were harvested on October 31 and NAT steers on November 1, 2013.

Rumen Temperature Collection

Rumen temperature boluses (SmartStock, LLC, Pawnee OK) were administered with a bolus gun when steers were allocated to pens. Rumen temperatures were transmitted at 3 minute intervals to a receiver. Raw T_{rum} data was in Fahrenheit format and converted to Celsius using, C°= (F°-32) x (5/9).

Normal body temperature for feedlot steers was assumed to be above 38.61°C (Wahrmund, 2008) and was used as a baseline for all temperature analysis. Rumen temperatures that were < 38.61°C are assumed to be associated with water drinking events and were removed from the daily average and maximum T_{rum} analysis. Daily average T_{rum} for individual animal was averaged by hour, day, and then period average T_{rum}. The maximum T_{rum} for individual animal per day was averaged together for an overall daily and period maximum average T_{rum}.

Area under the curve was utilized to determine the amount of time spent > 38.61 ºC (**AUC$_{AB}$**) or below < 38.61 ºC (**AUC$_{BE}$**) the assumed normal body temperature, negative summed AUC calculation errors were removed from the analysis. Time and date were converted to a numerical value, summed together, and converted to Julian time by adding 2415018.50. The following equation was adapted from Wahrmund (2008) and was utilized for all daily T_{rum} observations:

$$\text{AUC} = \text{Julian Time} * \left(\frac{\text{Current Temperature (ºC)} + \text{Previous Temperature(ºC)}}{2}\right)$$

The AUC_{AB} was assumed to be associated with time spent above baseline temperature and was calculated by summing the calculated values for individual animal by hour, day, and then period. The AUC_{BE} was assumed to be associated with time spent below baseline temperature water drinking events and was calculated by subtracting the AUC_{AB} from the total AUC area. The AUC_{BE} was then summed for individual animal by hour, day, and then period.

To determine the average number of daily drinking events per pen, AUC_{BE} was summed for each hour of the day. From those summed values, each hour was assigned a value of 1 if AUC_{be} was > 0 or a 0 if the AUC_{BE} was = 0. Assigned hourly values were summed for individual animal per day and represent count of daily drinking events per pen daily (**DD$_N$**).

Environmental Data Collection

Environmental data was obtained from the Oklahoma Mesonet Stillwater station and included; maximum and average temperatures, humidity, solar radiation, and maximum and average CCI. Experiment 1 started on August 12, 2013 and ended on September 12, 2013 (Table 3.3; Figure 3.1). Experiment 2 started on October 1, 2013 and ended on October 31, 2013 (Table 3.3; Figure 3.5). The CCI can be used to determine discomfort of cattle that are housed in high heat environments without aid (Mader et al, 2010; Table 3.1).

Panting Scores and Respiration Rates

For steers that received T_{rum} monitoring boluses, BPM, and PANT were assigned during the ZHF and POST periods every other day at 1000 and 1700 h. Respiratory rates were measured by visual observation of flank movement for 30 seconds and multiplied by 2 to calculate breaths per minute. Panting scores were assigned by a trained individual that was blinded to the study, at the same time as BPM based on a 0 to 4 scale (Mader et al., 2006); 0 = normal respiration, 1 = elevated respiration, 2 = moderate panting and/or presence of a small amount of saliva, 3 = heavy open-mouthed panting; saliva usually present, 4 = severe open-mouthed panting accompanied by protruding tongue and excessive salivation; usually with neck extended forward.

Statistical Analysis

Temperature analysis was done using a randomized complete block design with PS of NAT, CONV, and CONV-Z and periods of PRE, ZHF, and POST for EXP1 and EXP2 with individual animal as the experimental unit and weight block being the random effect. The main effects were tested using PS and period and the PS × period interaction.

Average and maximum T_{rum} were analyzed for day and day was used as the repeated measure in PROC GLIMMIX (SAS 9.4; SAS Inst. Cary, NC). Area under the curve calculations were analyzed using hourly, daily, and period totals for all area, area above 38.61ºC, and area associated with drinking events. Area under the curve calculations were summed hourly and daily for pen and average of sums was used for analysis. Area under the curve calculations were summed hourly and daily for pen and average of sums was used for analysis. Day was used as a repeated measure in PROC GLIMMIX.

Average and maximum rates and PANT were recorded for the ZHF, and POST periods. Average daily number of drinks was calculated using area under the curve calculations and summed for individual animal per day and averaged across period. All averages were compared using PROC MIXED (SAS 9.4; SAS Inst. Cary, NC).

All differences and interactions were considered different when $P \leq 0.01$ and a trend when $0.01 > P \leq 0.05$.

Results

Experiment 1

There was a PS ($P < 0.001$) effect on the BW at the start of the ZH feeding period. The CONV steers had higher BW with CONVZ steers having the intermediate and NAT steers with the lightest (Table 3.9). There was also a ($P < 0.001$) effect for final BW. The CONVZ and CONV steers did not differ and the NAT steers had the lowest final BW. Initial ADG had a PS ($P < 0.001$) effect. The CONVZ and CONV steers had similar daily gains and the NAT steers gained less daily before the start of ZH (Table 3.9). There was a

PS ($P < 0.001$) effect on the ZH feeding period ADG with CONVZ having a slight advantage over CONV, NAT gained the least. The ADG for the overall feeding period had a PS ($P = 0.004$) effect. The CONV and CONVZ did not differ in their daily gains and NAT gained the least overall (Table 3.9).

There were no PS × period interactions for average or maximum T_{rum} ($P \geq 0.02$; Table 3.3). The PRE had lower average and maximum T_{rum} and the ZHF and POST were similar ($P < 0.001$; Figure 3.2, 3.3 and 3.4). Natural steers had lower maximum and average T_{rum} ($P < 0.001$). For average T_{rum}, CONV and CONVZ steers were similar but CONV steers had higher maximum T_{rum} ($P < 0.001$; Figure 3.5).

For AUC_{AB}, $AUC_{BE,}$ and DD_N there were no PS × period interactions ($P \geq 0.02$). for AUC_{AB}, time spent above baseline was similar for PRE and ZHF and decreased for the POST period ($P < 0.001$). For AUC_{BE}, the ZHF and POST had the least amount of time spent below baseline and PRE had the greatest ($P < 0.001$). Natural steers spend the greatest amount of time below baseline and had the greatest DD_N ($P < 0.001$). The CONVZ steers spend the least amount of time below the baseline temperature and had the fewest DD_N ($P < 0.001$). The AUC_{BE} and DD_N was greatest during the PRE period ($P < 0.001$).

There were no PS× period interactions ($P \geq 0.12$) for average and maximum PANT and BPM. The ZHF period had higher PANT than the POST during PM ($P = 0.01$; Table 3.5). For BPM in the PM, CONVZ had lowest averages, CONV had the highest maximum BPM, the NAT were the intermediate for both ($P < 0.001$). Respiration rates in the PM increased from the ZHF to POST periods for both average and maximum ($P < 0.001$).

Experiment 2

There was a tendency for a PS effect on the final BW ($P = 0.05$). With CONVZ having elevated BW over CONV and NAT (Table 3.9). There was a PS effect ($P < 0.001$) for initial, start, and overall ADG. The NAT steers gained less daily than the CONV and CONVZ steers over the feeding period. The CONVZ steers had a slight advantage over CONV in their daily gains (Table 3.9).

There were no PS × period interactions ($P \geq 0.02$) for average and maximum T_{rum}. The NAT and CONV had similar average and maximum T_{rum} and CONVZ were increased for both ($P < 0.001$). There were no PS × period interactions ($P \geq 0.63$) for AUC_{AB}, $AUC_{BE,}$ or $DD_{N.}$ The AUC_{AB} was greatest for the PRE period and the ZHF was the least ($P < 0.001$).

Discussion

The effects of feeding ZH to finishing feedlot cattle are well documented and when looking at the performance of the three PS, it is evident that feeding ZH was beneficial in improving efficiency and performance of the CONVZ steers as compared to the performance to NAT steers. Maxwell and others (2015) on a corresponding study, found a 37.8 % improvement in ADG when cattle were fed a conventional diet compared to natural. When comparing the CONV and CONVZ steers, there were similar improvements in ADG and BW gain prior to feeding ZH.

When looking at the influence of ZH on the T_{rum}, there was a similarity between PS through the PRE and ZHF periods, but in the POST period, the CONVZ steers had an increase in T_{rum}. With the change in CONVZ steers in moving from ZHF to POST, there was an effect of the removal of ZH from the diet on the body temperature. Experiment 1 and 2 had similar increases in CONVZ T_{rum} in the POST period regardless of the environmental influences. Wahrmund and others (2008) had similar results in spring-finished heifers and steers.

Experiment 1 had elevated CCI listed in the extreme to severe range which had an effect on steers in all PS. Steers in EXP1 experienced 4 days with the CCI classified as severe to extreme danger during ZHF, all PS experienced an increase in body heat load during these days. Borsh et al. (1998) found that with increased influence of solar radiation, there is also an increase in respiration rates, especially during the hottest parts of the day. This was particularly true for this set of cattle, especially during the ZHF feeding period. With increased rate of respiration. With increasing intensity of panting, an increase in energy expenditure is needed by respiratory muscles and decreases the needed metabolism within other tissues and having a negative effect on performance (Mader et al., 2006a). Hales and others (2014) found similar results, but were unsure whether the increased PANT and BPM were due to ZH or increasing BW that occurs that the end of the feeding period. Without evaluating separately, it is hard to determine if the increased BPM and PANT is from the feeding of ZH or the increased BW of the steers at the end of feeding period. When comparing CONVZ to NAT steers, CONVZ had increased BW during ZHF and POST but NAT and CONVZ steers had similar BPM. Further research would be beneficial to determine if PANT and BPM would be effected with steers in PS but with similar BW.

At the end of the feeding period, cattle are also experiencing increased BW, increased surface area, and increased back fat thickness. Dikmen et al (2011) states that within an increase in body fat percentage may act as an insulation mechanism and hold metabolic heat within the body, decreasing the ability of cattle to dissipate the extra heat load and contributing to heat stress conditions. In the present study, the CONV and CONVZ steers had increased T_{rum} but also had increased BW at the beginning and end of the ZH feeding period. The increased BW and fat percentages of CONV and CONVZ steers could have contributed to their overall body heat load quicker than the NAT steers. If the NAT steers were fed to a similar BW, they could have experienced heat stress in the high heat conditions similar to the other PS.

Little research has been done on using AUC as an indicator of water intake or heat stress in feedlot steers. According to the AUC calculations, steers in EXP1 spent more time above normal body temperature and less time below. Experiment 1 may have had more drinking events to compensate for their increasing T_{rum} and the temperature of the water may not have as much of an effect on decreasing the heat load. Steers in EXP1 during the ZHF period had as much as a 1.96ºC increase in temperatures over EXP2 steers in the same period. With increasing environmental temperatures, a rise in body temperature may over load the animal's heat mechanisms may be unable to cope with the heat conditions. When comparing EXP1 with EXP2 there was an influence in the elevated environmental factors on steers finished in EXP1.

Looking at the difference in performance between the 2 experiments, steers in all PS were started with similar BW. At the end of the ZHF feeding period, EXP2 steers had an increased ADG as well as final shipping weights. With the environmental factors influencing EXP1, it may have contributed to their decreased performance. Mader (2003) stated that with increased environmental conditions, feedlot cattle efficiency has seen as much as a 10% decrease in performance resulting to 10 kg/year, or 7 additional days on feed. Steers in EXP2 outperformed steers in EXP1 as much as 19 kg live weight and 0.8 kg/daily gains when comparing the CONVZ PS.

The objective of this study is to determine the effect of growth promoting technologies and various climatic factors on T_{rum}, BPM, and PANT during two periods. Comparing EXP1 to EXP2, there was an increase in T_{rum}, BPM, and PANT and a decrease in performance for EXP1 when fed ZH during high heat events with extreme danger to severe environmental conditions. The cattle fed during the cooler fall months, EXP2, had lower T_{rum}, BPM, and PANT, and increased performance as compared to steers in EXP1. Understanding the effects of feed additives on feedlot cattle heat stress loads and well-being will further increase understanding on ideal time of year to feed additive such as ZH.

Literature Cited

Arp, T. S., S. T. Howard, D. R. Woerner, J. A. Scanga, D. R. McKenna, W. H. Kolath, P. L. Chapman, J. D. Tatum, and K. E. Belk. 2014. Effects of dietary ractopamine hydrochloride and zilpaterol hydrochloride supplementation on performance, carcass traits, and carcass cutability in beef steers. J. Anim. Sci. 92:836-843.

Bernhard, B. C. 2014. Effects of Growth-promoting technologies of temperament, behavior, and mobility of finishing steers. PhD Diss. Oklahoma State Univ. Stillwater OK.

Blaine, B. L., and I.V. Nsahlai. 2010. The effects of shade on performance, carcass classes, and behavior of heat-stressed feedlot cattle at the finisher phase. Trop Anim Health Pro. 43:609-615.

Dikmen, S., H. Ustuner, and A. Orman. 2012. The effect of body weight on some welfare indicators in feedlot cattle in a hot environment. Int J Biometeorol. 56:297-303.

Elam, N. A., J. T. Vasconcelos, G. Hilton, D. L. VanOverbke, T. E. Lawrence, T. H. Montgomery, W. T. Nichols, M. N. Streeter, J. P. Hutcheson, D. A. Yates, and M. L. Galyean. 2009. Effect of zilpaterol hydrochloride duration of feeding on performance and carcass characteristics of feedlot cattle. J. Anim. Sci. 87:2133-2141.

Kamal, T. H., I. I. Ibrahim. 1969. The effect of the natural climate of the Sahara and controlled climate on the thyroid gland activity in Friesian cattle and water buffaloes. Int. J. Biometeorol. 13:275-285.

Hales, K. E., S. D. Shackelford, J. E. Wells, D. A. King, M. D. Hayes, T. M. Brown-Brandl, L. A. Kuehn, H. C. Freetly, and T. L. Wheeler. Effects of feeding dry-rolled corn based diets with and without wet distillers with solubles and zilpaterol hydrochloride on performance, carcass characteristics, and heat stress in finishing beef steers. J. Anim. Sci. 92:4023-4033.

Macia-Cruz, U., F. D. Alvarez-Valenzuela, N. G. Torrentera-Olivera, J. V. Velazquez-Morales, A. Correa-Calderon, P. H. Robinson, L. Avendano-Reyes. 2010. Effect of zilpaterol hydrochloride on feedlot performance and carcass characteristics of ewe lambs during heat-stress conditions. Animal Production Science. 50,10: 983-989.

Mader, T. L. 2002. Body Temperature in feedlot cattle. J.Anim. Sci, 81(E. Suppl. 2): E110-E119.

Mader, T. L., L. J. Johnson, and J. B. Gaughan. 2010. A comprehensive index for assessing environmental stress in animals. J.Anim. Sci. 88.6:2153-2165.

Mader, T. L., M. S. Davis, and J. B. Gaughan. 2006. Effect of sprinkling on feedlot microclimate and cattle behavior. Int J Biometerorol. 51:541-551.

Mader, T. L., M. S. Davis, and T. Brown-Brandl. 2006a. Environmental factors influencing heat stress in feedlot cattle. J. Anim. Sci. 84:712-719.

Mader, T. L., W. M. Kreikemeier. 2006b. Effects of growth-promoting agents and season on blood metabolites and body temperature in heifers. J. Anim. Sci. 84:1030-1037.

Maxwell, C. L. 2014. Advantages of technology use in beef production systems. PhD Diss. Oklahoma State Univ., Stillwater.

Maxwell, C. L., B. C. Bernhard, C. F. O'Neill, B. K. Wilson, C. G. Hixon, C. L. Haviland, A. N. Grimes, M. S. Calvo-Lorenzo, D. L. VanOverbeke. G. G. Mafi, C. J. Richards, D. L. Step, B. P. Holland, and C. R. Krehbiel. (2015). The effects of technology use in feedlot production systems on feedlot performance and carcass characteristics. J. Anim. Sci. 2015. 93:1340-1349.

Montgomery, J. L., C. R. Krehbiel, J. J. Cranston, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M.N. Streeter, D. T. Bechtol, E. Johnson, T. TerHune, and T. H. Montgomery. 2009. Dietary zilpaterol hydrochloride. I. Feedlot performance and carcass traits of steers and heifers. J. Anim. Sci. 87:1374-1383.

Parr, S. L., K. Y. Chung, M. L. Galyean, J. P. Hutcheson, N. DiLorenzo, K. E. Hales, M. L. May, M. J. Quinn, D. R. Smith, and B. J. Johnson. 2011. Performance of finishing beef steers in reponse to anabolic implant and zilpaterol hydrochloride supplementation. J. Anim. Sci. 89:560-570.

Rathmann, R. J., B. C. Bernhard, R. S. Swingle, T. E. Lawerence, W. T. Nichols, D. A. Yates, J. P. Hutcheson, M. N. Streeter, J. C. Brooks, M. F. Miller, and B. J. Johnson. 2012. Effects of zilpaterol hydrochloride and days on the finishing diet on feedlot performance, carcass characteristics, and tenderness in beef heifers. J. Anim. Sci. 90:3301-331.

Sullivan, M. L., A. J. Cawdell-Smith, T. L. Mader, and J. B. Gaughan. 2011. Effect of shade area on performance and welfare of short-fed feedlot cattle. J. Anim. Sci. 89:2911-292.

Wahrmund, J. L. 2008. Zilpaterol hydrochloride impact on core body temperature in feedlot cattle. PhD Dissertation. Oklahoma State Univ., Stillwater OK.

Wahrmund, J. L., J. R. Ronchesel, C. R. Krehbiel, C. L. Goad, S. M. Trost, and C. J. Richards. 2012. Ruminal acidosis challenge impact on ruminal temperature in feedlot cattle. J. Anim. Sci. 90:2794-2801.

Table 3.1: Arbitrary comprehensive climate index thermal stress threshold[1]

Environment	Hot Conditions
No Stress	< 25
Mild	25 to 30
Moderate	> 30 to 35
Severe	> 35 to 40
Extreme	> 40 to 45
Extreme Danger	> 45

[1] Adapted from Mader et al. 2006.

Table 3.2: Environmental conditions for Stillwater, Oklahoma from Oklahoma Mesonet archives for Experiment 1 and Experiment 2.

	Experiment 1			Experiment 2		
Environmental Measurement	PRE[1]	ZHF[2]	POST[3]	PRE	ZHF	POST
Maximum Temperature, ºC	28.33	34.22	34.07	26.75	20.19	22.59
Maximum Humidity, %	97.14	87.36	84.67	96.43	94.43	95.00
Average Wind Speed, kmph	8.19	8.21	8.21	25.31	10.60	11.75
Solar Radiation, MJ/m^2	20.83	22.17	20.88	18.19	12.60	7.45
Average Rain Fall, cm	0.66	0.00	0.00	0.30	1.06	0.25
Average CCI[4]	25.75	29.79	28.86	19.03	10.97	17.43
Maximum CCI	36.48	40.79	40.60	31.12	22.17	23.47

[1] 7 days before the feeding of zilpaterol hydrochloride.

[2] 20 days of feeding zilpaterol hydrochloride.

[3] 3 days of withdrawal from zilpaterol hydrochloride. [4] Dates are August 18 to September 12, 2013.

[4] Comprehensive climate index thermal threshold classification: No stress <25; Mild 25 to 30; Moderate > 30 to 35; Severe > 35 to 40; Extreme > 40 to 45; Extreme danger > 45. Adapted from Mader et al. 2006.

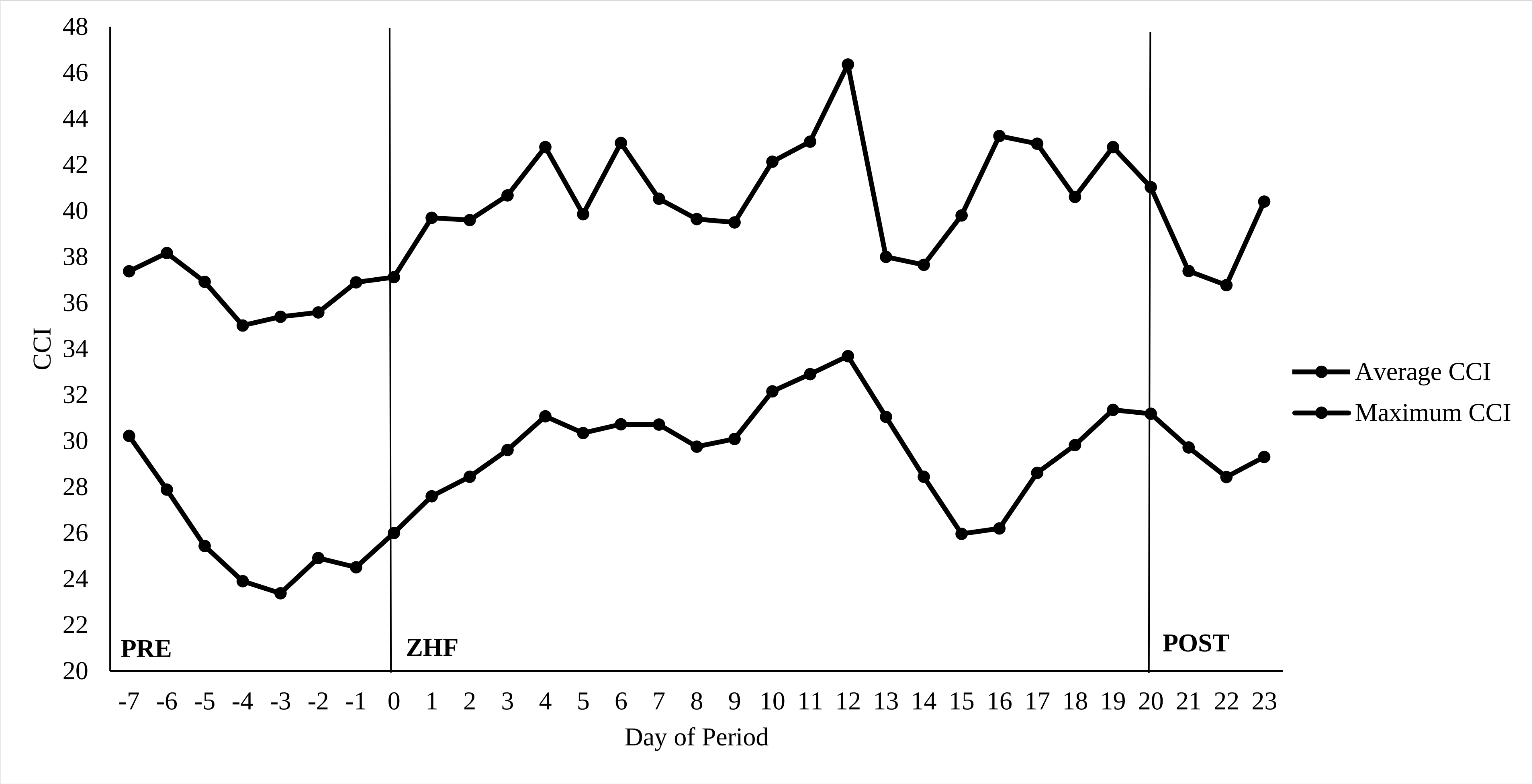

Figure 3.1: Average and maximum comprehensive climate index[1] (CCI) values (°C) for Stillwater Oklahoma from Oklahoma Mesonet for Experiment 1.

[1] Comprehensive climate index thermal threshold classification: No stress <25; Mild 25 to 30; Moderate > 30 to 35; Severe > 35 to 40; Extreme > 40 to 45; Extreme danger > 45. Adapted from Mader et al. 2006. PRE: Day -7 to 0: 7 days before the feeding of zilpaterol hydrochloride. ZHF: Day 1 to 21: 20 days of feeding zilpaterol hydrochloride. POST: Day 22 to 23: 3 days of withdrawal from zilpaterol hydrochloride. Period dates are August 18 to September 12, 2013

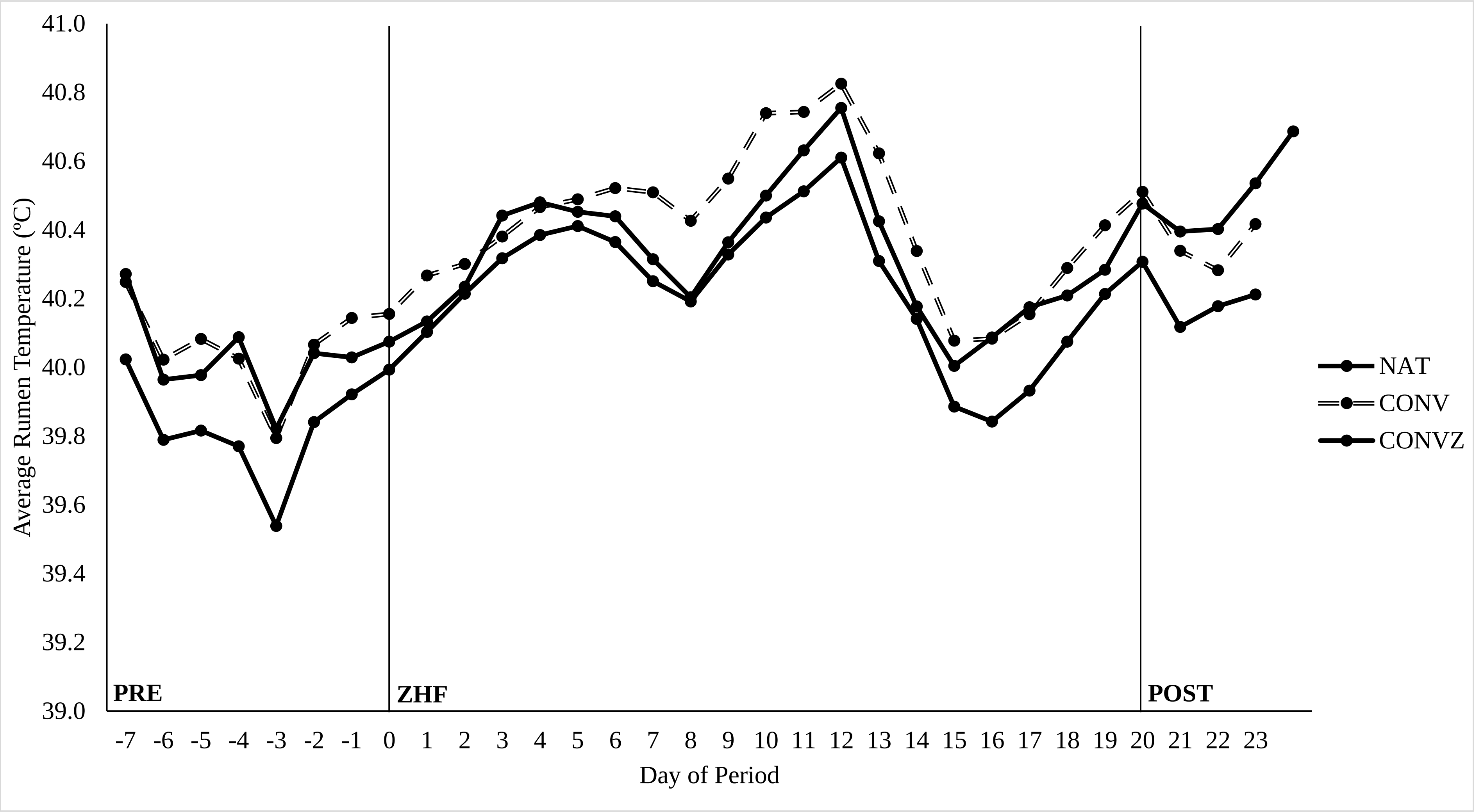

Figure 3.2: Average daily rumen temperatures (°C) by production system for Experiment 1.
Period *P* < 0.001. Production system *P* < 0.001. Production system × Period *P* = 0.02. SE = 0.07. NAT: Natural steers did not receive growth promoting technologies during feeding period. CONV: Conventional steers received an implant upon arrival and monensin and tylosin daily. CONVZ: Conventional with zilpaterol hydrochloride steers received an implant upon arrival, monensin and tylosin daily, and zilpaterol hydrochloride 20 days before harvest. PRE: Day -7 to 0: 7 days before the feeding of zilpaterol hydrochloride. ZHF: Day 1 to 20: 20 days of feeding zilpaterol hydrochloride. POST: Day 21 to 23: 3 days of withdrawal from zilpaterol hydrochloride.

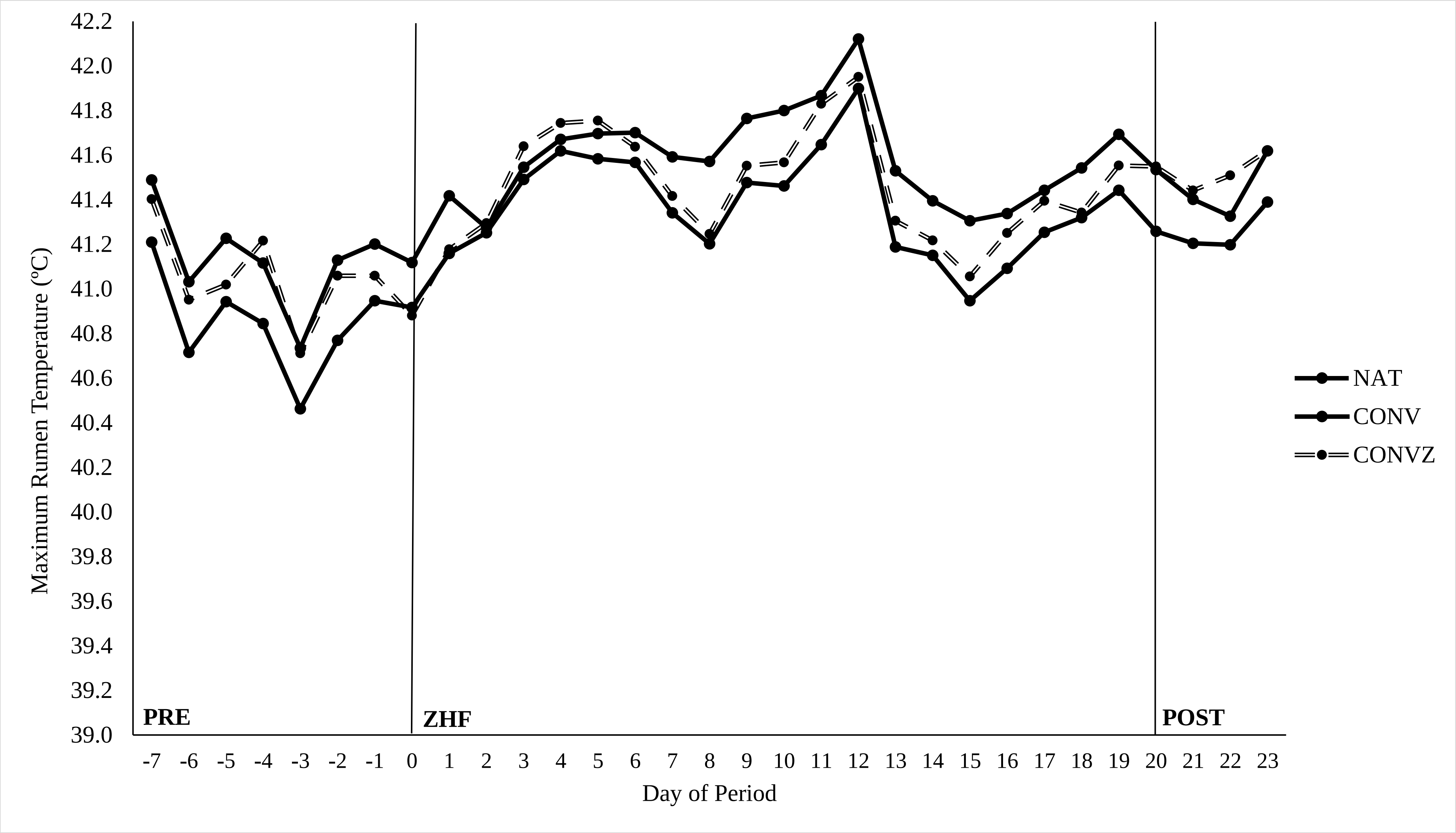

Figure 3.3: Maximum daily rumen temperatures (°C) by production system for Experiment 1.

Period *P* < 0.001. Production system *P* < 0.001. Production system x Period *P* = 0.12.SE = 0.07. Production systems include; NAT: Natural steers did not receive growth promoting technologies during feeding period; CONV: Conventional steers received an implant upon arrival and monensin and tylosin daily; CONVZ: Conventional with zilpaterol hydrochloride steers received an implant upon arrival, monensin and tylosin daily, and zilpaterol hydrochloride 20 days before harvest. PRE: Day -7 to 0: 7 days before the feeding of zilpaterol hydrochloride. ZHF: Day 1 to 21: 20 days of zilpaterol hydrochloride feeding period. POST: Day 21 to 23: 3 days of withdrawal from zilpaterol hydrochloride.

Table 3.3: Average and maximum period rumen temperature (ºC) and area under the curve for steers in 3 production systems (PS) in Experiment 1.

	Period												
	PRE[1]			ZHF[2]			POST[3]				*P* Values		
Measurement	NAT[4]	CONV[5]	CONVZ[6]	NAT	CONV	CONVZ	NAT	CONV	CONVZ	SEM	PS	Period	PS × Period
Pens, n	6	6	6										
Steers, n	36	36	36										
Rumen Temperature													
Average	39.80	40.23	40.21	40.05	40.43	40.40	40.05	40.33	40.51	0.07	<0.001	<0.001	0.02
Maximum	40.83	41.34	41.09	41.13	41.57	41.32	41.08	41.45	41.40	0.07	<0.001	<0.001	0.12
AUC[7]													
Above 38.61ºC	32.16	35.73	37.31	35.12	37.42	33.21	33.31	35.81	32.69	1.16	0.21	<0.001	0.02
Below 38.61ºC[8]	7.62	4.84	3.52	4.63	3.01	2.49	6.16	4.46	2.48	0.79	<0.001	<0.001	0.11
Daily Drinks, n[9]	7.25	4.86	4.90	5.10	3.67	3.86	4.07	2.89	2.49	0.52	<0.001	<0.001	0.11

[1] 7 d period before feeding of zilpaterol hydrochloride.

[2] 20 d zilpaterol hydrochloride feeding period.

[3] 3 d withdrawal period after feeding of zilpaterol hydrochloride.

[4] Natural: steers did not receive growth promoting technologies throughout feeding period.

[5] Conventional: steers received an implant upon arrival and monensin and tylosin daily.

[6] Conventional with zilpaterol hydrochloride: steers received an implant upon arrival, monensin and tylosin daily, and zilpaterol hydrochloride before harvest.

[7] Area under the curve. Calculated using the equation (time was converted to Julianne time for calculation): Total AUC = Time Difference (minute) * (Current Temperature (ºC)) + Previous Temperature (ºC))/2. A baseline temperature of 38.61ºC was used.

[8] AUC drinks calculated subtracting area below 38.61ºC assumed to be associated water drinking events.

[9] Average daily drinks.

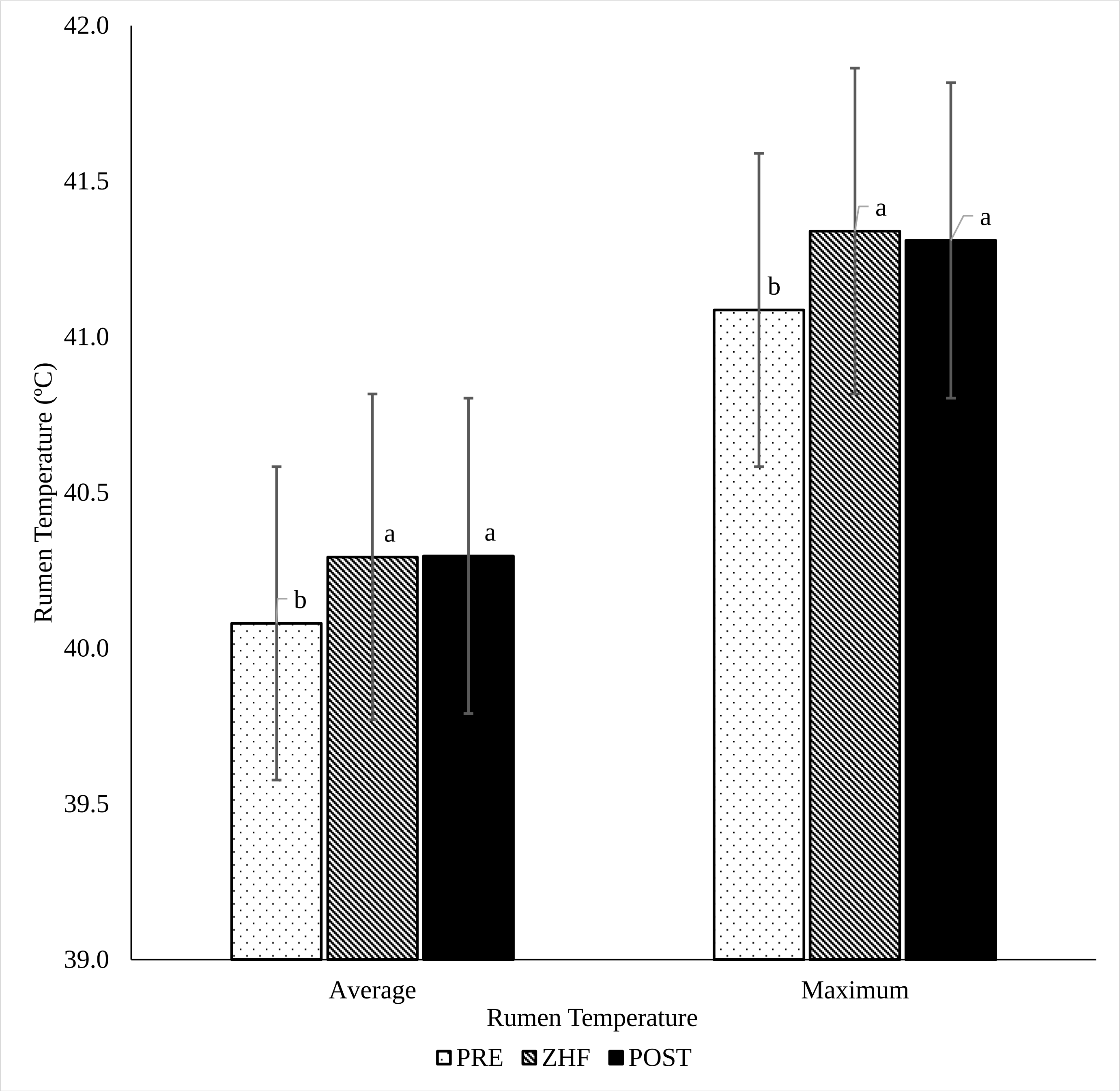

Figure 3.4: Period average and maximum rumen temperatures for Experiment 1 thirty days before harvest.

^{a,b,c} Superscripts with unique superscripts differ when $P < 0.01$.

Average: Period $P < 0.001$. SE = 0.07. Maximum: Period $P < 0.001$. SE = 0.07. PRE: 7 days before feeding zilpaterol hydrochloride. ZHF: 20 days of the feeding of zilpaterol hydrochloride. POST: 3 day withdrawal from zilpaterol hydrochloride.

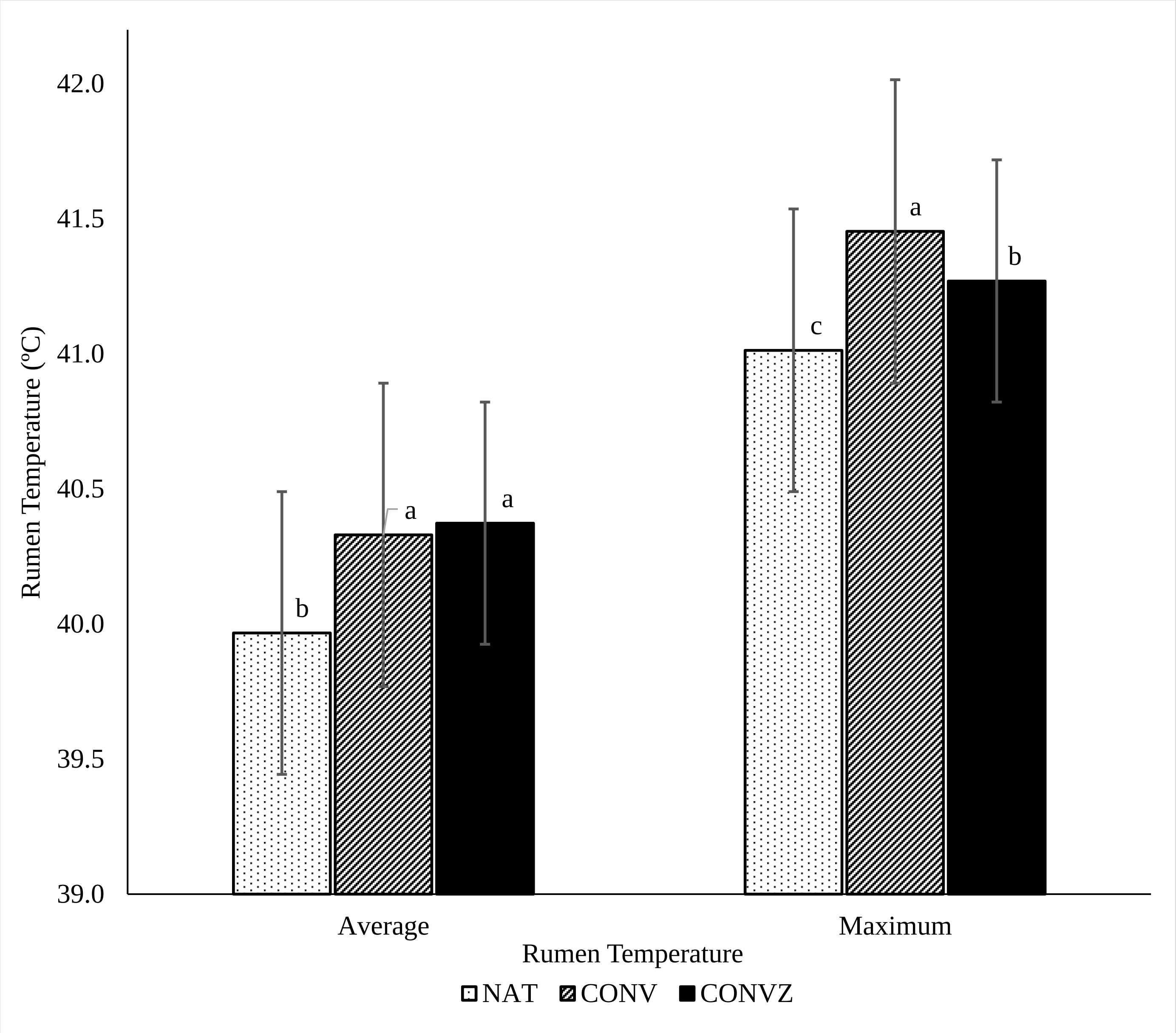

Figure 3.5: Production system average and maximum rumen temperatures for Experiment 1 thirty days before harvest.

^{a,b,c} Superscripts with unique superscripts differ when $P < 0.01$.

Average: Production system $P < 0.001$. SE = 0.07. Maximum: Production system $P < 0.001$. SE = 0.07. NAT: Natural steers did not receive growth promoting technologies. CONV: Conventional steers received an implant on arrival and were fed monensin and tylosin daily. CONVZ: Conventional with zilpaterol hydrochloride steers received an implant on arrival, were fed monensin and tylosin daily, and were fed zilpaterol hydrochloride before harvest.

Table 3.4: Average and maximum AM[1] and PM[2] panting scores[3] and respiration rates[4] by production system (PS) in Experiment 1.

	Period									
	ZHF[5]			POST[6]				*P*-Value		
Measurement	NAT[7]	CONV[8]	CONVZ[9]	NAT	CONV	CONVZ	SEM	PS	Period	PS × Period
AM Panting Score										
Average	1.08	1.01	1.24	1.08	0.97	1.17	0.14	0.23	0.68	0.94
Maximum	1.63	1.63	1.83	1.67	1.33	1.67	0.25	0.47	0.29	0.61
PM Panting Score										
Average	1.80	1.68	1.84	1.42	1.51	1.82	0.13	0.03	0.01	0.18
Maximum	2.30	2.20	2.45	2.00	2.17	2.33	0.22	0.33	0.25	0.69
AM Respiration Rate, bpm										
Average	70.60	74.80	65.48	71.48	76.20	67.48	0.91	0.02	0.49	0.97
Maximum	85.48	91.88	80.36	83.72	94.28	80.88	1.72	0.08	0.92	0.92
PM Respiration Rate, bpm										
Average	57.60	60.06	57.20	66.00	71.56	63.76	0.65	<0.001	<0.001	0.40
Maximum	68.08	73.96	70.96	75.76	94.60	79.24	1.23	0.01	<0.001	0.12

[1] Every other day of the ZHF and POST at 1000h.

[2] Every other day of the ZHF and POST at 1700h.

[3] Panting scores were assigned every other day using a 0 to 4 scoring system. 0 - normal respiration, 1 - elevated respiration, 2 - moderate panting and/or presence of drool or small amount of saliva, 3 - Heavy open mouth panting, saliva usually present, 4 - Severe open-mouth panting accompanied by protruding tongue and excessive salivation; usually with neck extended forward. Panting score adapted from Mader et al., 2006.

[4] Respiration rates were assigned individually every other day by observation of flank movement for 30 seconds and multiplied by 2.

[5] 20 days of zilpaterol hydrochloride feeding.

[6] 3 day withdrawal after zilpaterol hydrochloride feeding.

[7] Natural steers did not receive growth promoting technologies throughout the feeding period.

[8] Conventional steers received an implant at arrival and monensin and tylosin daily.

[9] Conventional with zilpaterol hydrochloride steers received an implant at arrive, monensin and tylosin daily, and zilpaterol hydrochloride before harvest.

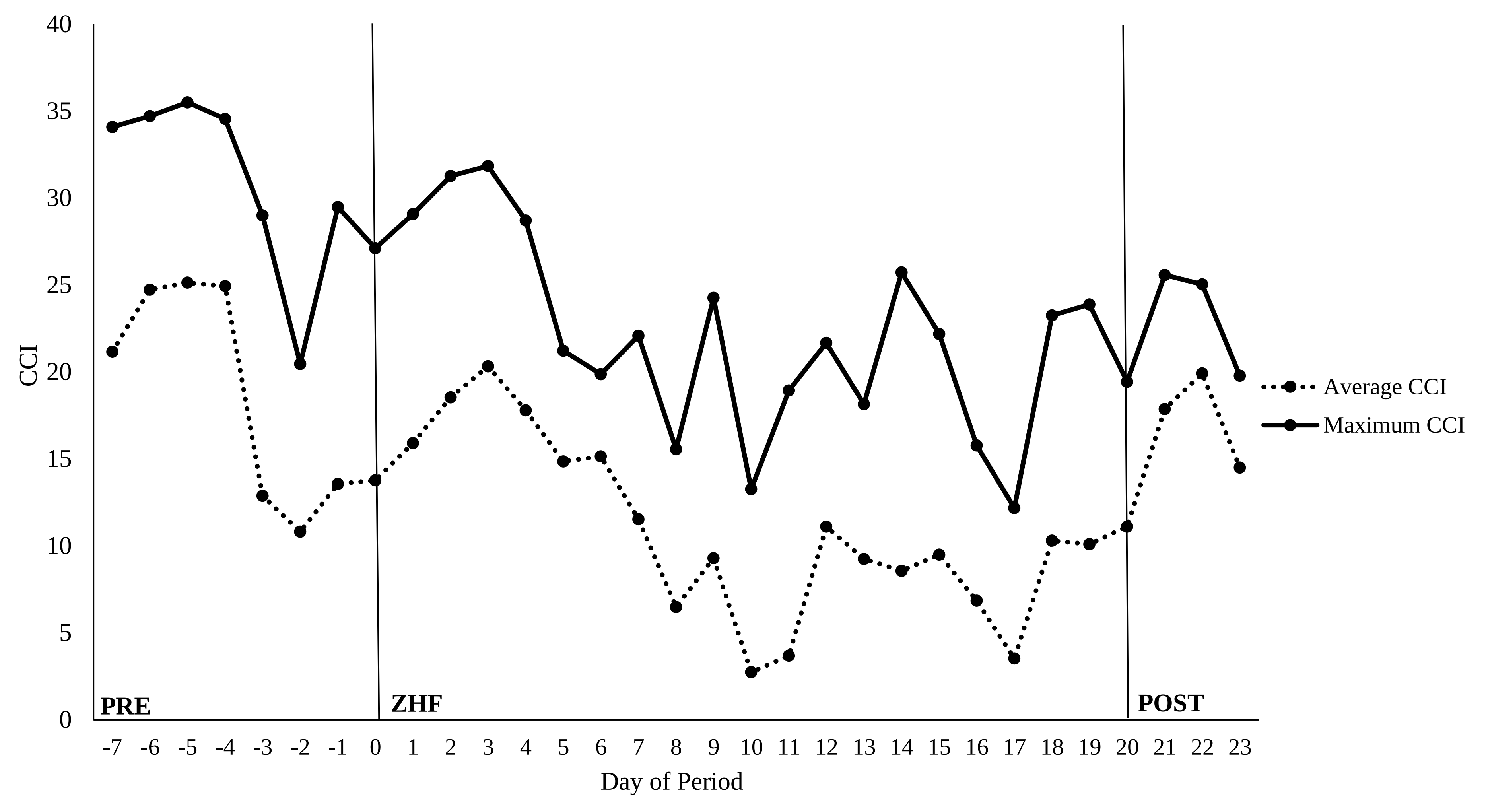

Figure 3.6: Average and maximum comprehensive climate index[1] (CCI) values (°C) for Stillwater Oklahoma from Oklahoma Mesonet for Experiment 2.

[1] Comprehensive climate index thermal threshold classification: No stress <25; Mild 25 to 30; Moderate > 30 to 35; Severe > 35 to 40; Extreme > 40 to 45; Extreme danger > 45. Adapted from Mader et al. 2006. PRE: Day -7 to 0: 7 days before the feeding of zilpaterol hydrochloride. ZHF: Day 1 to 21: 20 days of feeding zilpaterol hydrochloride. POST: Day 22 to 23: 3 days of withdrawal from zilpaterol hydrochloride. Period dates are October 1 - 31, 2013.

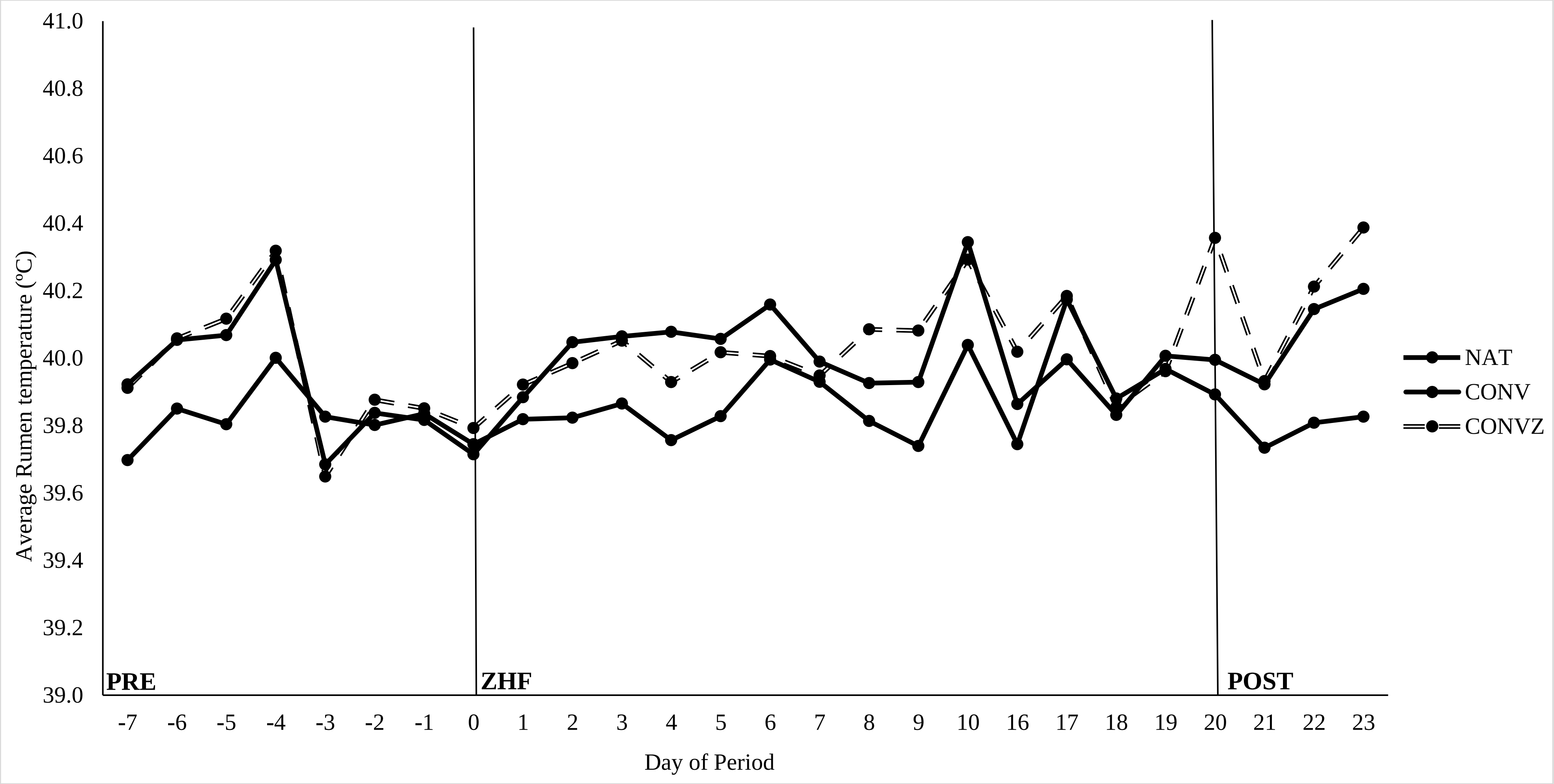

Figure 3.7: Average daily rumen temperatures (°C) by production system in Experiment 2.

Period *P* = 0.07. Production system *P* < 0.001. Production system x Period *P* = 0.05. SE = 0.07. NAT: Natural steers did not receive growth promoting technologies during feeding period. CONV: Conventional steers received an implant upon arrival and monensin and tylosin daily. CONVZ: Conventional with zilpaterol hydrochloride steers received an implant upon arrival, monensin and tylosin daily, and zilpaterol hydrochloride 20 days before harvest. PRE: Day -7 to 0: 7 days before the feeding of zilpaterol hydrochloride. ZHF: Day 1 to 21: 20 days of zilpaterol hydrochloride feeding period. POST: Day 21 to 23: 3 days of withdrawal from zilpaterol hydrochloride.

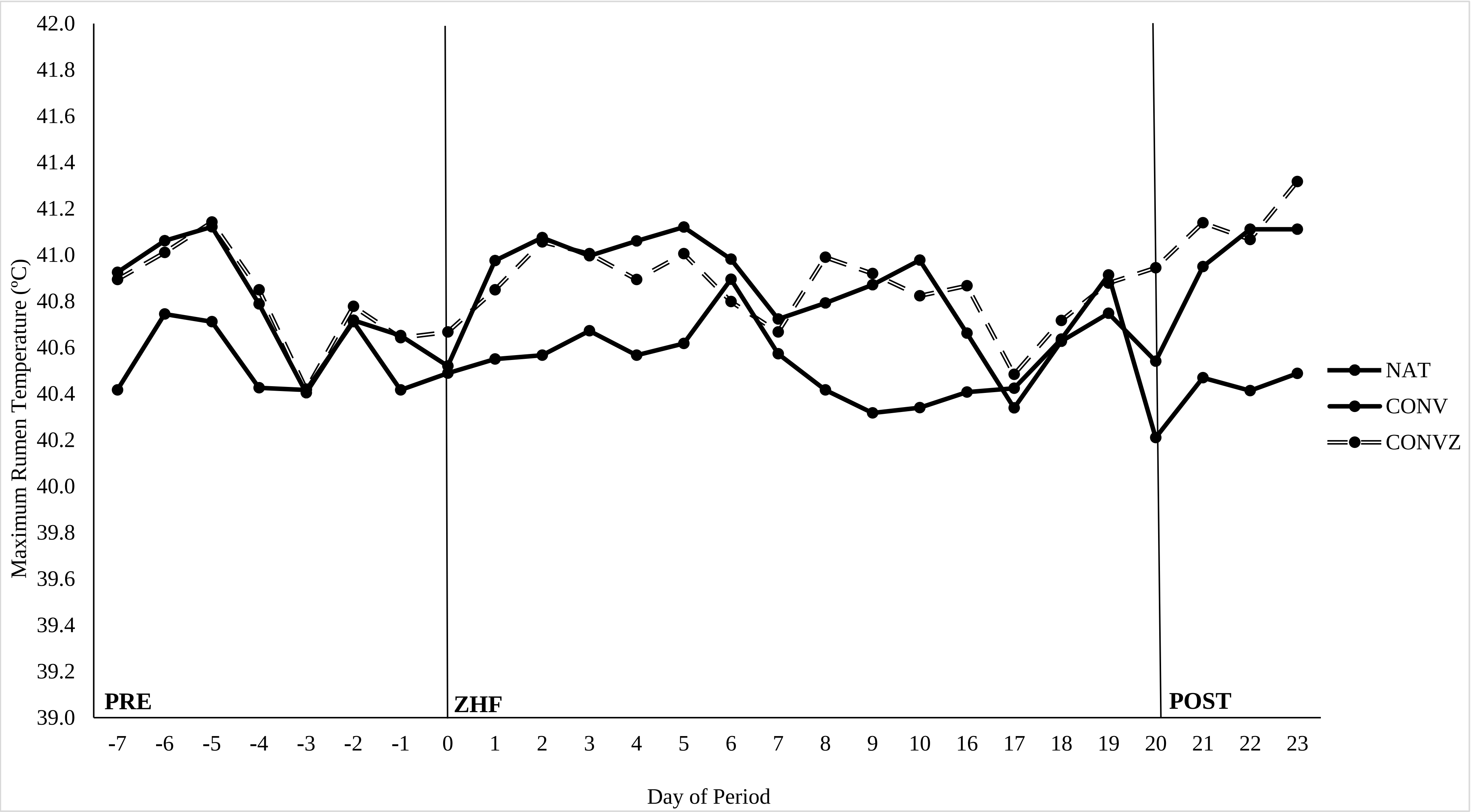

Figure 3.8: Maximum daily rumen temperatures (°C) by production system[1] in Experiment 2.

Period $P = 0.18$. Production system $P < 0.001$. Production system x Period $P = 0.02$. SE = 0.09. NAT: Natural steers did not receive growth promoting technologies during feeding period. CONV: Conventional steers received an implant upon arrival and monensin and tylosin daily. CONVZ: Conventional with zilpaterol hydrochloride steers received an implant upon arrival, monensin and tylosin daily, and zilpaterol hydrochloride 20 days before harvest. PRE: Day -7 to 0: 7 days before the feeding of zilpaterol hydrochloride. ZHF: Day 1 to 21: 20 days of zilpaterol hydrochloride feeding period. POST: Day 21 to 23: 3 days of withdrawal from zilpaterol hydrochloride.

Table 3.5: Average and maximum period temperature (ºC) and calculated area under the curve by production system (PS) for Experiment 2 .

	Period												
	PRE[1]			ZHF[2]			POST[3]				*P* Values		
Measurement	NAT[4]	CONV[5]	CONVZ[6]	NAT	CONV	CONVZ	NAT	CONV	CONVZ	SEM	PS	Period	PS × Period
Pens, n	12	10	11										
Steers, n	2	2	2										
Rumen Temperature													
Average	39.97	39.99	40.06	39.84	39.87	39.80	39.97	40.03	40.26	0.07	<0.001	0.07	0.05
Maximum	40.83	40.81	40.99	40.57	40.52	40.35	40.82	40.85	41.18	0.09	<0.001	0.18	0.02
AUC[7]													
Above 38.61ºC	35.44	43.94	37.20	35.06	41.69	25.94	34.46	44.39	28.14	2.92	0.54	<0.001	0.87
Below 38.61ºC[8]	4.07	4.31	3.81	5.46	3.88	3.90	5.33	3.85	1.80	1.06	0.30	0.28	0.63
Drinks, n[9]	5.72	4.92	5.91	5.53	4.52	5.51	6.19	4.00	4.23	0.98	0.08	0.56	0.73

[1] 7 d period before feeding of zilpaterol hydrochloride.

[2] 20 d zilpaterol hydrochloride feeding period.

[3] 3 d withdrawal period after feeding of zilpaterol hydrochloride.

[4] Natural: steers did not receive growth promoting technologies throughout feeding period.

[5] Conventional: steers received an implant upon arrival and monensin and tylosin daily.

[6] Conventional with zilpaterol hydrochloride: steers received an implant upon arrival, monensin and tylosin daily, and zilpaterol hydrochloride before harvest.

[7] Area under the curve. Calculated using the equation (time was converted to Julianne time for calculation): Total AUC = Time Difference (minute) * (Current Temperature (ºC)) + Previous Temperature (ºC))/2. A baseline temperature of 38.61ºC was used.

[8] AUC drinks calculated subtracting area below 38.61ºC assumed to be associated water drinking events.

[9] Average daily drinks.

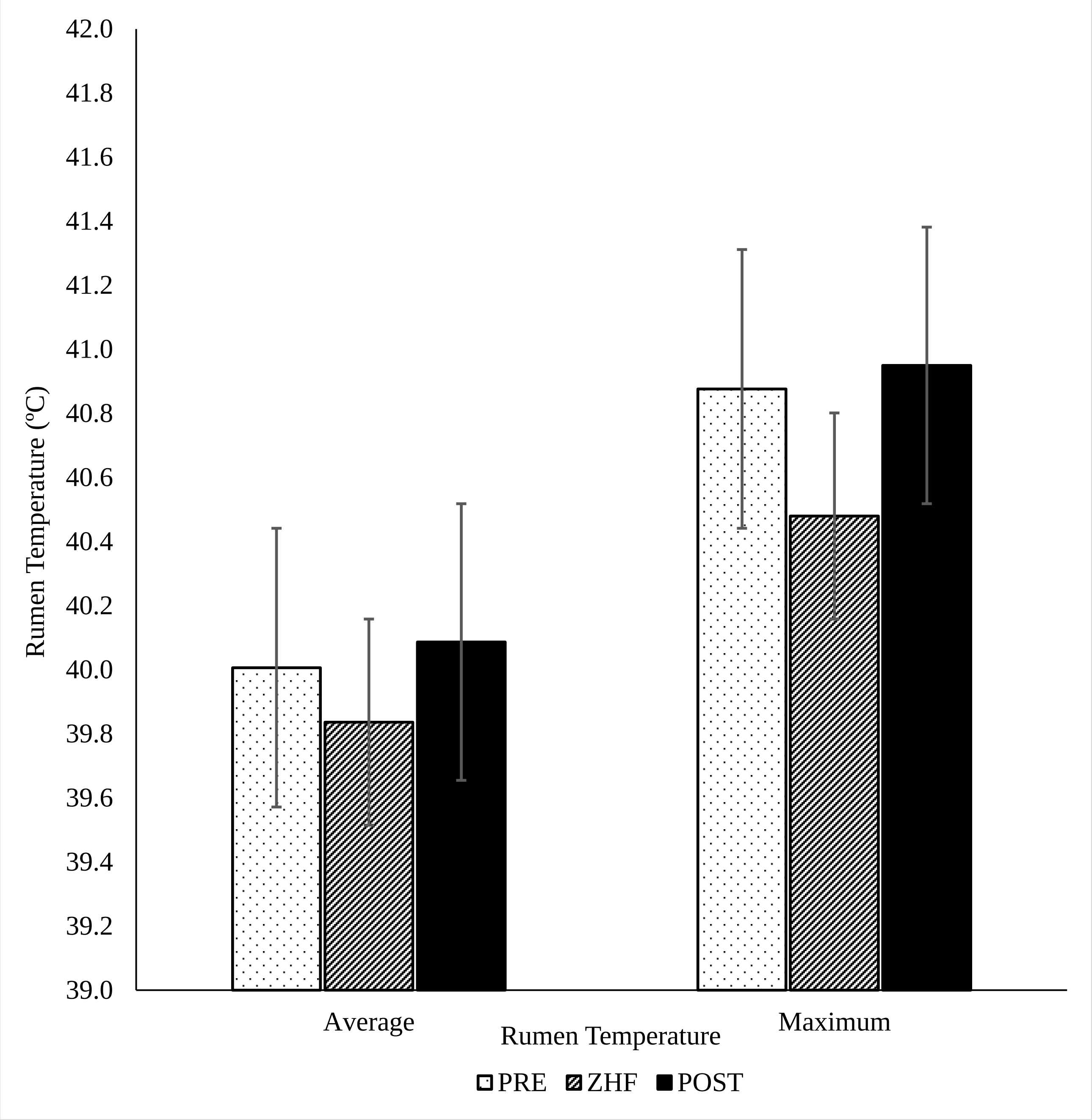

Figure 3.9: Period average and maximum rumen temperature for Experiment 2 thirty days before harvest.

Average: Period *P* = 0.07 SE = 0.07. Maximum: Period *P* = 0.18 SE = 0.09. PRE: 7 days before feeding zilpaterol hydrochloride. ZHF: 20 days of the feeding of zilpaterol hydrochloride. POST: 3 day withdrawal from zilpaterol hydrochloride.

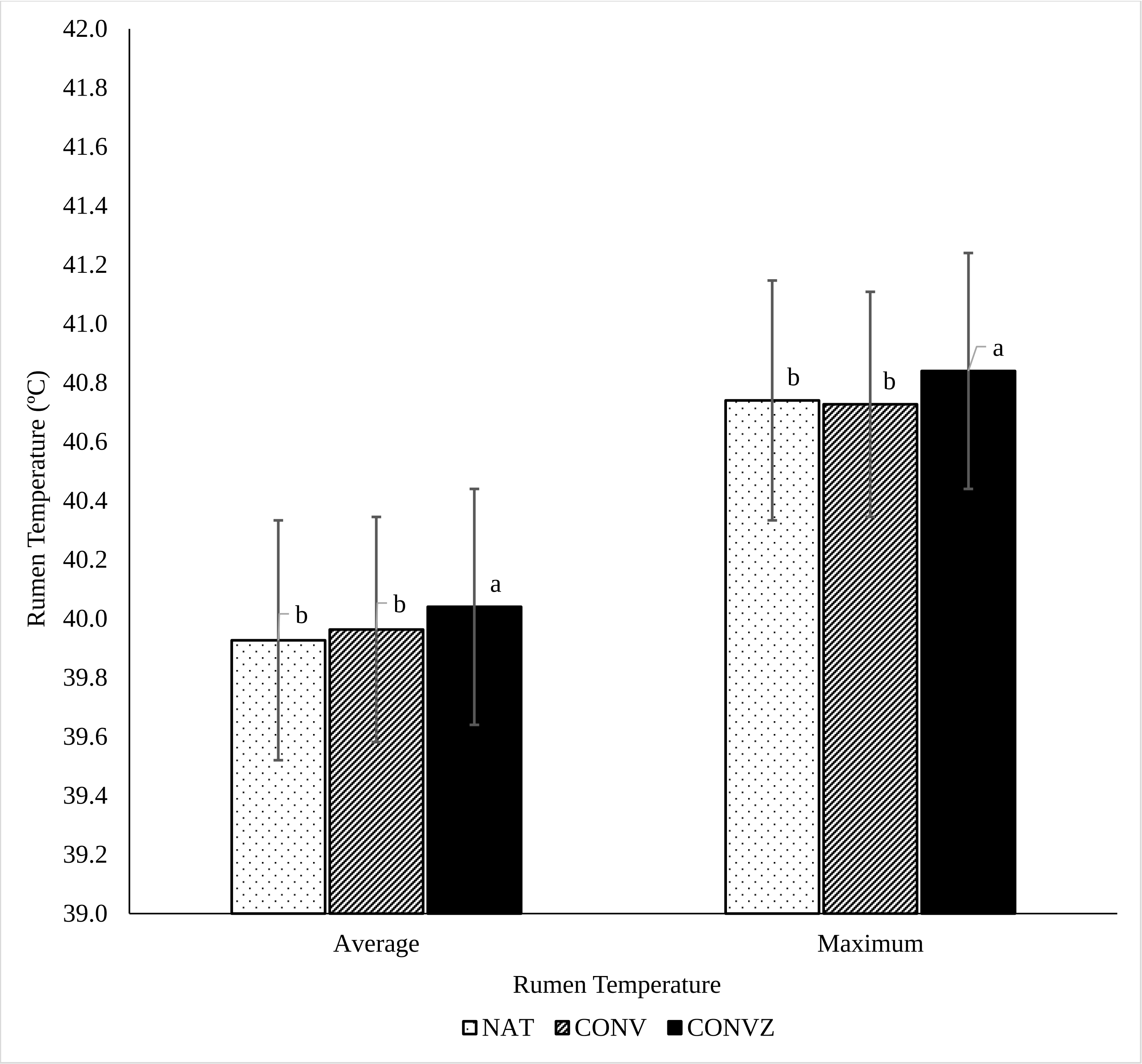

Figure 3.10: Production system average and maximum rumen temperatures for Experiment 2 thirty days before harvest.

^{a,b,c} Superscripts with unique superscripts differ when $P < 0.01$.

Average: Production system $P < 0.001$ SE = 0.07. Maximum: Production system $P < 0.001$ SE = 0.09. NAT: Natural steers did not receive growth promoting technologies. CONV: Conventional steers received an implant on arrival and were fed monensin and tylosin daily. CONVZ: Conventional with zilpaterol hydrochloride steers received an implant on arrival, were fed monensin and tylosin daily, and were fed zilpaterol hydrochloride before harvest.

Table 3.6: Average and maximum AM[1] and PM[2] panting scores[3] and respiration rates[4] by production system (PS) for Experiment 2.

	Period									
	ZHF			POST				*P* Value		
Measurement	NAT[7]	CONV[8]	CONVZ[9]	NAT	CONV	CONVZ	SEM	PS	Period	PS x Period
AM Panting Score										
Average	0.16	0.17	0.30	0.04	0.12	0.04	0.05	0.52	0.01	0.24
Maximum	0.27	0.18	0.59	0.25	0.14	0.25	0.23	0.61	0.09	0.35
PM Panting Score										
Average	0.13	0.04	0.26	0.08	0.01	0.27	0.14	0.38	0.71	0.92
Maximum	0.44	0.06	0.56	0.50	0.02	0.75	0.25	0.32	0.66	0.78
AM Respiration Rate, bpm										
Average	60.88	66.46	55.44	53.56	58.58	50.98	1.30	0.15	0.01	0.57
Maximum	73.64	81.62	69.94	61.56	71.20	57.96	2.32	0.11	0.01	0.91
PM Respiration Rate, bpm										
Average	55.00	65.49	50.90	55.58	67.44	48.70	2.54	0.06	0.96	0.82
Maximum	66.58	77.70	60.64	73.88	87.80	59.14	3.19	0.01	0.18	0.46

[1] Every other day of the ZHF and POST at 1000h.

[2] Every other day of the ZHF and POST at 1700h.

[3] Panting scores were assigned every other day using a 0 to 4 scoring system. 0 - normal respiration, 1 - elevated respiration, 2 - moderate panting and/or presence of drool or small amount of saliva, 3 - Heavy open mouth panting, saliva usually present, 4 - Severe open-mouth panting accompanied by protruding tongue and excessive salivation; usually with neck extended forward. Panting score adapted from Mader et al., 2006.

[4] Respiration rates were assigned individually every other day by observation of flank movement for 30 seconds then multiplied by 2 for breaths per minute.

[5] 20 days of zilpaterol hydrochloride feeding.

[6] 3 day withdrawal after zilpaterol hydrochloride feeding.

[7] Natural steers did not receive growth promoting technologies throughout the feeding period.

[8] Conventional steers received an implant at arrival and monensin and tylosin daily.

[9] Conventional with zilpaterol hydrochloride steers received an implant at arrive, monensin and tylosin daily, and zilpaterol hydrochloride before harvest.

Table 3.7: Feedlot performance by production system (PS) Experiment 1 and Experiment 2.

Measurement	PS				
Experiment 1[1]	NAT[3]	CONV[4]	CONVZ[5]	SEM	*P*-value
Pens, n	6	6	6		
Steers, n	84	84	84		
BW, kg					
Arrival	386	386	386	9	0.99
Start ZH[6]	527^b	568^a	565^a	8	<0.01
Final	556^b	606^a	606^a	8	<0.01
ADG, kg/d					
Pre ZH Feeding[7]	1.25^b	1.72^a	1.72^a	0.05	<0.01
ZH Feeding[8]	0.85^c	1.60^b	1.70^a	0.17	<0.01
Arrival to Final[9]	1.23^b	1.75^a	1.75^a	0.05	0.01
Experiment 2[2]					
Pens, n	2	2	2		
Steers, n	28	28	28		
BW, kg					
Arrival	357	358	358	9	0.99
Start ZH	526	573	596	16	0.12
Final	548	620	629	14	0.05
ADG, kg/d					
Pre ZH Feeding[6]	1.05	1.44	1.34	0.05	0.04
ZH Feeding[7]	1.12^c	1.52^b	1.61^a	0.04	<0.01
Arrival to Final[8]	1.11^c	1.47^b	1.59^a	0.05	0.01

[a,b,c] Values within a row with unique superscripts differ $P < 0.01$.

[1] Experiment 1: Started zilpaterol hydrochloride on August 18, 2013 and were harvested September 12, 2013. Were fed 125 days.

[2] Experiment 2: Started zilpaterol hydrochloride on October 7, 2013 and were harvested October 31, 2013. Were fed 173 days.

[3] Natural steers did not receive growth promoting technologies throughout the feeding period.

[4] Conventional steers received an implant at arrival and monensin and tylosin daily.

[5] Conventional with zilpaterol hydrochloride steers received an implant at arrival, monensin and tylosin daily, and zilpaterol hydrochloride before harvest.

[6] Day 0 of zilpaterol hydrochloride feeding period.

[7] Arrival to start of zilpaterol hydrochloride feeding period.

[8] Start of zilpaterol hydrochloride feeding period to the end of the feeding period.

[9] Arrival to final.

Table 3.8: Ingredient composition (% DM basis) of diets fed[1]

	Experimental diet	
Ingredient	NAT	CONV-Z
Dry-rolled corn	47.86	47.84
Switchgrass hay	6.88	6.88
Dried distillers grains	14.60	14.60
Sweet Bran®	15.15	15.15
Liquid supplement	10.37	10.37
Dry supplement, B-272[2]	5.14	-
Dry supplement, B-273[3]	-	5.17

[1] Actual DM formulation calculated based upon As-Is formulations and weekly ingredient DM values.

[2] Formulated to contain (DM basis): 6.92% urea, 29.86% limestone, 1.03% MgO, 0.38% salt, 0.119% copper sulfate, 0.117% MnO, 0.05% selenium premix (0.6% Se), 0.618% $ZnSO_4$, 0.311% vitamin A (30 IU/mg), 0.085% vitamin E (500 IU/g), 0% Rumensin 90, 0% Tylan 40, 39.46% ground corn and 21.04% wheat middlings.

[3] Formulated to contain (DM basis): 6.92% urea, 30.36% limestone, 1.03% MgO, 0.38% salt, 0.119% copper sulfate, 0.116% MnO, 0.05% selenium premix (0.6% Se), 0.618% ZnSO4, 0.311% vitamin A (30 IU/mg), 0.085% vitamin E (500 IU/g), 0.317% Rumensin 90, 0.195% Tylan 40, 38.46% ground corn and 21.04% wheat middlings.

[4] Conventional w/ Zilmax contained 6.76 mg/kg (90% DM basis) fed last 20 DOF with a 3 d withdrawal.

Table adapted from Maxwell (2014).

CHAPTER IV

EFFECT OF HOUSING ON BODY TEMPERATURE, PERFORMANCE, AND CARCASS CHARACTERISTICS OF BLACK-HIDED FEEDLOT STEERS IN TWO PRODUCTION SYSTEMS

Abstract:

The objective of this study was to determine the effect of housing, indoor/outdoor and outdoor, on body temperature, performance, and carcass characteristics of black-hided feedlot steers in 2 production systems during an 84 d feeding period. Steers were used for a randomized complete block design experiment with a 2 x 2 PS structure including 1 of 2 production systems (**PS**); natural (**NAT**; did not receive growth promoting technologies) and conventional (**CONV**; received growth promoting technologies) and sorted based on BW to 1 of 2 housings; indoor/outdoor facility (**SHADE**) with 55 steers (28 steers/treatment; initial BW 384 ± 2 kg) or open air feedlot pens (**NOSHADE**) with 54 steers (27 steers/treatment; initial BW 392 ± 2 kg). The feeding period was broken into monthly periods, d 1 to 11 (**MAY**), d 12 to 41 (**JUN**), d 42 to 72 (**JUL**), and d 73 to 84 (**AUG**). Performance was broken into 28-d weigh periods for BW and ADG. Carcass characteristics included HCW, dressing percentage, marbling score, and longissimus area. Average and maximum air temperatures, solar radiation, and comprehensive climate index was greatest for JUL and AUG with a range between mild to severe. There was not a PS effect on average and maximum T_{rum} ($P \geq 0.11$); NAT NOSHADE had lower maximum T_{rum} and CONV NOSHADE had the highest in JUL ($P < 0.001$). Conventional steers had increased BW gain and ADG over the NAT throughout the feeding period ($P = 0.01$); there was a tendency for shade to have an effect on final BW ($P = 0.02$) but no effect on overall ADG ($P = 0.35$). There was no effect on carcass characteristics with the addition of shade but CONV steers had increased HCW, dressing percentage, and longissimus area and NAT steers had the advantage in marbling scores ($P < 0.001$). It appears that with the addition of shade it did not seem to favor one PS but was beneficial to decreasing maximum T_{rum} throughout the periods. The CONV PS was beneficial for improving BW, ADG, HCW, dressing percentage, and longissimus area but PS did not seem to effect body temperature.

KEYWORDS

bovine, feedlot, days on feed, rumen temperature, natural, conventional

INTRODUCTION

With increased environmental temperatures over an extended period of time, heat stress can occur when an animal cannot effectively control their body heat load. Providing shade during the feeding period can help by decreasing solar radiation exposure and can positively impact performance and overall well-being (Blaine and Nsahlai, 2010; and Sullivan et al., 2011). Not providing shade to cattle in high heat environments has a negative impact on respiration rates, feed intake, body temperature regulation, and can lead to death (Mader et al., 2006; Blaine et al., 2010; and Mader 2002).

High solar radiation, humidity, air temperature, and wind speed are a few of the environmental factors that influence heat stress in cattle. A comprehensive climate index (**CCI**) has been created to take into consideration environmental factors that cattle are effected by on a daily basis and creates a ‘real-feel’ temperature adjustment (Mader et al., 2010; Table 4.1). A CCI listed above 40 is considered the extreme, critical threshold and there is a higher chance for deceased discomfort, well-being, and potentially death.

The addition of growth-promoting technologies such as implants, ionophores, and low-dose antibiotic impact feedlot performance, feed intake, and efficiency (Maxwell et al, 2015; Arp et al., 2014; Montgomery et al., 2009). Ionophores and low dose antibiotics are approved for use in feedlot cattle throughout the feeding period to improve feed efficiency, preventing acidosis, and decreasing liver abscesses (Rumensin® and Tylan®, Elanco Animal Health, Greenfield, IN). There is little evidence of the impact of these technologies paired with housing on the body temperature, performance, and carcass characteristics of cattle fed in a high heat environment.

The objective of this study was to determine the effect of housing, indoor/outdoor and outdoor, on body temperature, performance, and carcass characteristics of black-hided feedlot steers in 2 production systems.

MATERIALS AND METHODS

Cattle Management

In Spring of 2013, 110 black-hided, certified natural, cross-bred steers arrived at Willard Sparks Beef Research Center in Stillwater OK and were used for a RCBD experiment with a 2x2 factorial comparing the effects of housing and production system. Fifty-five Steers were housed in open air, feedlot pens (**NOSHADE**; 28 steers/production system; 384 ± 2kg) and 54 steers housed in an outdoor/indoor facility (**SHADE**; 27 steers/production system; 392 ± 2kg).

Steers in NOSHADE were in 4 pens, that were 12.2 x 30.5 m, soil surfaced open air, feedlot pens, with 12.16 m of bunk line and 76 L fence line waterers. Water sprinkling was provided on days where the CCI was greater than 42 for NOSHADE, those days were included in the temperature data but were not further analyzed. The SHADE pens were housed in a outdoor/indoor facility with four 11.9 x 30.5 m soil surfaced feedlot pens with a solid surface, covered awning covering the feed bunks and 6.10 m of the pen. The awning was solid surfaced and did not allow solar radiation to reach the pen surface. The pens contained 6 feed bunks and 1 water bunk and were all equipped with the Insentec system (Insentec, Marknesse, the Netherlands) which has the ability to record individual animal’s daily feed and water intakes.

The two production systems (**PS**) included natural (**NAT**) and conventional (**CONV**); NAT steers did not receive an implant, ionophores, antibiotics, or beta-agonists throughout their feeding period and CONV steers were implanted upon arrival and fed an ionophore and antibiotic daily. Conventional steers were fed a beta-agonist, zilpaterol hydrochloride, for the last 20 d of the feeding period this analysis will not be included. Steers were blocked by BW such that the heaviest steers were sorted off to be house into the SHADE pens. Steers were then randomized to a production system.

The 84 d feeding period was broken into 4 monthly periods for further temperature and performance analysis. Analysis started on May 21, 2013, following training to SHADE barn and the ration transition. Periods included, d 1-11 (**MAY**), d 12-41 (**JUNE**), d 42-72 (**JULY**), and d 72-84 (**AUG**), the analysis period ended on August 18, 2013.

Steers were fed twice daily at approximately 0700h and 1300h with NAT first, CONV last to reduce supplement contamination. The finishing ration was formulated to meet the NRC requirements (2000) and consisted of dry rolled corn, dried distillers grains with solubles, wet corn gluten feed, switchgrass hay, and dry and liquid supplementation (Table 4.1; Maxwell et al., 2014). All PS received the same finishing ration with unique supplementation depending on PS; NAT steer’s supplement did not contain ionophores, antibiotics, or beta agonists; CONV steer’s supplement contained 33 mg/kg of Monensin and 9 mg/kg Tylosin (Rumensin and Tylan, respectively, Elanco Animal Health, Greenfield, IN). Conventional steers were fed the beta-agonist, zilpaterol hydrochloride, for the last 20 d of the feeding period, further analysis will not be included. All steers received a direct fed microbial daily by mixing 2.26 kg of ground corn with 1 g/hd of Bovamine (Bovamine, Nutrition Physiology Company, Guymon OK).

Feedlot Performance and Carcass Characteristics

Extended feedlot performance and carcass characteristics, including zilpaterol hydrochloride period, can be found in Maxwell et al. (2015).

All steers in pens were used for performance and carcass parameters. Steers were weighed on d 0, 28, 56, and the morning before they were shipped for harvest. A 4% pencil shrink was applied to all BW and daily gains calculations for performance.

On September 12, 2013 and September 13, 2013, CONV and NAT steers were slaughtered, respectively. The difference in slaughter dates is determined by the scheduling of the packing plant. All cattle were shipped to Creekstone Farms, in Arkansas City, KS. All cattle were weighed individually on the day of shipment and this weight will be used to determine dressing percentages. Carcass data was collected by trained Creekstone personnel using E+V vision grading camera (VBG2000, E+V Technology, Oranienbury, Germany).

Rumen Temperature Collection

Rumen temperature boluses (SmartStock, LLC, Pawnee OK) were administered with a bolus gun when steers were allocated to pens. Rumen temperatures were transmitted at 3 minute intervals to a receiver. Raw T_{rum} data was in Fahrenheit format and converted to Celsius using, $C° = (F° - 32) \times (5/9)$.

Normal body temperature for feedlot steers was assumed to be above 38.61°C (Wahrmund, 2008) and was used as a baseline for all temperature analysis. Rumen temperatures that were < 38.61°C are assumed to be associated with water drinking events and were removed from the daily average and maximum T_{rum} analysis. Daily average T_{rum} for individual animal was averaged by hour, day, and then period average T_{rum}. The maximum T_{rum} for individual animal per day was averaged together for an overall daily and period maximum average T_{rum}.

Area under the curve was utilized to determine the amount of time spent > 38.61 ºC (**AUC_{AB}**) or below < 38.61 ºC (**AUC_{BE}**) the baseline temperature, negative summed AUC calculation errors were removed from the analysis. Time and date were converted to a numerical value, summed together, and converted to Julian time by adding 2415018.50. The following equation was adapted from Wahrmund (2008) and was utilized for all daily T_{rum} observations:

$$\text{AUC} = \text{Julian Time} * \left(\frac{\text{Current Temperature (ºC)} + \text{Previous Temperature(ºC)}}{2}\right)$$

The AUC_{AB} was assumed to be associated with time spent above the baseline temperature and was calculated by summing the calculated values for individual animal by hour, day, and then period. The AUC_{BE} was assumed to be associated with time spent below baseline temperature or associated with water drinking events and was calculated by subtracting the AUC_{AB} from the total AUC area. The AUC_{BE} was then summed for individual animal by hour, day, and then period.

To determine the average number of daily drinking events per pen, AUC_{BE} was summed for each hour of the day. From those summed values, each hour was assigned a value of 1 if AUC_{BE} was > 0 or a 0 if the AUC_{BE} was = 0. Assigned hourly values were summed for individual animal per day and represent count of daily drinking events per pen daily (**DD_N**).

Environmental Data

Environmental data was collected for the feeding period through the Oklahoma Mesonet (Oklahoma Mesonet, Mesonet.org) archives. Environmental factors include average and maximum temperature, humidity, and wind speed, accumulated rain fall, and solar radiation, broken into monthly period, MAY, JUN, JUL, and AUG (Table 4.2). Comprehensive climate index was utilized to determine cattle comfort situations (Mader et al., 2006).

Statistical Analysis

All data analysis was done using a randomized complete block design in a 2 x 2 PS structure with PS and housing as main effects and PS × housing as the interaction.

Average and maximum T_{rum}, DD_N, AUC_{AB}, and AUC_{BE} 38.61° C were analyzed for each monthly period using GLIMMIX procedure of SAS (SAS 9.4; SAS Inst. Cary, NC) with day as the repeated measure and pen as the experimental unit and block as the random effect.

Effects and interactions with T_{rum} analysis were considered significant when $P \leq 0.01$ and a trend when $0.01 < P \leq 0.05$.

Performance and carcass characteristics, were analyzed using the GLIMMIX procedure of SAS with pen as the experimental unit, and block was used as the random effect.

Effects and interactions were considered significant when $P \leq 0.01$ and a trend when $0.01 < P \leq 0.05$.

RESULTS

Feedlot Performance

There were no PS × housing interactions for performance parameters ($P \geq 0.16$; Table 4.5). Because of the study design and the heavier steers being moved to SHADE at initial sorting, there was a tendency for a housing effect on initial BW ($P = 0.05$). There was a PS effect on both d 56 and final BW with CONV steers being heavier than NAT steers ($P <0.01$). For ADG, there was a tendency for a housing effect on the d 29-56 period with SHADE steers gaining more daily than the NOSHADE ($P = 0.05$). For the d

57 to final and overall ADG there was a PS effect (*$P < 0.01$*). The CONV steers gained 0.46 kg more daily than NAT over the 84 d period (*$P < 0.01$*). For G:F, there was a PS effect with the CONV steers having a greater conversion than the NAT steers (*$P < 0.012$*).

Carcass Characteristics

For carcass characteristics, there was a PS × housing interaction (*$P < 0.01$*). The SHADE NAT steers having the greatest marbling score at 504 and the CONV SHADE having the lowest score at 410 (*$P < 0.01$*; Table 4.5). The NOSHADE NAT and CONV steers were intermediate to the SHADE steers (*$P < 0.01$*). There was a PS effect on HCW, and LM area (*$P < 0.01$*). The CONV steers had a 44 kg heavier HCW than the NAT steers (*$P < 0.01$*). For LM area, the CONV steers had a 10.53 cm^2 increase in area over the NAT steers (*$P < 0.01$*).

Rumen Temperature

With the exception of JUL and AUG (*$P = 0.01$*) there were no PS × housing interactions for MAY and JUN. In JUL and AUG, NAT steers had lower average T_{rum} (Table 4.4; Figure 4.3 and 4.4). For maximum $T_{rum,}$ JUL and AUG (*$P < 0.001$*) had a PS × housing interaction. The NOSHADE NAT steers had the lowest and CONV had the highest maximums in both JUL and AUG. Steers housed in SHADE had similar maximum T_{rum} in both JUL and AUG (*$P = 0.07$*).

With the exception of JUL ($P < 0.01$), there were no PS × housing interaction for AUC_{AB}. In JUL, SHADE steers had increased AUC_{AB} over NOSHADE and NAT NOSHADE had least AUC_{AB}. In JUL and AUG ($P < 0.001$), there was a PS × housing interaction for AUC_{BE}. Nature NOSHADE had the highest AUC_{BE}, SHADE steers had similar AUC_{BE}, and CONV NOSHADE were in the median. For JUL and AUG, there was a PS × housing interaction for DD_N ($P < 0.01$). The NAT NOSHADE had increased DD_N and SHADE steers were similar in their $DD_{N.}$

DISCUSSION

Summer conditions above normal ambient temperatures paired with high humidity, solar radiation, and wind speed can contribute greatly to the cattle’s overall heat load and has the potential to decrease performance and profitability. Mader et al., (2010) stated that the CCI can be used to determine a maximum threshold for cattle in hot and cold conditions and can be utilized for optimal cattle management. For the current study, the month of MAY had the lowest CCI value, air temperatures, and solar radiation. As the feeding period progressed, JUL and AUG had the highest CCI and JUL had the highest amount of rain fall during the feeding period. The weather conditions in the current study provided sufficient hot days to encounter and observe a heat stress response from the cattle in both housings. The SHADE solid structure, could be considered an unconventional shade structure. The solid structure, could have trapped dissipated heat from the steers to accumulated and decrease the ability of the steers to decrease their heat load.

Gaughan and others (2010) reported the maximum difference between body temperature of shade and non-shade cattle 0.60 ºC, with the shade cattle being cooler. Boyd et al. (2015) in a study with environmental conditions with less of a heat load, found that the addition of shade was beneficial in regulating body temperatures when environmental factors have increased. There were similar results in the present study, CONV steers in SHADE had higher average and maximum body temperatures than housed in NOSHADE. Natural steers housed in SHADE barn had lower average and maximum body temperatures than NOSHADE NAT steers in both experiments throughout the 84-d period.

Montgomery et al. (2009) found that the addition of a β – agonist at the end of the feeding period improved performance will increase ADG by 14%, an 18% improvement in G:F, and a 2% decrease in DMI. Boyd et al. (2015) did not find a difference in feedlot performance for cattle housed in shade and non-shaded pens. In the current study, when comparing BW throughout the feeding period, although NOSHADE NAT and CONV steers started with lighter initial BW, through the feeding period they caught up to the growth of SHADE steers and at the end of the feeding period. In SHADE, the technology and the difference in bunks may have been disadvantage on the steers in their normal feeding behaviors. Learning the functionality and establishing a dominance feeding order in the pens would add as a disadvantage to the cattle to perform and eat in a normal environment at within the first month of the feeding period which may have contributed to lack of gain. With this disadvantage, the NOSHADE steers were able to eat out of a normal feedlot bunks with normal behaviors allowing them to out-perform the steers in SHADE.

In 2009, Wileman and others in a series of several studies comparing conventional to natural feedlot production systems, found that with the addition of growth promoting technologies there was an increase in efficiency. When comparing implanted to non-implanted, there was an improvement of ADG by 0.25 kg/d. Similarly, Gaughan (2010) found that shaded cattle had improved ADG and efficiency over non-shaded cattle. They found a 0.03 decrease in G:F and a 16% decrease in ADG when comparing conventional raised beef to organic raised. In this study, comparing the performance of NAT and CONV systems, CONV steers had better ADG and BW gains in both SHADE and NOSHADE. The SHADE and NOSHADE housings had similar gains throughout the feeding period but the G:F was greater for the SHADE steers in both NAT and CONV PS, even though the DMI differed by approximately 0.24 kg/d.

Gaughan (2010) compared liters of water intake for shaded and non-shaded steers, the shaded steers consumed 3.8 L /d more than non-shaded steers. They also found that as the heat load increased, water intakes increased for both shade and non-shaded steers. For this study, there was a decrease in daily water drinking events when comparing NAT and CONV production systems with NAT steer drinking approximately 87% more water daily than CONV steers. In the beginning of the feeding period when the environmental temperatures were cooler, steers had similar number of daily drinks. With increasing environmental temperatures at the end of the period, SHADE steers consumed 7.5% less water daily than NOSHADE steers. Natural steers in both locations had an increased daily number of drinks when compared to CONV steers. This suggests that with the addition of shade there may be a decrease in water intake for either PS.

Maxwell et al. (2014) in a corresponding study, confirmed the improvement of carcass characteristics and feedlot performance with the addition of growth enhancing technologies. Montgomery et al. (2009) found that with the addition of zilpaterol hydrochloride, there was an improvement of HCW, dressing percentage, and LM area but there was not an effect on marbling scoring or 12th rib back fat thickness. The current study had similar results, there was a 1.64% improvement in dressing percentage, 15 kg increase in HCW, and similar fat thickness measurements, when comparing NAT and CONV production systems.

The current study has concluded that with the addition of a conventional growth promoting technologies, there is improvement in performance and carcass characteristics, similar to several previously stated studies. There was not however, an increase in body temperature with the addition of those technologies and there was not a large difference in body temperatures with shaded and non-shaded barns. With the addition of shade, consistency was seen for body temperature as well as daily and period gains for steers without the direct exposure of solar radiation and environmental factors.

With the addition of shade, there was not a huge effect on T_{rum} for either production system with NAT and CONV steers in SHADE and NOSHADE having inconsistent changes in average and maximum T_{rum}. The decreased BW for the NAT steers could have been beneficial to them because it decreases surface area and fat accumulation that can contribute to insulation effects in high heat environments. The addition of shade seems to help with consistent body temperature fluctuations and daily water drinking events, but did not seem to effect one production system over another. From this data set, it appears the addition of shade was more beneficial for consistent gains throughout the feeding period but was not beneficial for overall feed efficiency and some carcass characteristics. This data set has also proven a point from many other studies that with the addition of growth promoting technologies was beneficial to BW gain, ADG, HCW, and dressing percentage.

Literature Cited

Beatty, D.T., A. Barnes, E. Taylor, and S.K. Maloney. 2007. Do changes in feed intake or ambient temperature cause changes in cattle rumen temperature relative to core temperature? Journal of Thermal Biology. 33(1), 12-19.

Blaine, B.L. and I.V. Nsahlai. 2010. The effects of shade on performance, carcass classes, and behavior of heat-stressed feedlot cattle at the finisher phase. Trop Anim Health Pro. 43:609-615.

Boyd, B. M., S. D. Shackelford, K. E. Hales, T. M. Brown-Brandl, M. L. Bremer, M. L. Sprangler, T. L. Wheeler, D. A. King, and G. E. Erickson. Effects of shade and feeding zilpaterol hydrochloride to finishing steers on performance, carcass quality, heat stress, mobility, and body temperature. J. Anim. Sci. 2015. 93:5801-5811.

Dikmen, S. H., Ustuner, and A. Orman. 2012. The effect of body weight on some welfare indicators in feedlot cattle in a hot environment. Int J Biometeorol. 56:297-303.

Gaughan, J. B., T. L. Mader, S. M. Holt, M. L. Sullivan, and G. L Hahn. 2010. Assessing the heat tolerance of 17 beef cattle genotypes. Int. J. Biometeorol. 54:617-627.

Gomes, R. C., R. D. Sainz, S. L. Silva, M. C. Cesar, M. N. Bonin, P. R. Leme. Feedlot performance, feed efficiency re-ranking, carcass traits, body composition, energy requirements, meat quality, and calpain system activity in Nellore steers with low and high residual feed intake. J. Liv. Sci. 2012. 150:265-273.

Lefcourt, A. M., and W. R. Adams. 1996. Radiotelemetry measurement of body temperatures of feedlot steers during summer. J. Anim. Sci. 74:2633-2640.

Mader, T. L. Body Temperature in feedlot cattle. J.Anim. Sci. 2002. 81(E. Suppl. 2) E110-E119.

Mader, T. L., M. S. Davis, and T. Brown-Brandl. Environmental factors influencing heat stress in feedlot cattle. J. Anim. Sci. 2006. 84:712-719.

Mader, T. L., L. J. Johnson, and J. B. Gaughan. 2010. A comprehensive index for assessing environmental stress in animals. J.Anim. Sci. 88.6: 2153-2165.

Maxwell, C.L. 2014. Advantages of technology use in beef production systems. PhD Diss. Oklahoma State Univ., Stillwater.

Maxwell, C.L. B.C. Bernhard, C.F. O'Neill, B.K. Wilson, C.G. Hixon, C.L. Haviland, A.N. Grimes, M.S. Calvo-Lorenzo, D.L. VanOverbeke. G.G. Mafi, C.J. Richards, D.L. Step, B.P. Holland, and C.R. Krehbiel. (2014). The effects of technology use in feedlot production systems on feedlot performance and carcass characteristics. J. Anim. Sci. 2015. 93:1340-1349.

Montgomery, J. L., C. R. Krehbiel, J. J. Cranston, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. N. Streeter, D. T. Bechtol, E. Johnson, T. TerHune, and T. H. Montgomery. Dietary zilpaterol hydrochloride. I. Feedlot performance and carcass traits of steers and heifers. J. Anim. Sci. 2009. 87:1374-1383.

Sullivan, M.L., A.J. Cawdell-Smith, T.L. Mader, and J.B. Gaughan. 2011. Effect of shade area on performance and welfare of short-fed feedlot cattle. J. Anim. Sci. 89:2911-2925.

Wileman, B. W. D. U. Thompson, C. D. Reinhardt, and D. G. Renter. 2009. Analysis of modern technologies commonly used in beef cattle production: Conventional beef production versus nonconventional production using meta-analysis. J. Anim. Sci. 87:10:3418-3426.

Table 4.1: Ingredient composition (% DM basis) of diets fed[1]

	Experimental diet[2]	
Ingredient	NAT	CONVZ
Dry-rolled corn	47.86	47.84
Switchgrass hay	6.88	6.88
Dried distillers grains	14.60	14.60
Sweet Bran®	15.15	15.15
Liquid supplement	10.37	10.37
Dry supplement, B-272[3]	5.14	-
Dry supplement, B-273[4]	-	5.17

Table adapted from Maxwell et al., 2014.

[1] Actual DM formulation calculated based upon As-Is formulations and weekly ingredient DM values.

[2] Production systems include 1) Natural – no antibiotics, ionophores, growth implants or beta-agonists (NAT), 2) Conventional – fed tylosin, monensin, received growth implant, no beta-agonist (CONV).

[3] Formulated to contain (DM basis): 6.92% urea, 29.86% limestone, 1.03% MgO, 0.38% salt, 0.119% copper sulfate, 0.117% MnO, 0.05% selenium premix (0.6% Se), 0.618% $ZnSO_4$, 0.311% vitamin A (30 IU/mg), 0.085% vitamin E (500 IU/g), 0% Rumensin 90, 0% Tylan 40, 39.46% ground corn and 21.04% wheat middlings.

[4] Formulated to contain (DM basis): 6.92% urea, 30.36% limestone, 1.03% MgO, 0.38% salt, 0.119% copper sulfate, 0.116% MnO, 0.05% selenium premix (0.6% Se), 0.618% $ZnSO_4$, 0.311% vitamin A (30 IU/mg), 0.085% vitamin E (500 IU/g), 0.317% Rumensin 90, 0.195% Tylan 40, 38.46% ground corn and 21.04% wheat middlings.

Table 4.2: Arbitrary comprehensive climate index thermal stress threshold[1]

Environment Risk	Hot Conditions
No Stress	< 25
Mild	25 to 30
Moderate	> 30 to 35
Severe	> 35 to 40
Extreme	> 40 to 45
Extreme Danger	> 45

[1] Table adapted from Mader et al. 2006.

Table 4.3: Monthly environmental conditions for Stillwater, Oklahoma from Oklahoma Mesonet.

	Period			
Measurement	MAY[1]	JUN[2]	JUL[3]	AUG[4]
Air Temperature, ºC				
Average	21.57	25.56	26.94	25.91
Maximum	26.26	30.91	32.46	31.39
Humidity, %				
Average	79.73	65.30	67.29	74.50
Maximum	95.55	90.10	89.68	93.50
Wind Speed, km/h				
Average	14.25	12.28	10.07	13.65
Maximum	42.92	42.36	36.23	33.71
Solar Radiation, J/m^2	15.83	26.50	23.08	21.16
Rain Fall, cm	1.13	0.33	3.13	0.21
CCI, ºC[5]				
Average	20.89	26.92	27.40	28.63
Maximum	31.96	37.82	39.11	39.12

[1] MAY d 1-11

[2] JUNE d 12-41

[3] JULY d 42- 72

[4] AUG d 73-84

[5] Comprehensive climate index thermal threshold classification: No stress <25; Mild 25 to 30; Moderate > 30 to 35; Severe > 35 to 40; Extreme > 40 to 45; Extreme danger > 45. Adapted from Mader et al. 2006.

Table 4.4: Monthly average and maximum rumen temperatures (ºC) and area under the curve for production systems (PS) housed in shade and no shade.

		Housing					*P* Value		
		SHADE[1]		NO SHADE[2]					
Measurement	PS	NAT[3]	CONV[4]	NAT	CONV	SEM	PS	Housing	PS × Housing
Pens, n		2	2	2	2				
Steers, n		27	27	12	12				
Rumen Temperature, ºC									
Average									
MAY[5]		39.86	39.83	39.86	40.06	0.07	0.11	0.03	0.03
JUN[6]		40.52	40.49	40.12	40.24	0.06	0.29	<0.001	0.08
JUL[7]		40.20^{a}	40.15^{a}	39.95^{b}	40.15^{a}	0.06	0.14	0.65	0.01
AUG[8]		40.14^{a}	40.08^{a,b}	39.97^{b}	40.19^{a}	0.06	0.14	0.65	0.01
Maximum									
MAY		40.65	40.55	40.67	40.98	0.17	0.20	0.23	0.02
JUN		40.69	40.69	40.32	40.45	0.08	0.17	<0.001	0.18
JUL		41.16^{b}	41.13^{b}	41.04^{c}	41.35^{a}	0.06	<0.001	0.06	<0.001
AUG		41.09^{b}	41.02^{b,c}	40.98^{c}	41.30^{a}	0.07	0.07	0.19	0.01
AUC, Above 38.61ºC[9]									
MAY		33.50	34.15	32.81	34.53	1.44	0.29	0.89	0.63
JUN		36.23	36.36	33.93	35.35	1.29	0.16	0.30	0.24
JUL		36.80^{a}	36.72^{a}	31.14^{c}	34.23^{b}	0.81	<0.01	<0.001	<0.01
AUG		36.28	36.64	33.00	36.06	0.84	0.07	0.03	0.03
Below 38.61ºC[10]									
MAY		5.27	5.18	6.67	5.39	1.07	0.31	0.24	0.38
JUN		3.76	3.75	5.95	5.12	0.93	0.29	0.13	0.32
JUL		3.27^{c}	3.33^{c}	8.52^{a}	5.77^{b}	0.74	<0.01	<0.001	0.01
AUG		3.67^{c}	3.33^{d}	6.83^{a}	4.06^{b}	0.80	<0.01	<0.001	<0.01
Drinks, n[11]									
MAY		6.13	5.95	5.27	4.70	0.65	0.39	0.02	0.67
JUN		6.15	5.96	5.48	5.00	0.39	0.10	<0.001	0.47
JUL		5.30^{b,c}	5.50^{d}	6.86^{a}	5.17^{b}	0.63	0.02	0.03	<0.01
AUG		4.38^{b}	4.36^{b}	5.36^{a}	3.77^{c}	0.80	0.01	0.50	<0.01

[a,b,c] Interaction within row with unique superscripts differ when $P < 0.01$.

[1] Steers housed in indoor/outdoor facility.

[2] Steers housed in open air feedlot pens.

[3] Natural: steers did not receive growth promoting technologies throughout feeding period.

[4] Conventional: steers received an implant upon arrival and monensin and tylosin daily.

[5] d 1-11; May 21-31, 2013

[6] d 12- 41; June 1-30, 2013

[7] d 42- 72; July 1-30, 2013

[8] d 73- 84; August 1-12, 2013

[9] Area under the curve. Calculated using the equation: Total AUC = Julian Time * (Current Temperature (ºC)) + Previous Temperature (ºC))/2. A baseline temperature of 38.61ºC was used.

[10] AUC drinks calculated subtracting area below 38.61ºC associated with drinking events from the total area.

[11] Average daily drinks.

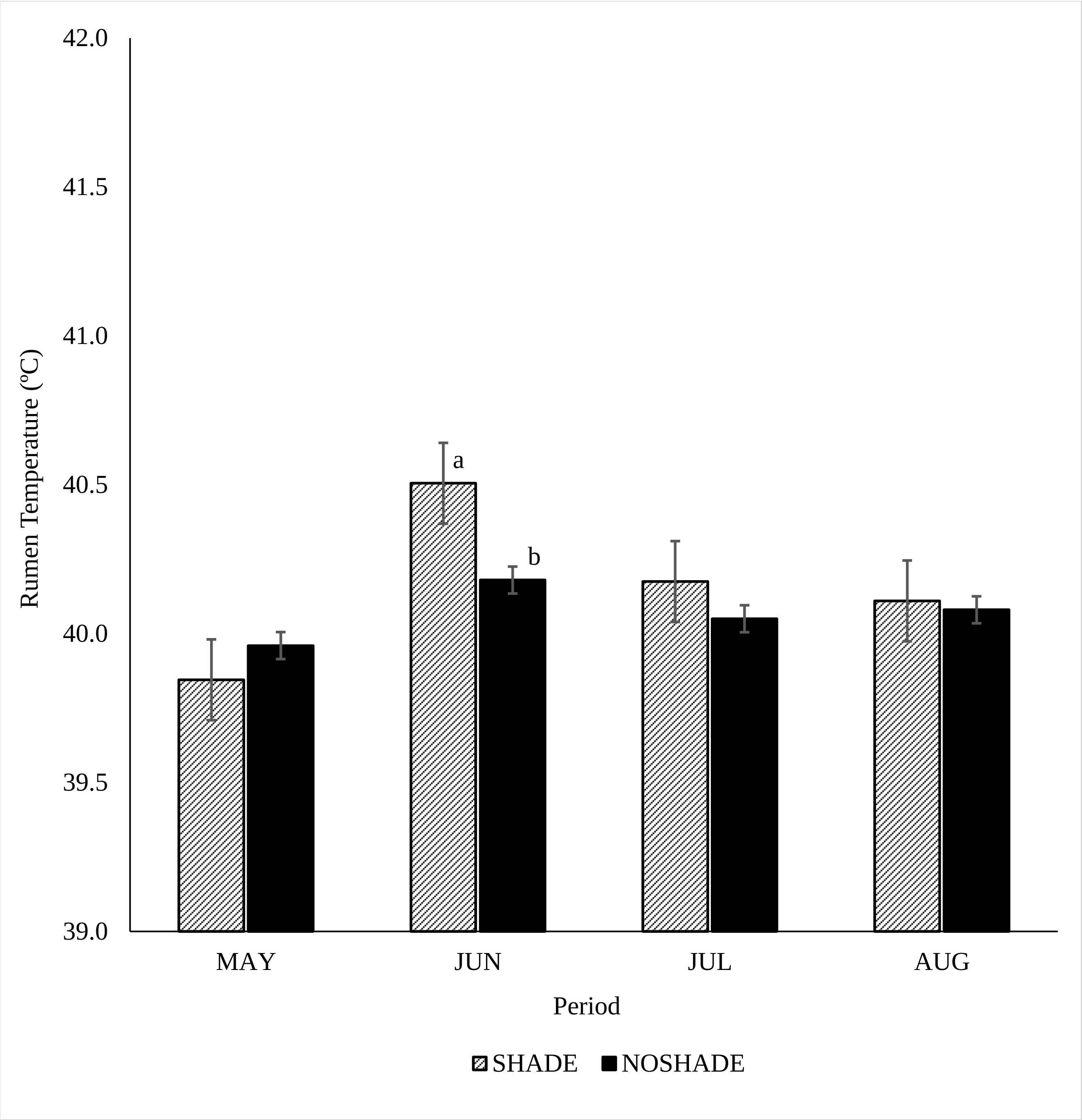

Figure 4.1: Period average rumen temperatures for steers housed in shade and no shade.

^{a,b} Bars with unique superscripts differ when *P* < 0.01. MAY d 1-11 (*P* = 0.03 SE = 0.07); JUN d 12-41 (*P* < 0.001 SE = 0.06), JUL d 42- 72 (*P* = 0.65 SE = 0.06); AUG d 73-84. (*P* = 0.65 SE = 0.06). SHADE: steers housed in indoor/outdoor facility. NOSHADE: Steers housed in open air feedlot pens.

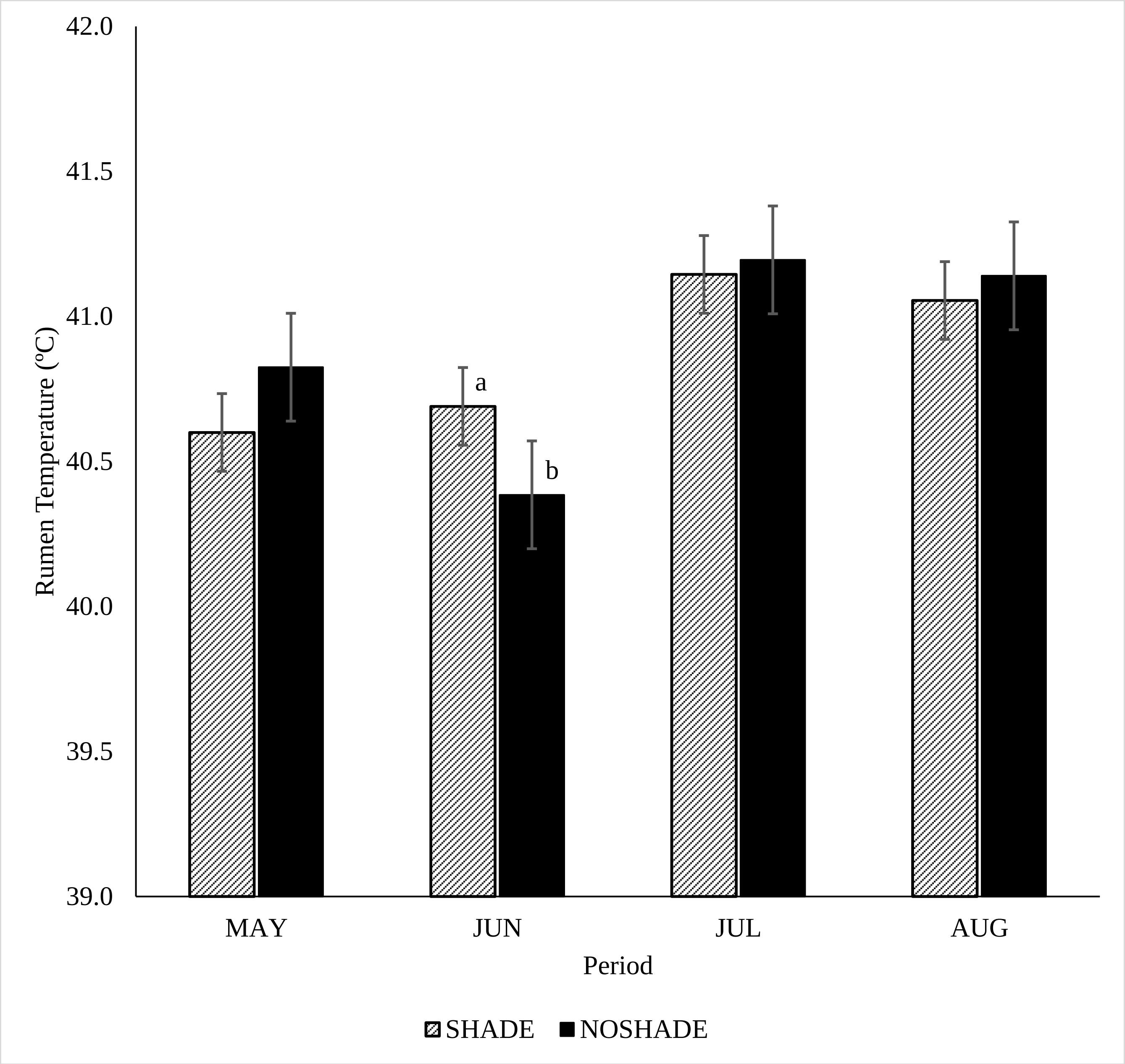

Figure 4.1: Period maximum rumen temperatures for steers housed in shade and no shade.

[a,b] Bars with unique superscripts differ when $P < 0.01$. MAY d 1-11 ($P = 0.23$ SE = 0.17); JUN d 12-41 ($P < 0.001$ SE = 0.08), JUL d 42- 72 ($P = 0.06$ SE = 0.06); AUG d 73-84 ($P = 0.19$ SE = 0.07). SHADE: steers housed in indoor/outdoor facility. NOSHADE: Steers housed in open air feedlot pens.

Table 4.5: Effects of production systems (PS) and housing in shade and no shade on performance and carcass characteristics.

		Housing							
		SHADE[1]		NO SHADE[2]			*P* Value		
Measurement	PS	NAT[3]	CONV[4]	NAT	CONV	SEM	PS	Housing	PS × Housing
Pens, n		2	2	2	2				
Steers, n		27	27	28	28				
BW, kg[5]									
Initial		391	392	384	384	1	0.72	0.05	0.16
d 28		429	444	449	457	5	0.02	0.12	0.21
d 56		468	496	465	485	3	<0.01	0.06	0.20
Final		539	596	551	602	2	<0.01	0.09	0.24
ADG, kg/d									
d 0-28		1.33	1.80	2.25	2.55	0.2	0.03	0.09	0.35
d 29-56		1.36	1.85	0.57	0.99	0.17	0.12	0.05	0.87
d 57-final		1.21	1.72	1.17	1.65	0.07	<0.01	0.50	0.85
d 0-final		1.28	1.77	1.28	1.71	0.03	<0.01	0.33	0.30
DMI, kg/d		9.76	10.00	10.10	10.17	0.14	0.23	0.27	0.47
G:F		0.131	0.177	0.127	0.168	0.03	<0.01	0.12	0.52
Carcass Characteristics									
HCW, kg		340	389	347	388	4	<0.01	0.60	0.46
LM area, cm^2		76.14	87.23	79.73	89.71	1.43	<0.01	0.10	0.72
12th rib fat thickness, cm		1.14	1.19	1.10	1.02	0.09	0.71	0.48	0.22
Marbling score[6]		504^{a}	410^{b}	$466^{a,b}$	$433^{a,b}$	22	<0.01	0.83	<0.01
Dressing percentage, %		3.19	3.02	3.00	2.72	0.15	0.21	0.29	0.69
Yield Grade		63.13	65.33	62.9	64.49	0.001	0.08	0.51	0.65

[1] Steers housed in indoor/outdoor facility.

[2] Steers housed in open air feedlot pens.

[3] Natural steers did not receive growth promoting technologies throughout feeding period.

[4] Conventional received an implant at arrival and were fed monensin and tylosin daily.

[5] A calculated shrink of 4% is applied to all BW measurements and calculated daily gains.

[6] 400 = small00, 500 = Mondest00, 600= Moderate00.

APPENDIX

All procedures involving live animals were approved by the Oklahoma State University Institutional Animal Care and Use Committee

Protocol # AG 12-2

VITA

Catherine Lee Haviland

Candidate for the Degree of

Master of Science

Thesis: RUMEN TEMPERATURE AS A BIOMARKER FOR HEAT STRESS

Major Field: Animal Science

Biographical:

Personal Data: Born Chubbuck, ID on September 30, 1988, the daughter of Allen and Diane Haviland

Education: Graduated from Highland High School in June of 2007. Started bachelors at Carroll College in Helena, MT; completed 4 years at Idaho State University in Pocatello, ID in Biochemistry; received Bachelor of Science in Animal Science with emphasis in Biotechnology at Oklahoma State University in May 2013. Completed the degree requirements for Masters of Science in Animal Science at Oklahoma State University in December 2016.

Experience: Worked as veterinary technician in Blackfoot, ID from 2009 to 2011; Stillwater Country Club, Beverage Manager, 2011 to 2015; Willard Sparks Beef Research Center, Graduate Research Assistant, 2011 to present; Interim Herd Manager.

Professional Memberships: Animal Society of Animal Science; Graduate and Professional Student Government Association; Animal Science Graduate Student Association; Sigma