Effect of shade and limit feeding on growing cattle during heat stress

by

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Abstract

Two experiments were conducted concurrently during the summers of 2021 and 2022 to evaluate the effects of shade allocation and diet type on growth performance, animal comfort, water usage, diet digestibility, and ruminal fermentation on growing heifers. In Exp. 1, 852 heifers (initial body weight = 250 ± 28 kg) were purchased from Iowa, Kansas, and Missouri and transported to Kansas State Beef Stocker Unit. Heifers were assigned to one of four treatments: high-energy diet limit-fed at 2.2% body weight (dry matter basis; LIM) or high-roughage diet fed for ad libitum intake (ADLIB) with shade (SH) or without shade (NSH). Pen body weights were measured weekly from day 14 to 84 and individual body weights were measured on days 0, 90, and 97. Pen weights were used to adjust weekly intakes of LIM. Refusals for ADLIB were targeted at 5% of feed consumed the previous day. Following the 90-day feeding period, a gut-fill equilibration diet was fed to all cattle at 2.5% of body weight (dry matter basis) for 7 days to balance for differences in gut-fill between dietary treatments. Dry matter intake was lesser ($P < 0.01$) for LIM compared with ADLIB. Average daily gain and gain:feed was greater($P \leq 0.03$) for LIM compared with ADLIB. Average daily gain and gain:feed was greater ($P < 0.01$) for SH compared with NSH. Water usage was less ($P < 0.01$) for SH heifers compared with NSH and was less ($P < 0.01$) for LIM compared with ADLIB. Mean panting scores were lower ($P < 0.01$) for SH compared with NSH and LIM compared with ADLIB. In Exp. 2, 16 heifers (initial body weight = 254 ± 22) were used in digestibility trials to evaluate treatments used in Exp. 1. Apparent total tract digestibility of dry matter and organic matter was greater ($P < 0.01$) for LIM compared with ADLIB. LIM had a lower ($P = 0.03$) ruminal pH compared with ADLIB. Liquid passage rate was slower ($P < 0.01$) for LIM compared with ADLIB. Shade did not affect ($P > 0.05$) diet digestibility; however, SH had greater ($P < 0.01$) ruminal pH compared with NSH. In conclusion, limit-fed high-energy diets improved feed efficiency, reduced mean panting score and reduced water consumption compared with diets fed for ad libitum intake. In addition, shade improved growing calf performance, reduced water usage, and improved animal comfort during periods of heat stress. Utilization of limit-fed high-energy diets and the use of shade during periods of heat stress may improve animal comfort, decrease water usage and improve growing calf performance.

Key words: growing cattle, heat stress, limit feeding, shade, water

Table of Contents

List of Figures

List of Tables

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Chapter 1 - Review of Literature

Introduction

Heat stress has been a focal point for animal production and animal welfare in the beef industry. Cattle housed in outdoor environments are often exposed to extreme weather events which often results in production losses. Due to an increasing need for the beef industry to promote new and improved sustainability practices, enhancements in animal welfare and efficiency are needed to produce a more ethical and efficient product for consumers. Increasing global temperatures and extreme weather events (i.e., heat stress events) require implementation of environmental mitigation strategies (Lees et al., 2019). Excessive heat load can produce varying physiologic and behavioral outcomes in beef cattle as well as reduce production efficiency (Brown-Brandl et al., 2005). Mitigation strategies including shade and dietary adaptations can be used to reduce the impact of heat stress events and improve performance in the beef industry (Edwards-Calloway et al., 2021). Limit feeding a high-energy diet can be used to improve feed efficiency while maintaining average daily gain and body weight gains in growing cattle (Spore et al., 2019). Limiting dry matter intake has beneficial effects on ruminal characteristics which can improve feed utilization and improve feed efficiency. By reducing dry matter intake, water usage can also be reduced, thus providing another avenue to increase sustainability in growing calf operations. Understanding the connection between heat stress and limit feeding strategies can improve animal welfare and promote sustainability in the industry while also improving productivity. The objective of this review is to assess the impact of heat stress on cattle wellbeing and productivity along with evaluating limit feeding strategies to improve feed efficiency and profitability.

Sustainability in the Beef Industry

Environmental concerns present challenges for the beef production industry to overcome. Improving feed efficiency and reducing greenhouse gas emissions (GHG) has become a high priority for the agriculture industry. Since the 1960's, the beef industry has reduced GHG emissions by 40%; reductions in GHG were a result of improved management practices and greater feed efficiency (NCBA, 2022). Recently, climate neutrality has become a key talking point for the beef industry with current goals of reaching neutrality by 2040 (NCBA, 2022). Cattle remain a vital component of carbon sequestration, recycling, and upcycling in the food system (Gleason and White, 2019). Transition to grain or grain byproduct and coproduct diets from traditional roughage-based diets can improve feed efficiency and overall sustainability (Greenwood, 2021). Implementation of various management strategies (i.e. heat stress mitigation practices) can be also used to promote a more sustainable animal welfare model. In addition, water usage is another segment of beef sustainability which must be addressed. Depending on management strategy, between 200 and 4,000 L of water is needed to produce 1 kg of beef while 4 to 15 L of water is required per kg of feed consumed (Winchester and Morris, 1956; Gleason and White, 2019). Strategies such as environmental management and dietary adjustments can be used to reduce the water footprint of the beef industry. Although the efficiency of beef cattle production has improved over time, there remain multiple ways to improve sustainability and animal welfare in the beef industry.

Heat stress

Chronic hyperthermia, more commonly referred to as heat stress, impacts all sectors of the livestock industry. Although a majority of research has been conducted in dairy systems, several studies have been conducted in beef cattle feedlots with minimal research evaluating the impacts of heat stress on growing calves or backgrounding cattle (Edwards-Callaway, 2021).

Cattle typically experience heat stress during summer months when climatic factors such as solar radiation, ambient temperature, humidity, and wind speed result in increased heat load in livestock (Mader et al., 1997, 1999a; Hubbard et al., 2013).

Heat stress events have a significant economic impact to the livestock industry. St. Pierre et al. (2003) discussed the economic impact of heat stress on the U.S. livestock industry with emphasis on performance losses, mortality, and reproduction losses. Beef production economic losses due to heat stress were estimated at approximately $369 million per year (St. Pierre et al., 2003). Frequency of hot climatic conditions are expected to increase during the 21st century based on trends of surface temperature from 1901 to 2021 (EPA, 2021). As a result, heat stress events are expected to increase in intensity and volume in the coming decades. Thorton et al. (2022) evaluated heat stress losses in both high and low greenhouse emission scenarios and estimated losses associated with heat stress on beef production between $11.4 and $15.2 billion per year between 2022 and 2045. Understanding the impact of an ever-changing climate on the welfare and productivity of livestock provides opportunity to develop heat-stress mitigation strategies.

Heat stress losses can be quantified by losses in performance and, in extreme cases, mortality. During the summer of 2022, over 2,000 feedlot cattle succumbed to an abnormal heat stress event in southwestern Kansas (NPR, 2022). Although this is only one example of a significant heat stress mortality event, many others have been documented in North America in both beef and dairy herds in recent decades (Bushby and Loy, 1997; Hahn and Mader, 1997; Hahn, 1999; Brown-Brandl et al., 2006a, 2006b; Associated Press, 2017; Lees et al., 2019). As the incidence of extreme heat load events increases, it is critical that beef producers utilize the best tools to mitigate any negative impacts of heat stress on beef production.

Production livestock species have a defined thermal neutral zone where production and health are maximized (Ames, 1980). This thermal neutral zone can be affected by environmental factors such as ambient temperature, relative humidity, solar radiation, and wind. Cattle regulate their body temperature through convection, conduction, and radiation (Maia et al., 2005). At high temperatures the ability of cattle to dissipate heat through passive transfer is minimized because the transfer of heat from a cooler to warmer environment cannot occur. Therefore, cattle utilize various other physiologic responses such as panting, increased water intake, satiety, sweating, and shade-seeking to dissipate heat and maintain homeostasis (Hahn and Mader, 1997; Mader et al., 1999b). Watts and Mclean (1977) defined homeostasis by the equation: $HP - HL = \Delta T_{body} \times C_p \times m$, where H*P* = heat production, HL = heat loss, ΔT_{body} = change in body temperature (°C), C_P = specific heat of the animal (J/ (kg × °C)), and m = body weight (kg). Therefore, an increase in body temperature must be accompanied with increased heat loss or a reduction in heat production to maintain homeostasis. Consequently, reducing heat load results in less energy required to maintain homeostasis.

To reduce heat production, cattle reduce their dry matter intake which reduces heat produced via ruminal fermentation and energy metabolism. Reductions in dry matter intake are associated with decreased performance (Sullivan et al, 2011; Edwards-Calloway et al., 2021). Cattle will also reduce activity to reduce heat production by metabolism in muscle tissues (NRC, 1981; Brown-Brandl, 2018). By understanding animal responses to thermal heat stress and factors that exacerbate heat stress, livestock producers can evaluate their environment and implement mitigation strategies to combat an increased heat load.

Quantifying heat stress

Heat stress events can negatively influence beef cattle performance and animal welfare. With a changing world climate, it is increasingly important to study the effects and quantify the parameters which define heat stress events. The thermal neutral zone has been used to define the optimum zone for cattle performance and welfare, and it can be defined as the range at which cattle are best able to maintain homeostasis (Ames, 1980). During summer months, a combination of elevated solar radiation, reduced wind speed, increased relative humidity, and increased ambient temperature contribute to heat stress events and decrease animal performance (Mader et al., 1997, 2006; Hubbard et al., 2013; Guaghan et al., 2008).

In an attempt to determine the relationship between climatic factors and heat stress several models have been developed since the 1950s. Thom (1959) first developed the temperature humidity index (THI) defined by: $THI = Ta – (0.55 – (0.55 * (RH/100))) * (Ta – 58)$ where Ta = ambient temperature (°C) and RH = relative humidity (%). Thermal neutral conditions are described to be < 74, values 74 to 79 representing an alert level of heat stress, values 79 to 84 representing dangerous levels, and values > 84 being extreme. Heat stress begins to occur above THI 74. This equation has been used throughout industry and literature since its inception; however, the Thom (1959) equation only takes into account ambient temperature and relative humidity and no other weather factors.

To incorporate wind speed and solar radiation, Mader et al. (2006) displayed the relationship which takes into account all major influences on heat stress in cattle including solar radiation and wind speed. Mader et al. (2006) described a THI between 70 and 74 to be of significant value to begin looking at possible effects of heat stress in livestock. Mader et al. (2006) used adjustments for hourly wind speed and solar radiation to more accurately describe the effects of heat stress events with more environmental conditions taken into account. Adjustments by Mader et al. (2006) are described by reducing THI by 2 units for every 1-m/s increase in wind speed and increasing THI 0.68 units for each 100-W/m^2 increase in solar radiation.

Mader et al. (2010) described a comprehensive climate index to define animal stress related to both hot and cold environmental conditions. This climate index provides an adjustment for wind speed, solar radiation, and relative humidity concerning changes in ambient temperature (Mader et al., 2010). These relationships consider < 25 °C to be no stress during hot conditions whereas > 45 °C are considered an extreme danger to the animal (Mader et al., 2010). Gaughan et al. (2008) compiled data from multiple studies totaling 17,750 animals across 8 years to determine heat load on feedlot cattle taking into account solar radiation, wind speed, management factors, and animal differences. To assess animal comfort, panting scores are often used to evaluate an animal's comfort level at a specific time. Panting scores take into account respiration rates, open mouth breathing, drooling, and overall animal discomfort. Panting score data from 2,490 Angus steers were used to calculate regression models of the heat load index (HLI). Authors evaluated night time weather conditions to develop an equation for accumulated heat load (AHL) to take into account night time heat dissipation. Mean panting score was more highly correlated to HLI and AHL (r^2 = 0.93 and 0.92) than to THI (r^2 = 0.61). Authors concluded the new HLI and AHL equations may be used to predict animal responses to heat stress more accurately than previous equations.

Physiologic responses to heat stress

As a result of heat stress, livestock accumulate heat and body temperature increases. To dissipate heat during high heat load events, many physiologic and behavioral changes occur.

Physiological responses to heat stress include increased respiration rate and panting, increased body temperature, increased sweating, and satiety (Edwards-Calloway et al., 2021). Behavioral changes are associated with these physiologic responses such as shade seeking, increased time standing, and reduced feed intake (Brown-Brandl et al., 2005). Maintenance energy requirements are considerably higher during heat stress conditions resulting from an increased need to expel heat from the body (Morrison., 1983). As a result, decreasing feed intake and increased metabolic requirements result in decreased animal performance. Water intake will also increase along with heat load as a means to aid in evaporative heat loss and replenish water loss associated with such evaporative heat loss (NRC, 2016).

Panting is a heat loss mechanism initiated in beef cattle to attempt to return the body to homeostasis (Bernabucci et al, 2010). Increasing respiratory rate creates increases respiratory ventilation which aids in evaporative heat loss (Robertshaw, 2006). Increased respiratory rate accelerates the metabolism rate of respiratory muscles. To cope with this accelerated metabolism, non-respiratory muscles decrease their metabolic rate (Robershaw, 2006). Panting increases evaporative heat loss by increasing heat exchange during respiratory ventilation and humidification of gases within the respiratory tract (Robertshaw, 2006).

Ruminants generate substantial amounts of heat during fermentation of feedstuffs. Microbial fermentation accounts for 3 to 8% of the total heat production in cattle (Lees, 2019). Therefore, an increase in heat load will generally lead to a reduction in dry matter intake or a shift to eating during cooler hours of the day (Lees et al., 2019). The heat of fermentation can influence an animal's ability to efficiently dissipate heat due to continual internal heat generation (Mader and Griffin, 2015).

Elevated heat load is also associated with many metabolic changes in livestock. During elevated heat load events metabolism of nutrients shifts from tissue development to homeostasis control (Lees et al., 2019). To increase evaporative heat loss associated with sweating and panting, blood is diverted to extremities and the respiratory tract. Maintenance requirements also increase during heat stress by as much as 25% (NRC, 2016). Increased energy requirements and reduced feed intake that occur during periods of heat stress ultimately reduce animal performance and efficiency.

Physiologic responses to heat stress, although required to maintain homeostasis, are often detrimental to livestock production. Although some breed differences occur, specifically between *Bos Indicus* and *Bos Taurus* cattle (Beatty et al., 2006), intervening (i.e., providing shade) before heat is allowed to accumulate may improve animal performance and comfort.

Animal comfort

Panting scores represent a visual observation of animals and are used to evaluate heat-stress and animal comfort. Panting scores take into account respiratory rate, movement, drooling, and labored breathing to provide an overall assessment of the animal welfare. Panting scores typically range from 0 = no stress to 4 = extreme stress with varying intermediate scores. By taking into account the panting score along with other health and behavioral measurements, the effects of thermal stress on animal welfare can be determined and properly managed. Traditionally body temperature has been used to evaluate an animal's physiologic response to heat stress. Body temperature is a good measure of a calf's health status, but it is not a practical indicator of heat stress in commercial settings (Mader et al., 2006). Studies have found a delay between heat stress events and increased body temperature. Hahn and Mader (1997) described the delay in body temperature peaks in response to moderate temperature events as well as heat stress events. Peak body temperature occurred with an 8- to 10-hour delay after moderate temperature (18 ± 7 °C) events (Hahn and Mader, 1997). During heatwave events (32 ± 7 °C), the lag between peak ambient temperature and peak body temperature was 3 to 5 hours (Hahn and Mader, 1997).

Similar to body temperature, changes in respiration rate that occur as a result of heat stress are also delayed by 2 to 4 hours (Hahn et al., 1999; Gaughan et al., 2000). These two studies were conducted in temperature-controlled environments with no influence of solar radiation or wind speed. Brown-Brandl et al. (2005) conducted a similar experiment where cattle were housed outside, exposed to solar radiation, and exposed to changes in wind speed. During this study changes in respiratory rate preceded increases in dry-bulb temperature (air temperature measured without the presence of radiation or moisture) changes by an average of 1 hour (Brown-Brandl et al., 2005). Authors suggested the relationship between dry-bulb temperature and respiration rates in the previously described studies of Gaughan et al. (2000) and Hahn et al. (1999) were due to the influence of other weather conditions. Brown-Brandl et al. (2005) found a similar relationship between dry-bulb temperature and respiration rate in each category of heat stress as defined by the study. The relationship between solar radiation, respiration rate, and the dry-bulb temperature is also described by Brown-Brandl et al. (2005). Changes in solar radiation preceded changes in dry-bulb temperature by approximately 2 hours, whereas changes in respiration rate preceded changes in dry-bulb temperature by 1 hour (Brown-Brandl et al., 2005). This relationship suggests the respiratory rate is an accurate indicator of the physiologic response to heat stress conditions.

These results have been further evaluated by Gaughan et al. (2000) who also observed differences in respiratory rate responses to ambient temperature changes during nighttime versus daytime responses. This difference is associated with dissipation of heat during cooler temperatures at night which is crucial in the return to homeostasis.

There have been several variations of methods to determine panting scores in feedlot cattle. Modifications to panting score assessments can be made while maintaining the integrity of the system. By taking into account respiration rates and open mouth breathing, researchers can accurately evaluate the effects of heat stress on animal comfort in a noninvasive manner. Panting scores, in conjunction with respiration rates, can provide a more accurate measurement of physiologic responses to heat stress during a heat stress event (Brown-Brandl et al., 2005; Gaughan et al., 2000). Panting scores should be measured before solar radiation peaks, during ambient temperature peaks, and post-heat stress events to obtain a proper baseline for analysis of physiologic responses to heat stress during a heat stress event (Gaughan et al., 2000; Brown-Brandl et al., 2005). These measurements should provide an assessment of animal comfort which can allow beef cattle producers to implement various mitigation techniques.

There have been several variations of methods to determine panting scores in feedlot cattle. Davis et al. (2001) conducted a study to determine the relationship between feeding for ad libitum intake or restricted feeding and performance while also taking into account the behavior and body temperature of 144 individuals. Observations of behavior, including panting score, occurred at 0900, 1300, 1700, and 2100 h based on methods described by Davis et al. (2001). Panting scores were assigned to each individual within an experiment and were derived from 15 days of observations within each experiment. Panting scores were assessed on a 0, 1, and 2 scale and were measured before and after peak heat stress events. This scale was not based on details regarding any physiologic reactions outside of respiration rate except a panting score of 2 which was described by excessive panting and salivation. The study concluded that there was no significant difference in panting scores between treatments in the thermal neutral zone. However, during days of THI > 75 and measurement at 1700 h, limit-fed steers had lower panting scores compared with those fed for ad libitum intake. By limiting intake and shifting peak metabolic heat production, panting scores can be reduced.

Mader et al. (2006) set out to determine the impact of environmental conditions that influence heat stress in beef cattle. The study used 3 experiments and 4 validation studies to evaluate the influence of wind speed and solar radiation on heat stress response. Panting scores were recorded for all individuals between 1400 and 1700 h via visual observations, and animals were assigned a score between 0 and 4. Measurements were primarily on days when THI exceeded 69 and environmental predictors (i.e., ambient temperature, humidity) to determine when panting scores should be collected in experiments 4 through 7. This method reduced the number of observations and data points and allowed more accurate collection of data during periods of heat stress. Experiment 7 only utilized panting score data above a score of 1.5 because authors determined a score of 1.5 represents the stage at which heat stress begins to occur and mitigation should be attempted (NRC, 1981; Mader et al., 2002). Panting score was negatively correlated to wind speed. The ambient temperature at 1500 h and relative humidity were positively correlated to panting score. Mean panting scores were determined for experiments 4 through 7 to determine the accuracy of panting score prediction. Mean panting score in experiment 4 was 1.22 ± 0.55 compared with a predicted panting score of 1.15 ± 0.65. Mean panting score in experiment 5 was 0.94 ± 0.42 compared with a predicted panting score of 1.17 ± 0.51. In addition, mean panting score of Angus cattle in experiment 6 was 1.32 ± 0.89 compared with a predicted panting score of 1.30 ± 0.71. Authors indicated that coat color influenced the predictive model of panting score in experiment 6. In experiment 6 actual mean panting score of

Charolais cattle was 0.73 ± 0.73 compared with the predicted panting score of 1.30 ± 0.71. Experiment 7 showed a similar predictive model problem where mean panting scores and predicted panting scores for black hided animals were 2.00 ± 0.39 and 1.96 ± 0.34, respectively, whereas mean panting scores and predicted panting scores were 1.22 ± 0.97 and 1.96 ± 0.34 for white hided animals, respectively.

Gaughan and Mader (2014) recorded body temperature and panting scores on 30 Angus steers for 120 days. Panting scores were based on the panting score of the 4-point system used by Mader et al. (2006). Observations occurred for individual animals at 0600, 1200, and 1600 throughout the study. Individual panting scores were used to calculate the mean panting score for the entire pen during each observation time. Only one observer was used throughout the trial to reduce variance in panting score assessment. During the study, 8352 observations were taken to observe the panting score across all three collection times. During the same period in which panting scores were measured, climate data were obtained which included ambient temperature, black globe temperature, solar radiation, relative humidity, wind speed, and rainfall from onsite weather monitors. Data collected on panting scores showed a trend of increased panting scores when observations were collected at 1200 and 1600 when compared with the 0600 collection. These data suggest there would be a benefit to collecting panting scores before and after peak ambient temperature and solar radiation to create a baseline for comparison.

A review by Gaughan et al. (2002) attempted to describe the current assessment of cattle during periods of high heat load or heat stress events. Gaughan et al. (2002) found that respiration rates should be recorded at least 4 hours before and 4 hours after a heat stress event to observe true physiologic responses to heat stress. This assessment demonstrated that panting score observations should occur before 0800 h and once every 2 hours until at least 1800 h.

Determining panting scores during this period would ensure a large portion of any heat stress event was measured and allow comparison of panting scores during a heat stress event to baseline panting scores measured before 0800 h.

By using non-invasive measurement techniques such as panting scores researchers can minimize stress to animals. Panting score systems allow researchers to collect several measurements in a short period of time. As previously described, these measurements are accurate indicators of heat stress and can be used to evaluate and improve animal comfort.

Strategies to mitigate heat stress

Several methods have been evaluated to alleviate heat stress by reducing heat load accumulated by an animal. The effectiveness of heat stress mitigation strategies can be assessed by evaluating animal growth performance or physiological behavior (i.e., panting scores, respiration rates, body temperature). The first priority during heat stress events should be reducing animal heat load. Methods of reducing heat load include feed modulation, water application, and environment modification.

Holt et al. (2004) examined bunk management and limit feeding as possible heat stress mitigation strategies. Six Hereford steer calves were housed in temperature controlled rooms to evaluate feeding behavior. All animals were fed at 1600 h with limit-fed steers provided 85% of ad libitum feed offerings, whereas bunk-managed steers were offered feed only from 1600 to 0800 h each day for 15 days. Half of the calves were exposed to thermal neutral conditions whereas remaining calves were exposed to heat stress conditions up to 32.9 °C. After 5 days of heat stress conditions, calves fed for ad libitum intake had greater rectal temperatures compared with limit-fed calves. Bunk managed calves had a peak rectal temperature between 2100 and 2200 h, whereas calves fed for ad libitum intake peaked between 1400 and 1500 h. Authors concluded limit feeding and night-time feeding during heat stress events can alleviate heat stress in cattle fed grain-based diets. Due to the innate ability of calves to compensate after times of short duration heat stress, via night time cooling, it is possible that other heat stress mitigation strategies would be more beneficial in a feedlot setting (Baccarri et al., 1983).

In addition to feeding strategies, sprinkling systems have also been evaluated as a means to mitigate heat stress in feedlot cattle These systems involve the application of water directly to the animal or to pen surface. The intention of water application is to increase evaporative heat loss and/or decrease body temperature during periods of heat stress.

Mader and Davis (2004) evaluated sprinkling the pen surface in the morning or afternoon and also evaluated sprinkling and time of feeding as heat stress mitigation strategies. Pens sprinkled in the morning tended to have better feed efficiency compared with pens sprinkled in the evening. There were no differences in body weight, dry matter intake, or feed efficiency between non-sprinkled and sprinkled calves. These data suggest sprinkling in the afternoon would not be an effective heat stress mitigation strategy whereas sprinkling cattle in the morning could potentially alleviate heat stress although improved efficiency would be minimal compared with non-sprinkled animals. In an additional experiment, Mader and Davis (2004) altered time of feeding and sprinkling and observed no differences among treatments in dry matter intake, body weight, or feed efficiency. These results are in partial agreement with Garner et al. (1989) who indicated sprinkling system effectiveness is likely a result of the climatic environment in which they are implemented, namely air movement and relative humidity. Several sprinkler studies have shown improved performance in feedlot cattle primarily in hot, arid environments where the evaporative cooling would be greatest following water application (Armstrong, 1983; Morrison 1983).

Mitlöhner et al. (2001) evaluated the effects of water misting and shade in two experiments with feedlot heifers during two summers in west Texas. These experiments assessed performance and physiologic effects. Heifers provided no means of heat stress alleviation had the greatest respiration rates. Heifers provided both shade and misting had the lowest respiration rates. Heifers provided only misting and heifers provided shade with no misting were intermediate. Misting had no effect on performance, but shaded heifers had greater average daily gains and dry matter intakes compared with non-shaded heifers. Overall, authors observed no growth performance advantages of misting. Differences in growth performance when cattle are misted are likely associated with the manner water is applied to the skin of cattle. Misting cattle with fine water droplets can exacerbate heat stress symptoms by not penetrating the hair coat and reaching the skin of the animal. Sprinkling however, uses large water droplets which can reach the skin and increase vaporization, thus increasing heat loss (Mitlöhner et al., 2001).

Shade as a mitigation strategy

The use of shade has been an established method of mitigating heat stress in feedlot cattle; however, minimal research has been conducted on growing cattle. Early shade research conducted by Kelly and Ittner (1951) demonstrated increased growth performance when shade was used to mitigate heat stress. Although some studies have shown varied results in growth performance when cattle are provided shade, the use of shade during periods of heat stress has added management and animal welfare benefits, such as decreased panting behavior, respiration rates, and improvements in feed efficiency (Fuquay, 1981; Morrison, 1983; Brown-Brandl, 2018; Edwards-Callaway et al., 2021).

To determine the effect of access to wind barriers and shade allocation, Mader et al. (1999a) conducted three summertime trials with steers fed for ad libitum intake. Calves were assigned to pens without shade or to pens with 2.65 m^2 of shade per animal with or without wind barriers. There were no differences in dry matter intake, but feed efficiency from days 0-56 was better for calves provided wind barriers. No differences in feed efficiency, dry matter intake, or average daily gain were observed when the three trials were compiled; however, cattle provided shade had greater average daily gain and feed efficiency during trial 1. Authors noted there were numerically less days above THI 72 for years 2 and 3, and this could have precluded beneficial effects of shade. Overall, authors concluded that provision of shade when THI is elevated improves animal performance, particularly when longer duration heat stress events occur.

Gaughan et al. (2010) evaluated physiological responses to heat stress in calves housed in shaded or non-shaded pens. Shade was provided at 3.3 m^2 per animal and 4 m above the ground. No differences in body temperature were detected when averaged over the entire duration of the study; however, during a 21-day heat stress event, body temperature was lower in calves provided shade compared with calves not provided shade. In addition, shaded cattle also had greater average daily gains, feed efficiencies, and final body weights than non-shaded cattle. These data are in agreement with previous research demonstrating improvements in growth performance with the addition of shade (Beede and Collier, 1986; Mitlöhner et al., 2001, 2002; Edwards-Callaway et al., 2021)

Hayes et al. (2017) evaluated performance, panting scores, and respiration rates of cattle provided shade or not provided shade. Shade was comprised of a two-tiered snow fence system that was designed to increase and decrease in size as the sun rose and set; shade was placed 4.5 m above the ground. Calves were placed in either shaded or non-shaded pens. the study was undertaken during summer months when heat stress events are typically present, but no prolonged periods of heat stress were recorded. Authors observed reductions in panting score and respiration rates for calves provided shade compared with non-shaded calves. Likely due to the lack of prolonged heat stress events, no performance differences were detected, although numerical differences in average daily gain and feed efficiency hinted at improved performance for calves provided shade. Although performance differences were inconclusive, reduced physiologic responses to heat stress demonstrated a benefit of shade inclusion. During periods of heat stress, shade allocation may improve performance characteristics, and physiologic responses (i.e., panting) to heat stress are less severe (Gaughan and Mader, 2014).

Analysis of panting and respiration rates during periods of heat stress provides a better understanding of the benefits of shade as a heat stress mitigation strategy than assessments when heat stress is absent. Hagenmaier et al. (2016) evaluated shade allocation and zilpaterol (ZH) provision on feedlot performance and physiological symptoms of heat stress. Shade was allocated at 1.5 m^2 per animal. Cattle were observed between 1500 and 1700 h to quantify prevalence of open mouth breathing (panting). Calves provided shade had lower open mouth breathing on days when THI was > 79 compared with non-shaded calves. Shaded cattle had greater dry matter intake compared with non-shaded cattle; however, non-shaded cattle had greater feed efficiency. No differences were observed for average daily gain between shaded treatments. Administration of ZH decreased dry matter intake for all calves; however, decreases in dry matter intake for shaded cattle were less compared with non-shaded cattle. Shade can improve dry matter intake when calves are fed for ad libitum intake; conversely, feed efficiency has had mixed results (Mitlöhner et al., 2001, 2002)

Shade area allowance is an important factor when determining economic impact of shade allocation as a mitigation strategy. Sullivan et al. (2011) assessed shade area allowance on animal performance and physiologic indicators of heat stress. Cattle were provided 0, 2.0, 3.3, or

4.7 m^2 per animal provided by 70% shade cloth that was 4 m high. During heat wave events characterized by a HLI > 86, panting scores were greater for calves in non-shaded pens compared with those in shaded pens. Dry matter intake, average daily gain, feed efficiency, and final body weight was greater for shaded cattle compared with non-shaded cattle. Calves provided 4.7 m^2 of shade had the greatest average daily gain; however, calves provided 4.7 m^2 also had the lowest feed efficiency of the shaded cattle. An economic analysis was conducted to determine return on investment for each shade area provision compared with no shade provision. Value of each treatment was calculated by adding feed cost, yardage, health cost, and pen maintenance subtracted from carcass value to obtain an animal value. Animal values for 0, 2. 3.3, 4.7 m^2 were $565.69, $642.57, $623.81, $627.54, respectively. Ultimately, the 2.0 m^2 treatment had greater financial gain when compared with the remaining shade treatments. Conversely, the 2.0 m^2 shade treatment resulted in greater mean panting scores compared with the 3.3 or 4.7 m^2 groups. Overall, cattle provided access to shade had reduced panting score intensity and better feed efficiency suggesting the provision of shade can be used to improve animal welfare and production efficiency.

Aguilar-Quiñones et al. (2022) evaluated differences in shade area for feedlot cattle in an arid environment. A total of 510 *Bos Indicus* and *Bos Taurus* heifers were assigned to pens of 2.7 or 3.7 m^2 of shade area. The average THI of the study was 81.7 which indicates severe heat stress for feedlot cattle. *Bos Indicus* heifers showed lower respiratory rate compared with *Bos Taurus* heifers. In addition, heifers provided 3.7 m^2 of shade had greater feed efficiency, average daily gain, and total weight gain compared with heifers provided 2.7 m^2 of shade; however, no differences in dry matter intake were observed. These results indicate, based on performance and respiration rate measurements, increasing shade area is beneficial in feedlot cattle reared in an arid environment.

The use of shade by producers to mitigate heat stress varies across the United States from 17% in feedlot pens (Samuelson et al., 2016) to 50% in dedicated hospital pens (Simroth et al., 2017). Rusche et al. (2021) surveyed Midwestern cattle feeders and found that on average 54% of respondents used shade structures. As discussed previously, shade allocation can improve cattle comfort indices and performance markers. When considering feeding cattle during periods of heat stress, cattle feeders should consider improvements in growth performance and animal comfort associated with shade.

In conclusion, heat stress is the culmination of multiple climatic factors which reduce the ability of an animal to return to homeostasis (Gaughan et al., 2000; Brown-Brandl et al., 2018; Edwards-Calloway et al., 2021; NRC, 2016). Factors which affect heat stress severity in cattle can include animal type, dietary energy, and climatic factors (i.e., solar radiation, temperature, wind speed, and relative humidity). These factors must be taken into consideration when feeding cattle during periods of heat stress events. Mitigation strategies should be considered as a component to maximize animal comfort and performance.

Limit feeding high-energy diets

Limit feeding has been utilized in both growing and finishing systems for decades. Restricted feeding refers to limiting the amount of feed an animal is allowed to consume below ad libitum intake (Galyean et al., 1999). Programmed feeding refers to the use of net energy equations to target a specific gain and calculate the amount of feed needed for maintenance and gain (Galyean et al., 1999). Restricting intake through limit feeding is a strategy used in many growing systems to improve feed efficiency, mitigate health risks, and improve management practices. While feeding for ad libitum intake is generally thought to improve performance, by providing the maximum amount of feed possible to an animal, there may be a loss associated with decreases in animal efficiency throughout the feeding period (Loerch, 1990; Ferrell and Jenkins 1998). In a growing calf model, feed efficiency is a crucial factor for determining profitability and sustainability. Limit feeding can improve efficiency and profit margins for many producers.

Limit feeding high-energy diets have considerable advantages compared with traditional high-roughage diets (Galyean, 1999). Since the development of the net energy system to determine the net energy requirement for both maintenance (NE_m) and gain (NE_g), producers can accurately determine the quantity of feed required for a specific amount of gain (Lofgreen and Garrett, 1968; Galyean, 1999). The net energy concentration of feed is negatively correlated to the level of intake; diets will tend to have higher net energy values when fed at lower levels of intake compared to higher intake levels (Lofgreen and Garrett, 1968).

Utilization rates of energy and protein are improved in diets that are limit fed compared with diets fed for ad libitum intakes. Sip and Pritchard (1991) evaluated nitrogen utilization of ruminants that were limit fed high-concentrate diets. In experiment 1, steers were limit fed diets containing 90, 100, 110, or 120% of the crude protein requirement of medium-framed growing steers with monensin included at 120, 180, or 240 mg/day. In experiment 2, steers were either given ad libitum access to a corn silage based or a limit-fed high moisture corn based diet with the same crude protein levels as experiment 1. Limit fed high concentrate diets led to greater feed efficiency than the corn silage diet provided for ad libitum access. Authors also noted no metabolic disorders, such as bloat or acidosis, arising from limit-fed high-concentrate diets. In experiment 3, using 24 lambs the effect of diet on nitrogen digestion and metabolism was assessed when net energy intake was identical. Lambs were provided corn silage for ad libitum intakes or limit fed a high-moisture corn diet. Limit-fed lambs had less fecal output compared with lambs fed for ad libitum intake. Reducing fecal output has implications for decreased management costs associated with manure removal and reduced environmental impact associated with manure decomposition or runoff.

Knoblich et al. (1997) fed finishing steers for ad libitum intake or restricted intake to determine if limited intakes had negative consequences on animal performance. Steers were programmed to gain 1.13 kg/d and intake subsequently increased to achieve a gain of 1.36 kg/d once targeted gains of 31.7, 77.1, 77.1, or 54.4 kg depending on the feeding system (1-4) they were assigned. Steers were then maintained at a growth rate of 1.36 kg/d until they reached targeted gains of 77.1, 122.4, 77.1, or 99.8 kg for feeding systems 1-4. Once steers reached the final targeted gain they were fed for ad libitum intake. Steers under restricted intake for a longer duration had greater compensatory gain when moved to being fed for ad libitum intake. Authors observed no negative impacts on final performance when calves were limit-fed for varying days on feed; however, limit-fed calves had better feed efficiency compared with calves fed for ad libitum intake.

Felix et al. (2011) evaluated the impact of dietary energy source during the growing phase on subsequent feedlot performance. Treatments included dried distillers grains or corn and were limit fed to allow gains of 0.9 kg/day or 1.4 kg/day. After 98 days of growing phase treatment, calves were all transitioned to the same diet for the remainder of the study. During the growing phase, inclusion of corn led to greater dry matter intake, average daily gain, and feed efficiency compared with diets fed dried distillers grains. There was no difference in feed efficiency for calves fed for gains of 0.9 kg/day or 1.4 kg/day, but dry matter intake and average daily gain were less for the 0.9 kg/day group than for the 1.4 kg/d treatment. During the finishing phase final body weight did not differ among treatments; however, calves fed to gain 0.9 kg/day took longer to reach final body weight compared with calves fed to gain 1.4 kg/day. By favoring corn as an energy source in limit-fed scenarios greater feed efficiency can be achieved which is a primary benefit of limit feeding growing calves.

Most recently, Spore et al. (2019) evaluated diets of increasing dietary NE_g concentrations from 0.99, 1.10, 1.21, and 1.32 Mcal NE_g/kg of dry matter fed for a targeted gain of 1 kg/day. Diets were formulated to contain 40% wet corn gluten feed with increasing amounts of dry rolled corn replacing prairie hay and alfalfa to modulate energy levels. Daily gains did not differ among treatments, but dry matter intake (i.e., the amount offered) decreased linearly with increasing energy concentration and feed efficiency increased linearly with greater NE_g concentrations. Morbidity and mortality were not different among dietary treatments while average daily gains, by design, were consistent among treatments. Although increasing dietary grain concentration has previously led to increased morbidity, improved performance with increased dietary grain concentration can offset observed morbidity (Rivera et al., 2005; Richeson et al., 2019).

One perceived limitation to industry acceptance of limit feeding is a requirement to have ample bunk space for a majority of calves to eat at the same time. Daily gain and body weight gain variation are also potential concerns when bunk space allotment is reduced when limit feeding growing or finishing calves. Lake (1986) observed no differences in performance when calves were limit-fed twice daily with bunk space of 23 or 30 cm per animal. Zinn (1989) observed no body weight variation differences when feedlot calves were limit-fed with bunk space of 15, 30, 45, or 60 cm. Duncan et al. (2022) evaluated bunk space requirements of limit-fed growing calves with treatments consisting of 25.4, 38.1, 50.8, or 63.5 cm of bunk space per animal and observed no differences in average daily gain or variation in average daily gain over a 58-day growing trial. These data provide an insight into the minimal requirements of bunk space for growing calves limit-fed a high-energy diet.

Use of corn coproducts

Corn processing, into products such as ethanol, produce byproducts and coproducts commonly included in livestock diets. Examples of these coproducts include wet distillers grains and wet corn gluten feed. During ethanol production, starch is removed from corn grain leaving behind a product with relatively low concentrations of starch but high concentrations of fermentable fiber, crude protein, and fat. A common concern with feeding high-energy diets to cattle is an increased incidence of rumen acidosis and liver abscesses (Nagaraja and Titgemeyer, 2007). However, by using a highly fermentable fiber product as an energy source in growing diets, incidence of acidosis and metabolic disorders are similar to roughage-based diets (Spore et al., 2019).

Growing calves are often fed a high-roughage low-energy diet with the intention of reducing mortality and morbidity upon arrival at the feedlot. Wet corn gluten feed, consisting of corn bran and corn steep, has been studied since the 1980's and proven to be an effective ingredient in ruminant diets (Firkins et al., 1985). Corn coproducts, such as wet corn gluten feed, have been evaluated in recent years for effects on performance and health of limit-fed cattle.

Montgomery et al. (2003) attempted to determine the ideal inclusion rate of wet corn gluten feed in limit-fed diets containing alfalfa hay and steam flaked corn. In experiment 1, diets were offered at 1.8% of body weight (dry matter basis) once daily. All experimental diets contained 40% wet corn gluten feed with increasing levels of 0, 10, and 20% alfalfa hay and steam-flaked corn. A control diet contained 20% alfalfa, 65% steam flaked corn and no wet corn gluten feed. Average daily gain and feed efficiency decreased with wet corn gluten feed inclusion, but average daily gain and feed efficiency of the diet containing 10% alfalfa hay and 40% wet corn gluten feed was not different compared with control. In experiment 2, calves were fed at 1.6% of body weight (dry matter basis) once daily. Diets contained 10, 20, or 30% alfalfa and 0, 40, or 68% wet corn gluten feed, with the remainder of the energy provided by steam flaked corn. Average daily gain and feed efficiency decreased as inclusion of wet corn gluten feed or alfalfa increased, although the diet with 40% wet corn gluten feed and 30% alfalfa hay inclusion yielded average daily gain similar to 0% wet corn gluten feed diets with 20 or 30% alfalfa inclusion. Feed efficiency was better for diets containing 40% wet corn gluten feed and 30% alfalfa compared with diets containing no wet corn gluten feed. Authors concluded inclusion of alfalfa hay with wet corn gluten feed may improve the net energy value of wet corn gluten feed. Aggressive meal eating behavior was observed when calves were limit fed 1.6% body weight daily, likely leading to an unstable rumen environment.

Diet digestibility of limit-fed diets

Traditional roughage-based growing diets are typically less digestible than high concentrate limit-fed diets. Increasing dry matter digestibility can improve energy utilization and growth performance. Maximum feed efficiency is thought to be reached when intake is maximized; however, feed efficiency may be maximized at levels below maximum intake when animals are fed diets of greater energy density. Although results in average daily gain have been mixed, increases in feed efficiency can improve the economic viability of limit feeding (Loerch and Fluharty, 1998). Improvement in feed efficiency is a function of dry matter intake and diet digestibility. When calves are limit-fed, utilization of protein and energy in the diet changes due to modulation of passage rate.

Restriction of intake can be used to improve diet digestibility and improve efficiency. Galyean et al. (1979) fed growing steers at maintenance, 1.33, 1.67, and 2 times maintenance to assess differences in diet digestibility and liquid passage rate. Total tract digestibility was greater for calves fed at maintenance and 1.33 times maintenance compared with calves fed 1.67 and 2 times maintenance. Total tract starch digestion was greater for steers fed at maintenance compared with steers consuming diets above maintenance. Passage rate was less for steers fed at maintenance compared with steers fed above maintenance. Compared to higher feeding levels, feeding calves at or near maintenance requirements can improve diet digestibility by reducing passage rate.

Reductions in passage rate improve diet digestibility by allowing more efficient absorption of nutrients by the gastrointestinal tract in the ruminant animal. Murphy at al. (1994) evaluated the effects of corn processing and intake on diet digestibility and blood metabolites. Treatments consisted of limited or ad libitum feeding and whole or processed corn. Limiting intake to 70% of ad libitum intakes reduced passage rate and ruminal volume. In addition, limiting intake and feeding rolled corn led to the greatest digestion of DM, OM, and N. These effects are likely a result of decreased passage rate resulting from a lower dry matter intake.

Montgomery et al. (2004) fed two diets containing 0 or 40% wet corn gluten feed fed for ad libitum intake or at 1.6% body weight (dry matter basis) once daily. Total volatile fatty acid (VFA) concentrations were lower for the wet corn gluten feed diet compared with the diet containing no wet corn gluten feed. Propionate was present in lower concentrations when wet corn gluten feed was included in the diet likely due to a reduction in corn grain. Limit feeding reduced total tract OM and NDF digestion likely as a result of feeding once daily as compared with the findings of Galyean et al. (1979) which limit-fed diets multiple times per day. Rumen pH increased prior to feeding and 12 hours after feeding but decreased immediately post-feeding in limit-fed diets compared with diets offered at ad libitum intakes. Limit-fed diets were consumed in a short time-frame compared with diets fed for ad libitum intake resulting in a more volatile rumen environment when fed at 1.6% bodyweight daily.

Restriction of intake without accounting for dietary energy balance can have adverse consequences in limit-feeding systems. Roberts et al. (2007) fed a common diet containing primarily corn silage and alfalfa hay to growing heifers. Heifers were either fed for ad libitum intake or restricted to 80% of ad libitum intake. Although feed efficiency was better with feed restriction, average daily gain and body weight were less for limit-fed calves compared with cattle allowed ad libitum access to feed. In this experiment, authors did not increase dietary energy concentrations to provide equivalent energy to animals provided restricted diets; therefore, performance differences were likely a result of decreased dietary energy intake in the restricted groups.

Spore et al. (2019) compared diets of increasing energy concentrations at decreasing intake amounts to assess diet digestibility and liquid passage rate. Authors observed a decrease in passage rate with increasing dietary energy and decreasing intake. Acetate concentrations decreased and propionate concentrations increased with increasing dietary energy concentration. Fibrolytic bacteria, which produce predominately acetate, are active at higher pH whereas propionate production by starch digesting bacteria are more active at lower pH. With increasing concentrations of energy in the diet due to increasing levels of starch provided, propionic acid producing bacteria are more active. Propionic acid production is more efficient in ruminant animals as it serves as a hydrogen sink preventing the loss of energy as methane into the environment. Also, propionic acid production provides substrate for gluconeogenesis in the liver.

Use of fermentable fiber in the form of corn co-products as a means to mitigate metabolic disorders associated with high-energy diets allows producers to reduce roughage inclusion in growing diets. Shifts in rumen fermentation characteristics and passage rate associated with limit feeding high-energy diets provide promise for improving efficiency and promoting similar gains associated with traditional roughage based growing calf diets. By reducing feed required per unit of gain, producers are better able to realize greater economic returns and promote sustainable agricultural practices.

Rumination and activity quantification

Behavior and digestibility parameters are affected by a combination of dietary and environmental factors. By quantitatively measuring activity and rumination of growing calves' researchers can better understand how diet and environment impact animal behavior. Traditionally, visual observations of behavior have been the main way to assess activity and rumination. Recent research has used axial accelerometers to quantitatively measure rumination and activity.

Activity and rumination have been measured by axial-accelerometers to quantify differences in animal behavior and rumination characteristics. Being able to objectively measure activity allows for automated monitoring of animal health which can be used in conjunction with visual observations. Reduction in total activity is generally associated with the onset of disease or lameness in beef cattle operations (Richeson et al., 2018). An objective measurement of bovine respiratory disease (BRD) serves as an opportunity to better evaluate disease within the beef cattle industry.

Bovine respiratory disease detection can be achieved accurately via accelerometers monitoring animal activity (Pillen et al., 2016). Munoz et al. (2020) measured activity levels of cattle challenged with BRD to determine a correlation between activity levels and disease prevalence; calves diagnosed with BRD had decreased activity levels. This agrees with multiple observations of a decrease in animal activity during a disease or lameness challenge. Martin et al. (2021) evaluated pain associated with BRD in cattle induced with bacterial pneumonia. Calves with greater lung lesion scores were less active than calves with lower lesion scores representing an inverse relationship of disease severity and activity level. Meanwhile rumination time was not affected by disease severity or treatment group. These data suggest activity level is correlated to disease severity, which is in agreement with previous literature.

Wolfger et al. (2015) conducted an analysis of feeding behavior measured by visual observation and axial accelerometers to evaluate efficacy of accelerometers in sick animal detection. Authors noted high variability between animal's recorded rumination and observed feeding behavior; however, there was a correlation between visual and automated monitoring giving confidence that automated monitoring can be used to assess animal rumination and feeding behavior. Kononoff et al. (2002) evaluated differences in rumination and eating behavior for observation and automated measurements. Authors noted 3.6 to 10.3% greater time spent eating and ruminating with observational measurements.

Digestion and mastication differences among diets with varying roughage concentrations were evaluated by Jennings et al. (2016). Dietary treatments comprised of different cornstalk levels (5, 10, 15%) were used to assess rumination differences in diets with altered roughage levels. Authors found greater rumination time for animals fed 15% corn stalks compared with those fed 5 and 10% corn stalks. Carvalho et al. (2020) also evaluated differences in rumination and feeding time for Holstein and Angus steers fed a forage or grain based diet. Rumination and feeding times were greater for steers provided forage based diets compared with grain based diets. These findings have been extensively studied and show repeatable results in either observed or automated systems (Beauchemin, 2018).

Although axial accelerometers have been traditionally used in the dairy industry to monitor estrus cycles and lameness, beef cattle operations and research can benefit from automated monitoring to detect disease and evaluate performance of individual animals in a quantitative manner (Richeson et al., 2018). Environmental changes and dietary differences can modulate activity and rumination times in growing calves (Scilacci et al., 2022). Accounting for these environmental and dietary factors can allow researchers to better understand behavioral changes in beef cattle.

Water usage by cattle

Water is considered one of the six required nutrient classes for livestock health. Without adequate water intake, cattle have a limited survival time; therefore, it is necessary to provide growing cattle access to clean water. Estimation of water consumption by Klopatek and Oltjen (2022) indicated U.S. beef cattle directly consumed 599 billion liters of water per year. Water is a critical resource for beef production. For example, the Ogallala aquifer supplies much of the plains region with water for both crop and livestock production. Research has shown the Ogallala aquifer continues to be depleted and without proper management of this resource agricultural production could be diminished (Rhodes et al., 2023). During periods of heat stress; water consumption tends to increase as a means for cattle to return to body temperature homeostasis. The benefit of water consumption during a heat stress period is related to the ability of cattle to use evaporative cooling processes (NRC, 2016).

Since the 1950s, several studies have estimated water consumption in cattle. Winchester and Morris (1956) measured water intake in both dairy and beef cattle. The authors compiled data from previous studies using both individual animal data and animals in a group setting to evaluate the relationship between water intake, dry matter intake, and ambient temperature. Water intake remained relatively constant when ambient temperatures ranged from -12.2 to 4.4 °C and increased exponentially when ambient temperature increased above 4.4 °C. Water intake as a function of dry matter intake and ambient temperature increased from 3.09 L/kg at 4.4 °C to 7.34 L/kg at 32.2 °C for beef cattle. As body weight increases, dry matter intake requirements for maintenance and growth increase along with the daily water requirement. As THI increases, heavier cattle require more water to alleviate the symptoms of heat stress (Brown-Brandl et al., 2006; Wagner and Engle, 2021). During summer months, dry matter intake decreases while water usage increases; the inverse is true in the winter months where dry matter intake tends to increase while water usage decreases (NRC, 2016).

Hicks et al. (1988) estimated water consumption using equations from Winchester and Morris (1956) that included factors such as maximum daily temperature, daily precipitation, and dietary salt concentrations as well as body weight and dry matter intake. Hicks et al. (1988) found increasing salt concentrations decreased water consumption which conflicts with Murphy et al. (1983) where authors observed an increase in water consumption with increased salt inclusion in diets fed to Holstein cows. Maximum temperature and dry matter intake explained 65% of the variation between treatment groups. This finding agrees with Winchester and Morris (1956), suggesting temperature and dry matter intake impact water consumption by beef cattle.

Bond et al. (1976) indicated restricting water intake decreases dry matter intake. Authors observed a 13% increase in water intake when calves were withheld feed when consuming high-concentrate diets; conversely, calves consuming an 88% forage diet had a 92% reduction in water usage when feed was withheld. These data suggest water usage may be correlated to dry matter intake and diet composition.

Water usage can vary between summer and winter months. Arias and Mader (2011) compiled seven studies using feedlot cattle during summer and winter months to determine the effects of mean ambient temperature, maximum temperature, minimum temperature, precipitation, relative humidity, wind speed, solar radiation, temperature-humidity index, and dry matter intake on daily water usage. Water usage was greater during summer months compared with winter months. During periods of heat stress, cattle dissipate heat through evaporative processes such as evaporative cooling or panting, which increase water intake (Beede and Collier, 1986). Assessment of different climatic factors indicated THI, solar radiation, minimum temperature, and mean temperature were the primary factors in predicting water intake. Daily minimum temperature influences an animal's ability to dissipate heat overnight during the summer months and maintain body temperature during the winter months.

To determine effects of bunk management on water usage, Ahlberg et al. (2018) summarized water intake and climatic conditions of steers fed for ad libitum intake or steers fed using a slick bunk protocol. Authors observed under bunk managed conditions that dry matter intake and ambient temperature were primary drivers of water intake, whereas water intake of calves fed for ad libitum intake was correlated to animal body weight and ambient temperature.

Mader and Davis (2004) evaluated different feeding strategies to reduce heat stress in cattle. In experiment 1, 144 steers were used to determine differences in water intake when calves were fed for ad libitum intake at 0800, fed at 1600 adjusted to have no feed left at 0800 the following day, or limit-fed at 85% of ad libitum intake at 1600. Limit feeding reduced water intake by 6.8 L/day compared with calves fed for ad libitum intake. Reduced water intake in limit-fed calves compared with calves fed for ad libitum intakes demonstrate the expected correlation between water intake and dry matter intake (Winchester and Morris, 1956; NRC, 1981; Davis et al., 2014; Sexson et al., 2012). In experiment 2, 96 steers fed the same diet were used to evaluate the effects of no pen surface water application, pen surface water application between 1000 and 1200 h, or pen surface water application between 1400 and 1600 h. No differences in water intake or dry matter intake were observed among treatment groups; however, feed efficiency tended to be better for calves sprinkled during the morning hours. In experiment 3, 192 steers were provided treatments arranged in a 2×2 factorial comprised of feeding time (i.e., 0800 vs 1400 h) and sprinkling (i.e., sprinkling vs no sprinkling) of pens. Calves fed at 0800 h and not sprinkled had greater water intake compared with all other treatments. Based on these observations, cattle exposed to heat stress have greater water consumption compared with calves exposed to heat stress mitigation strategies.

Brew et al. (2011) evaluated water intake of heifers, bulls, and steers of both *Bos Taurus* and *Bos Indicus* origin. Calves were housed in a group setting, and individual water usage was measured using a GrowSafe system. Temperatures remained within the thermal neutral zone for the duration of the study, so no heat or cold stress occurred. Authors observed greater water consumption of *Bos Taurus* breeds compared with *Bos Indicus* breeds which agrees with previous studies evaluating breed differences in water intake (Winchester and Morris, 1956; Colditz and Kellaway, 1972; Beatty et al., 2006). On average, calves consumed 2.98 L/kg of dry matter per day while gaining 1.41 kg/day. These data are in agreement with Winchester and Morris (1956); however, water intakes were significantly less than predictions from equations derived from Hicks et al. (1988). Authors attributed this divergence to differences in animal housing and environmental conditions.

To evaluate correlations between dry matter intake and water consumption, Davis et al. (2014) measured body weight gain, dry matter intake, and total water intake using 143 crossbred steers. Authors determined that dry matter intake explained most of the variation in body weight gain between animals. Water intake also correlated to dry matter intake and body weight which aligns with previous literature (Winchester and Morris, 1956; Hicks et al., 1988; Arias and Mader, 2011; Ahlberg et al., 2018).

In conclusion, many animal, management, and environmental conditions contribute to water intake of cattle. Several studies have concluded that ambient temperature, dry matter intake, and animal weight are significant driving factors behind water usage. Water conservation is necessary, given projections of a reduced water supply for a majority of the United States through 2070 (Brown et al., 2019). By understanding the water consumption of beef cattle in U.S. production systems, producers can more accurately predict and plan for livestock water usage.

Conclusion

Environmental impacts such as heat stress have a profound impact on beef cattle well-being and productivity. Implementing heat-stress mitigation strategies, such as shade, that are economically viable for producers in geographic locations prone to elevated ambient temperatures and solar radiation, can provide cattle a more suitable environment. Use of heat stress mitigation techniques (i.e. shade) can improve animal performance, reduce water usage, improve animal comfort and allow livestock to better cope with extreme environmental conditions. Replacing roughages in traditional growing diets with fermentable fiber sources can reduce costs associated with roughages and improve animal performance during the growing phase. Utilization of limit-fed high-energy diets can improve diet digestibility by reducing passage rate and maintenance requirements in growing cattle, leading to improved efficiency and reduced water usage. Using heat stress mitigation strategies and limit-feeding have the potential to improve sustainability within the growing calf industry.

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Chapter 2 - Effects of limit feeding and shade on growing cattle during periods of heat stress

INTRODUCTION

Periods of elevated heat load can negatively affect productivity and animal welfare in beef cattle systems (Edwards-Calloway, 2021). In extreme instances, elevated temperatures paired with high relative humidity and solar radiation can result in mortality losses in livestock systems (NPR, 2022). St. Pierre et al. (2003) quantified economic losses to the beef industry as a result of heat stress to be approximately $369 million/year due to mortality, reproduction loss, and performance loss. With abnormal heat stress events continuing to occur, it is evident mitigation strategies must be implemented to improve livestock efficiency and animal comfort. Heat stress mitigation strategies (e.g., shade) can be used to improve performance, animal comfort, and reduce water consumption in beef cattle (Morrison, 1983; Beede and Collier, 1986; Edwards-Calloway et al., 2021).

Recent research has demonstrated high-energy limit-fed diets can improve feed efficiency without detrimental effects on performance characteristics (i.e., body weight gain, average daily gain; Spore et al., 2019). By replacing traditional high-roughage diets fed for ad libitum intake with limit-fed high-energy diets, producers can achieve similar gains with less total feed input. In addition, reducing dry matter (DM) intake may modulate heat production, which could potentially improve animal welfare and performance (Mader and Davis, 2004).

To our knowledge, no work has been conducted evaluating limit-fed high-energy diets in conjunction with shade in growing cattle. The objectives of this study were to evaluate the use of shade and limit feeding a high-energy diet on performance, animal comfort, water usage, diet digestibility, and ruminal characteristics during periods of heat stress.

MATERIALS AND METHODS

All procedures involving the use of animals were approved by Kansas State University Institutional Animal Care and Use Committee (IACUC #4181 and #4182).

Experiment 1-Receiving Trial, Year 1

A total of 413 black-hided heifers (246 ± 15.1 kg) were purchased from Kansas and Missouri and transported to Kansas State University Beef Stocker Unit on May 19, May 26, and June 19, 2021. Heifers were blocked by truckload (4), stratified by individual arrival weight within block, and assigned to pens containing 9 to 12 heifers. Each block contained 8 pens. Within block, pens were assigned to 1 of 4 treatments for a total of 40 pens and 10 replications per treatment. The experimental design was a randomized block design with a 2 × 2 factorial arrangement of 4 treatments: limit-fed shade, limit-fed no shade, ad libitum shade, and ad libitum no shade. Pen was the experimental unit.

On arrival (d -1), cattle were individually weighed, assigned a visual identification ear tag and an electronic identification ear tag, and provided 2.27 kg of prairie hay per animal (DM basis) with ad libitum access to water. On d 0, heifers were administered a 7-way clostridial vaccine (Vision 7 with SPUR, Merck Animal Health, Madison, NJ), a modified-live vaccine to protect against infectious bovine rhinotracheitis, parainfluenza, and bovine viral diarrhea type 1 and 2 (Vista Once SQ, Merck Animal Health), and an anti-parasitic drench (Valbazen, Zoetis Animal Health, Parsippany-Troy Hills, NJ).

Prior to arrival, two shade structures (12.19 m × 12.19 m) per block of 8 pens were randomly assigned to cover 2 pens per structure; for the two pens under a common shade structure, one pen was fed each of the dietary treatments. Therefore, 4 pens per block were shaded (SH), and the remaining 4 were non-shaded (NSH). Shade structures provided 7.2 ± 0.6

m^2 of shade per animal (Strobel Manufacturing Inc., Clarks, NE). Pens were soil-surfaced and of equal size (9.1 × 15.2 m) with bunks of 9.1 m in length attached to a 3.6-m concrete apron.

Experimental diets are presented in Table 2.1 and Table 2.2. Dietary treatments included a high-energy diet formulated to provide 1.32 Mcal NEg/kg DM limit-fed at 2.2% of body weight/d (LIM) and a high-roughage diet formulated to provide 0.99 Mcal NEg/kg of DM fed for ad libitum intake (ADLIB). Animals were fed once daily beginning at 0700 h using a Roto-Mix feed wagon (Model 414-14B, Dodge City, KS). Bunks were observed prior to feeding to estimate ad libitum intake. Refusals for ad libitum diets were targeted at 5% of dry matter consumed the previous day. Using a pen scale (Rice Lake Weighing Systems, Rice Lake, WI), pen body weights were measured weekly from day 14 to 84 and on days 0, 90, and 97. Pen weights were used to adjust feed delivery for LIM diets and calculate animal performance. At the completion of the 90-day feeding period, a gut-fill equilibration diet was fed for 7 days to balance for differences in gastrointestinal tract fill between limit-fed calves and calves fed for ad libitum intake. The gut-fill equilibration diet was offered at 2.5% of body weight daily (DM basis) and formulated to contain 1.15 Mcal NEg/kg DM.

All animals were observed twice daily for signs of depression, lameness, nasal or ocular discharge, and morbidity. Animals displaying signs of morbidity were taken from the pen for further evaluation. Rectal temperature was measured and a clinical illness score was assigned. Animals pulled and exhibiting a rectal temperature of >40°C were treated according to study health protocol. Animals pulled for the first time were treated with florfenicol (Norfenicol, Norbrook Labs, Lenexa, KS), second treatment consisted of enrofloxacin (Enroflox 100, Norbrook Labs), and third treatment consisted of oxytetracycline (Pro LA 300, Norbrook Labs). Heifers treated three times were designated a chronic and removed from study.

Rumination and activity

In year 1, all animals received a 3-axial accelerometer on day 0 (Allflex Livestock Intelligence, Madison, WI). Tags continuously recorded activity and rumination, which was summarized in 2-h increments and compiled for daily activity and rumination measurements (min/day). Rumination measurements quantify rumination and mastication values. Activity measurements quantify all animal activity, not including rumination and mastication. Data from the first 10 days were removed to allow accelerometer readings to stabilize.

Nutrient Analysis

Feed ingredient samples were collected weekly. A portion of the sample was used to determine diet dry matter and the remaining feed sample was immediately frozen. Weekly ingredient dry matters were used weekly to adjust diet dry matter. At the completion of the feeding period, feed ingredient samples were thawed, composited, and sent to a commercial laboratory for nutrient analysis (dry matter [DM], organic matter (100 – ash; AOAC International, 1997), crude protein (N × 6.25; Van Soest, 1991), neutral detergent fiber (NDF; Van Soest, 1991), acid detergent fiber (ADF; Van Soest et al., 1991), calcium (Bowers and Rains, 1988), phosphorus (AOAC International, 1997); Table 2.1, Table 2.2, Table 2.4) by SDK Labs, Hutchinson, KS.

Weather measurements

Weather data was continuously measured using a Davis weather station (Vantage Pro 2, Davis Instruments Corporation, Hayward, CA) located in the center of the feedlot. Weather data collected included: ambient temperature (°C), relative humidity (%), wind speed (km/h), and solar radiation (W/m^2). These data were used to calculate temperature humidity index (THI).

Animal Comfort Index

Criteria used for panting score evaluation are presented in Table 2.3. To determine the effects of shade on animal comfort, animals were evaluated at 0930, 1330, and 1730 h on days when the temperature humidity index (THI) was estimated to be greater than 74 using the US MARC Animal Comfort Index. Using a method adapted from Guaghan et al. (2008; Table 2.3) individual panting score was determined using respiration rate and breathing conditions. Three animals per pen were selected randomly at each time point to represent each pen. The 3 values were averaged for each time point and for each day to obtain a mean panting score for each pen on an hourly and daily basis.

Water usage

Water usage was measured using iPERL water meters (SENSUS, Morrisville, NC) connected to individual automatic waterers (Lil' Spring 3000; Miraco Livestock Water Systems, Grinnell, IA) for each pen. Total water usage for each pen was divided by the number of animals per pen to determine daily water usage per animal.

Experiment 1-Receiving Trial Year 2

A total of 439 crossbred heifers (246 ± 15.2 kg) were purchased from Missouri and Iowa and shipped to the Kansas State University Beef Stocker Unit. Each of 5 truckloads represented a block and arrived on May 24h, May 25, and June 4, 2022. Three-axial accelerometers were not assigned in this experiment. All other experimental design and procedures are the same as receiving year 1.

Net Energy Calculations

In receiving trials, performance data were used to calculate net energy for maintenance and gain based on NRC (1996) nutrient requirement equations. Initial (d 0) and final (d 97) body weights were shrunk 4% prior to use in net energy calculations.

Experiment 2-Intake and Digestibility Study

Digestibility Trial Year 1

A group of 8 ruminally cannulated black-hided heifers (254 ± 29 kg) was used in a replicated 4 × 4 Latin square design with 4 consecutive 15-day periods. Experimental unit was animal within period. Eight soil surface pens (5.9 m × 11.8 m) with a group of 4 pens sharing a 378.5-L water tank were used to house the cannulated heifers. One group of 4 pens shared 2 shade structures, each 3.7 m × 4.9 m (JobSmart, Tractor Supply, Brentwood, TN) to provide 8.9 m^2 of shade per animal. Cattle were fed once daily at 1000 h. Feed was mixed for Exp 1. and the beginning of each wagon load was removed for feeding heifers in Exp. 2. Ingredient samples were collected on days 10 to 14 and frozen. At the conclusion of each period samples were composited and sent to a commercial laboratory for nutrient analysis (SDK Laboratories, Hutchison, KS; Table 2.4). All treatments from Exp. 1 were used in Exp. 2. Each 15-day period included 10 days for diet adaptation, 4 days for fecal collection, and 1 day for rumen sampling.

On days 4 to 14, 10 g of chromium oxide, which had been weighed into 29.57-mL gelatin capsules (Torpac, Fairfield, NJ), was placed through the rumen cannula below the hay mat for use in measuring total tract digestibilities. Fecal samples were collected from each animal on days 11 to 14 at 8-h intervals post-feeding. Fecal sampling times were advanced each day by 2 h to represent each 2-h interval post-feeding. Immediately following collection, 100 g of sample was composited within animal within each period.

On day 15 prior to feeding and 2, 4, 6, 8, 12, 18, and 24 hours after feeding, 4 locations of the rumen were sampled and composited immediately. Rumen fluid samples were strained through 8 layers of cheesecloth, then 1 mL of rumen fluid was pipetted into 4 2-mL microcentrifuge tubes containing 250 µL of 25% (wt/vol) m-phosphoric acid then immediately frozen at -20°C. At the completion of the experiment, samples were thawed and ruminal volatile fatty acid (VFA) and ammonia concentrations were measured. After rumen sampling prior to feeding (hour 0), 3 g of Cobalt-EDTA (containing 0.4 g cobalt) dissolved in 200 mL of deionized water was dosed via rumen cannula. Rumen fluid (15 mL) was collected and pipetted into 20-mL scintillation vials at 2, 4, 6, 8, 12, 18, and 24 hours after feeding and immediately frozen at -20°C. These samples were used to measure cobalt concentration to estimate liquid passage rate and ruminal liquid volume.

Laboratory Analysis

Feed samples were collected separately from Exp. 1, composited, frozen, and sent to a commercial laboratory for nutrient analyses previously described in Exp. 1 (dry matter, organic matter, crude protein, neutral detergent fiber, acid detergent fiber, calcium, phosphorus) by SDK Laboratories. After initial analyses, subsamples which had been dried and ground through a 1-mm screen were returned for further analyses.

Ruminal fluid samples for VFA and ammonia analyses were centrifuged at 17,000 × g for 30 min at 4°C. Supernatant for VFA analysis was analyzed using gas chromatography (Vanzant and Cochran 1994). With this analysis, isovalerate includes both 2-methylbutyrate and 3-methylbutyrate. Ruminal ammonia analysis was conducted according to the procedures described by Broderick and Kang (1980).

Cobalt concentration in rumen fluid samples and initial cobalt-EDTA dose were measured using atomic absorption spectrophotometry. Analysis of Cr was conducted to determine apparent total tract digestibility. Fecal samples were dried, ground through a 1-mm screen, and analyzed following procedures described by Williams et al. (1962).

Digestibility Trial Year 2

Eight ruminally cannulated heifers (255 ± 17 kg) were used to determine diet digestibility and ruminal characteristics. All experimental procedures were the same as experiment 2 year 1.

Animal Observations Removed from Data Analysis

One period of ruminal pH data was removed from year 1 due to a faulty pH meter. Measurements of pH, VFA, and ammonia during period 3 year 1 were missing for two heifers, one receiving LIM NSH and one receiving ADLIB NSH treatment due to loss of ruminal contents prior to collection on day 15. During year 2, 4 days were added to adaptation time at the beginning of period 4.

Statistical analyses

In Exp. 1, performance, dietary net energy concentrations, rumination, activity, panting scores, and water usage data were analyzed using the MIXED procedure of SAS (SAS 9.4, SAS Inst. Inc., Cary, NC). Data were analyzed separately for year 1 and year 2, and together. When analyzed by year, the model included fixed effects of diet, shade, diet × shade and a random effect of block. Pen served as the experimental unit. When analyzing data for both years, the model included fixed effects of diet, shade, diet × shade, year, diet × year, shade × year, diet × shade × year, and a random effect of block within year.

Panting score models included fixed effects of diet, shade, diet × shade, time, diet × time, shade × time, and diet × shade × time. Random effect of block was used. Panting score data were also averaged over the duration of the study by hour and analyzed with the models described for performance.

Rumination and activity data were analyzed with diet, shade, diet × shade, time, diet × time, shade × time, diet × shade × time as fixed effects with time (day or hour) as the repeated measure using pen as the subject; block was included as a random effect. The covariance structure for rumination and activity was spatial power as determined by better-fit characteristics of Akaike information criterion (AIC) and Bayesian information criterion (BIC). For the analyses by day, data were first averaged within day, whereas for analyses by hour data over d 10 to 89 were first averaged within hour.

In Exp. 2, all data were analyzed using the MIXED procedure of SAS with animal within period as the experimental unit. The nonlinear procedure of SAS was used to regress the natural logarithm of ruminal cobalt concentrations against time using samples collected from 2 to 18 h for each animal. Liquid passage rate was calculated as the additive inverse of the slope of this regression. Ruminal liquid volume was calculated by dividing the amount of cobalt dosed by the 0-h intercept of the regression after back converting the intercept to concentration.

Nutrient intakes, diet digestibility, liquid passage rate, and ruminal liquid volume were analyzed with diet, shade, diet × shade, and period as fixed effects and animal was included as the random effect. For repeated measurements, fixed effects were diet, shade, diet × shade, period, hour, diet × hour, shade × hour, and diet × shade × hour. Animal was included as a random effect. The repeated measure was hour, and animal × period served as the subject. For combined years, analyses also included fixed effects of diet × year, shade × year, shade × diet × year. Covariance structure was compound symmetry or spatial power according to AIC and BIC statistics. For all analyses, significance was declared at $P \leq 0.05$ and tendencies at $P \leq 0.10$.

RESULTS AND DISCUSSION

Experiment 1-Receiving Year 1

Effect of diet

Weather data

Weather data for 2021 (Year 1) are presented in Table 2.5. Mader et al. (2006) described $74 < THI < 79$ to be considered in the alert category for heat stress with $79 \leq THI < 84$ considered danger and $THI \geq 84$ considered emergency. Maximum THI throughout the feeding period was 96.6 and the minimum THI, which occurred at the beginning of the trial, was 49.2. The average THI during the trial period was 76.1 with a standard deviation of 7.9. Solar radiation averaged 445.8 W/m^2 from 0800 to 1900 h throughout the duration of the study.

Growth performance

Performance data from year 1 are presented in Table 2.6. On day 0, body weights did not differ ($P = 0.46$) between dietary treatments. Body weights on day 14 were greater ($P < 0.01$) and on day 90 tended to be greater ($P = 0.10$) for ADLIB compared with LIM. However, following the 7-day gut-fill equilibration period, ADLIB had lesser ($P < 0.01$) body weights compared with LIM. The reversal between diets for heavier body weights between days 90 and 97 can be explained by changes in gut fill, with LIM heifers gaining gut fill over this period. Through day 90, average daily gain was greater ($P = 0.04$) for ADLIB compared with LIM likely as a result of differences in gut-fill. Conversely, after the gut-fill equilibration period, average daily gain was greater ($P < 0.01$) from day 0 to 97 for LIM compared with ADLIB.

By design, dry matter intake from day 0 to 90 was greater ($P < 0.01$) for ADLIB compared with LIM. Dry matter intake did not differ ($P = 0.71$) between ADLIB and LIM treatments from day 90 to 97 because the gut-fill equilibration diet was provided at 2.5% of day

90 body weight daily to all treatments. Gain:feed (G:F) was greater ($P < 0.01$) for LIM compared with ADLIB throughout the duration of the study as a result of both greater average daily gain and less dry matter intake from days 0 to 97 for LIM compared with ADLIB. Performance-based net energy calculations were greater ($P < 0.01$) for LIM compared with ADLIB. Spore et al. (2019) also demonstrated improvements in feed efficiency of more than 23% when comparing a 1.32-Mcal/kg diet fed at restricted intake to a 0.99-Mcal/kg diet fed for ad libitum intake.

Health

Low incidence of respiratory morbidity and mortality were observed during year 1. A total of 11 animals were treated (2.66%) for respiratory illness with 1 from ADLIB NSH, 3 from LIM NSH, 2 from ADLIB SH, and 5 from LIM SH. A total of 42 animals (10.17%) were treated for pinkeye with 14 from ADLIB NSH, 8 from LIM NSH, 10 from ADLIB SH, and 10 from LIM SH. A total of 2 (0.4%) were treated for coccidiosis, 1 from ADLIB SH and 1 from LIM NSH.

Activity and Rumination

Rumination was greater ($P < 0.01$; Table 2.6; Figure 2.2) over the feeding period for ADLIB compared with LIM heifers. In addition, a diet × hour interaction was observed where ADLIB ruminated more ($P < 0.01$; Figure 2.1) compared with LIM from 2000 to 0600 h. ADLIB ruminated less ($P < 0.01$) compared with LIM at 1000 h. Jennings et al. (2016) observed increasing levels of cornstalk inclusion increased rumination time. Similarly, Carvalho et al. (2020) determined that rumination time was greater in roughage-based diets compared with grain-based diets. These data in combination with ours suggest increasing dietary roughage level increases time spent ruminating.

Overall, activity was lesser ($P < 0.01$) for ADLIB compared with LIM, but LIM were notably more active than ADLIB at 0600 h ($P < 0.01$). In populations of limit-fed animals with greater activity level prior to feeding, it may be easier to detect less active or lethargic (i.e., potentially sick). Limit-feeding has been used by producers as a means to improve disease detection and management (Galyean, 1999). Our data also suggest limit feeding may be beneficial in allowing detection of sick or distressed animals prior to feeding, which might improve disease treatment and decrease loss associated with morbidity.

Animal Comfort

Mean panting score data are presented in Figure 2.3 and Table 2.7. Panting scores did not differ ($P = 0.51$) when averaged across the study; however, when analyzing across days panting scores tended to be greater ($P = 0.09$; Figure 2.3) in ADLIB compared with LIM. Holt et al. (2004) compared responses of limit-fed heifers to those of heifers fed for ad libitum intake during periods of heat stress. Animals were fed at 1600 h throughout the study. Authors concluded that limit-fed heifers shifted maximum rectal temperatures to cooler hours of the day which contributed to a decrease in heat load during the hottest portions of the day. Our results show LIM accumulated less heat load compared to ADLIB as a result of their dietary and feed management differences.

Water Usage

Water usage data are presented in Table 2.6. Water usage was greater ($P < 0.01$) for ADLIB compared with LIM. Water intake is positivity correlated with dry matter intake (NRC, 1981; Davis et al., 2014); thus, as dry matter intake decreases, water intake decreases. Mader and Davis (2004) evaluated the effects of limit feeding and feeding for ad libitum intake on water consumption. The authors demonstrated less water intake in limit-fed calves compared with calves fed for ad libitum intake. In our experiment, dry matter intake was less for LIM compared with ADLIB; therefore, it appears that limit feeding could lead to a reduction in water usage.

Effect of shade

Growth performance

No diet × shade interactions ($P \geq 0.12$) were observed for body weight, dry matter intake, or G:F. Day 0 body weights did not differ ($P = 0.28$) between SH and NSH. Day 14 body weights did not differ ($P = 0.89$) between treatments. Shade had greater ($P = 0.04$) body weights compared with NSH on day 90; however, following the gut-fill equilibration period, day 97 body weights did not differ ($P = 0.19$). A diet × shade interaction was observed where SH increased ($P = 0.03$) average daily gain of ADLIB to a greater extent compared with LIM from day 0 to 90. Shade had greater ($P < 0.01$) average daily gain compared with NSH through day 90. Average daily gain tended to differ ($P = 0.06$) between SH and NSH treatments from day 0 to 97. Mader et al. (1999) observed no differences in average daily gain over a 3-year period which they attributed to the lack of days above THI 74; however, authors did observe greater feed efficiency for calves provided shade compared with calves not provided shade. Similarly, through day 90, shaded heifers tended to have greater ($P = 0.07$) G:F compared with non-shaded heifers.

Activity and Rumination

Total daily activity tended to be greater ($P = 0.10$; Table 2.6; Figure 2.2) for SH compared with NSH. A possible explanation for SH to have greater activity would be related to an increase in standing time of heat stressed animals (Edwards-Calloway et al., 2021). This could result in animals experiencing less heat stress conditions being more active within the pen. Overall, no differences ($P = 0.39$) were observed between shaded treatments for hourly activity and no shade interactions were observed.

Total daily rumination of SH was lesser (*P* = 0.02; Table 2.6; Figure 2.2) compared to NSH. Hourly rumination did not differ (*P* = 0.31) between shade treatments. However, a shade × hour interaction was observed where SH ruminated less (*P* < 0.01; Figure 2.1) than NSH from 1400 to 1600 h. Brscic et al. (2007) found cattle exposed to THI above 78 had greater rumination times compared with animals exposed to THI below 72. In our experiment, rumination times of NSH was greater which could be interpreted as animals exposed to greater levels of heat stress ruminate for greater durations.

Animal Comfort

Shade had lower (*P* < 0.01; Table 2.7) mean panting scores than NSH at 0930, 1330, 1730, and overall. Sullivan et al. (2011) determined that calves provided shade during periods of elevated heat load exhibited lower panting scores compared with non-shaded calves. The reduction in panting scores in their experiment was attributed to reduced solar radiation exposure in SH compared with NSH. Reducing solar radiation can limit the amount of heat absorbed by the animal and decrease the need to expend energy to remove heat by increasing respiration rate and panting behavior.

Water usage

No diet × shade interactions (*P* = 0.86) were observed for water usage. Water usage was less (*P* < 0.01; Table 2.6) for SH compared with NSH. Reduced water usage may be associated with a reduction in the heat load with shade provision. Schutz et al. (2010) evaluated differences in time spent at water troughs for calves housed in shaded or non-shaded pens. When calves were provided access to shade of 9.6 m^2 or 2.4 m^2 the amount of time spent at a water source was less than for calves without access to shade. These data in combination with ours suggest cattle provided shade spend less time drinking water or using water to alleviate heat stress symptoms through evaporative processes.

Experiment 1-Receiving Year 2

Effects of diet

Weather Data

Weather data for year 2 are presented in Table 2.8. Maximum THI during trial period was 87.9 while the minimum THI was 52.5 and occurred in the first month of the experiment. The average THI during the trial period was 76.2 with a standard deviation of 6.7. Throughout the study, THI was greater than 74 for 78 days. Solar radiation averaged 466.5 W/m^2 from 0800 to 1900 h throughout the study. These data suggest heat stress conditions were prevalent during the duration of the study. Year 1 weather conditions were similar to year 2; however, year 1 had greater THI standard deviation.

Growth performance

Performance data from Year 2 are presented in Table 2.9. Day-0 body weight did not differ (P = 0.79) among treatments. Day-90 body weights were greater (P = 0.03) for ADLIB compared with LIM. No differences in body weight (P = 0.99) were observed between diets on day 97. Average daily gain was greater (P < 0.01) for ADLIB compared with LIM from day 0 to 14 and from day 0 to day 90; however, average daily gain did not differ (P = 0.84) between diets following gut-fill equilibration period. These results agree with results of Schoonmaker et al. (2003) who indicated final body weights did not differ between steers fed for ad libitum intake compared with limit-fed steers. Throughout the duration of the study dry matter intake was greater (P < 0.01) for ADLIB compared with LIM. During the gut-fill equilibration period, no differences (P = 0.22) in dry matter intake were observed between treatments. Gain:feed between days 0 and 14 was greater ($P < 0.01$) for ADLIB compared with LIM. Differences in G:F from day 0 to 14 likely were the result of differences in gut-fill. Conversely, G:F from day 0 and 97 was greater ($P < 0.01$) for LIM compared with ADLIB. Our results are similar to those derived by Schoonmaker et al. (2003) who reported feed efficiency was improved by as much as 25% when calves were fed a high concentrate diet to gain 0.8 kg/d compared with calves fed a high fiber diet for ad libitum intake. Similarly, feed efficiency in our experiment was as much as 29% greater for LIM diets compared with ADLIB diets.

Health

Low incidence of respiratory morbidity and mortality were observed during year 2. A total of 8 animals were treated (1.82%) for respiratory illness with 1 from ADLIB NSH, 2 from LIM NSH, 2 from ADLIB SH, and 3 from LIM SH. A total of 12 of animals (2.73%) were treated for pinkeye with 4 from ADLIB NSH, 1 from LIM NSH, 4 from ADLIB SH, and 3 from LIM SH.

Animal Comfort

Mean panting scores were greater ($P < 0.01$; Table 2.7) for ADLIB compared with LIM. Increasing dry matter intake and roughage inclusion in ADLIB diets likely increases heat production because of increased ruminal fermentation. Achmadi et al. (1994) evaluated heat production of sheep in response to concentrate or roughage-based diets. These authors observed increased rectal temperature of sheep in a hot environment when fed roughage-based diets compared with diets composed primarily of concentrate; therefore, diets with greater roughage inclusion have a greater potential to increase heat load which can be exacerbated by periods of heat stress.

Water Usage

Water usage data are presented in Table 2.9. Water usage was greater (P < 0.01) for ADLIB compared with LIM. Similarly, Ahlberg et al. (2018) observed dry matter intake significantly affects daily water intake. As dry matter intake increases water intake increases in growing cattle. Therefore, the decrease in water usage observed in this study is likely associated with differences in dry matter intake between ADLIB and LIM treatments.

Effects of shade

Growth performance

No diet × shade interactions were observed for body weight or average daily gain. No differences (P = 0.43) in day-0 body weight between SH and NSH treatments were observed. Shade had greater (P < 0.01) body weights compared with NSH at day 97. Shade increased (P < 0.01) average daily gain compared with NSH. Diet × shade interactions (P < 0.01) were observed for dry matter intake from day 0 to 90 and day 0 to 97 for ADLIB to have increased dry matter intake when provided SH while no difference was observed for LIM between shade treatments. A diet × shade interaction ($P \leq 0.04$) was observed for G:F from day 0 to 90 and day 0 to 97 where ADLIB did not have a change in G:F when provided shade while LIM G:F improved when provided shade. Shade had greater (P < 0.01) dry matter intake and greater (P = 0.01) G:F compared with NSH from day 0 to 97. These results agree with Sullivan et al. (2011) who reported increased body weight, average daily gain, and feed efficiency in shaded calves compared with non-shaded calves. Based on diet × shade interactions for G:F (P = 0.04) as well as for calculated dietary NEg and NEm concentrations (P < 0.01), LIM were more energetically efficient when provided shade, whereas measures of efficiency were not affected when shade was provided to ADLIB. The inability of shade to improve efficiency of ADLIB may be due to the shade increasing dry matter intake, which may have decreased efficiency and offset the benefits of the shade.

Animal Comfort

Panting scores were lower ($P < 0.01$; Table 2.7) for SH compared with NSH. Similarly, Mitlöhner et al. (2001) observed a reduction in panting scores in shaded cattle compared with non-shaded cattle. Mader et al. (2006) compiled several experiments to determine the correlation between environmental factors and panting scores. Authors found a positive correlation between THI and panting scores and interpreted these results to suggest greater THI leads to elevated panting score. In our study, SH likely had less exposure to solar radiation resulting in decreased heat load contribution from solar radiation resulting in lower mean panting scores.

Water usage

Water usage was less ($P < 0.01$) for SH compared with NSH. Arias and Mader (2011) measured water intake during the summer and winter months to determine the effects of various environmental factors on water intake. They observed that animals exposed to lower THI had lower water intake compared with animals exposed to greater THI. The authors also determined that solar radiation had the greatest impact on water intake during the summer months. We interpreted these results to suggest that providing shade in our experiment reduced exposure to solar radiation and decreased heat load experienced by SH cattle resulting in decreased water intake.

Experiment 1 Receiving - Combined Years 1 and 2

Effect of diet

Growth performance

Performance data from Years 1 and 2 combined are presented in Table 2.10 On day 0, body weight did not differ (P = 0.96) between diets; however, on day 90 body weight tended to be greater (P = 0.08) for ADLIB compared with LIM. Following the gut-fill equilibration period, ADLIB tended to have lesser (P = 0.10) body weight compared with previously fed LIM. Different responses between diets during the gut-fill equilibration period demonstrate how diet roughage content and feeding regimen affect gut-fill and subsequently body weight comparisons between treatments. It is important to equalize gut-fill when comparing limit-fed cattle to cattle fed for ad libitum intake to obtain true differences in body weight gain. As discussed previously, Schoonmaker et al. (2003) indicated body weight did not differ when comparing limit-fed calves and calves fed for ad libitum intake at the end of finishing phase. They fed cattle a common diet at 1.8% of body weight daily for 5 days prior to final weighing. However, in that experiment calves were fed to a specific body weight and days to the final body weight were greater for limit-fed calves compared with calves fed for ad libitum intake.

Average daily gains from day 0 to 97 were lesser (P = 0.03) for ADLIB compared with LIM. These results are in contrast to Felix et al. (2011) which reported average daily gain decreased when limiting feed intake. In that experiment authors did not increase dietary energy concentration when reducing dry matter intake; thus, the reduction in average daily gain was clearly a result of reduced energy intake. In limit-fed diets, dietary energy concentrations must be increased to achieve similar or greater growth performance. Spore et al. (2019) observed no difference in body weight or average daily gain when comparing growing calves fed for ad libitum intake a diet formulated to contain 0.99 Mcal of NEg/kg or limit-fed a diet formulated to contain 1.32 Mcal of NEg/kg; however, the limit-fed diet was fed at 85% of ad libitum intake compared with feeding at 2.2% in our study.

By design, ADLIB had greater ($P < 0.01$) dry matter intake compared with LIM. Dry matter intake did not differ ($P = 0.70$) between diets during the gut-fill equilibration period. A diet effect was observed through day 97 for G:F where ADLIB had lower ($P < 0.01$) G:F compared with LIM. Greater G:F in LIM was associated with a lower dry matter intake and greater ($P < 0.01$) average daily gain in LIM compared with ADLIB. Scilacci et al. (2022) compared a limit-fed high-energy diet with a high-roughage diets fed for ad libitum intake. In that experiment, feed efficiency was improved by as much as 26% in limit-fed diets compared with diets fed for ad libitum intake, which is consistent with our findings. By decreasing intake and increasing dietary energy concentration, improvements in feed efficiency can be achieved (Scilacci et al., 2022; Spore et al., 2019).

Animal Comfort

Overall mean panting scores were less ($P < 0.01$ Table 2.7) for LIM compared with ADLIB. Lower panting scores for LIM may be associated with less dietary roughage in LIM diets or less dry matter intake for LIM resulting in lower heat production. Achmadi et al. (1994) assessed differences in heat production in sheep fed diets containing differing roughage levels. Rectal temperature was used to assess heat production, and results indicated increasing dietary roughage content increased heat production, especially during periods of high environmental heat load. Holt et al. (2004) also evaluated differences in dry matter intake during periods of heat stress and the subsequent impact on rectal temperatures. Calves were fed at 1600 h each day regardless of treatment. Treatments consisted of feeding for ad libitum intake, limit feeding at 85% of ad libitum intake and bunk managed to provide feed only from 1600 to 0800 h. Calves fed for ad libitum intake had the greater respiration rates and rectal temperature compared with limit-fed or bunk managed treatments. Limit-fed and bunk managed treatments shifted peak rectal temperature to 2100 to 2200 h compared with peak rectal temperature between 1400 and 1500 h. This shift would allow limit fed animals to reach peak temperature during the coolest portions of the day mitigating the effects of heat stress.

Water Usage

Water usage data are presented in Table 2.10. ADLIB had greater ($P < 0.01$) water usage compared with LIM. Differences in water usage between diets may be attributed to differences in dry matter intake. Winchester and Morris (1956) indicated the relationship between dry matter intake and water intake is positive. In addition, Ahlberg et al. (2018) evaluated slick bunk managed cattle compared with cattle fed for ad libitum intake and also observed a positive correlation between dry matter intake and water intake. Similarly, Mader and Davis (2004) evaluated water intake of limit-fed calves and calves fed for ad libitum intake. The authors determined dry matter intake was positively correlated to water intake. These data suggest limit-fed diets may decrease water usage in growing calves compared with calves fed for ad libitum intake.

Dietary NEm and NEg concentrations calculated from performance were less than expected from diet formulations in both experiments. Net energy values could be lower due to a number of factors in animal performance and growth, such as differences in body composition, which may not be reflected in the dietary energy density. Net energy values were lower ($P < 0.01$) for the ADLIB diet compared with LIM diet because the LIM diet was formulated to contain greater energy to balance the lower intake levels.

Effects of shade

Growth performance

On day 0, body weight did not differ (P = 0.62; Table 2.10) between SH and NSH. Shade had greater ($P \leq 0.04$) day-90 and day-97 body weights compared to NSH. Average daily gains from day 0 to 97 were greater ($P < 0.01$) for SH compared with NSH. Shade had greater (P = 0.04) G:F compared with NSH through day 97 likely resulting from improved animal performance due to reduced heat load under shaded conditions. Dry matter intake did tend to be greater (P = 0.07) during this period for SH compared with NSH because SH weighed slightly more than NSH on day 90 and cattle were limit-fed as a percentage of body weight. A diet × shade interaction (P < 0.01; Table 2.10) was observed through day 90 where SH, compared to NSH, led to greater dry matter intake for ADLIB but not for LIM. This result reflects the beneficial effects of SH on dry matter intake, although the response cannot be manifested when cattle are limit-fed. Our results are in agreement with Sullivan et al. (2011) where body weight, average daily gain, and feed efficiency were greater for shaded cattle compared with non-shaded cattle. Mader et al. (1999), however, observed no differences between shaded calves and non-shaded calves in three experiments. Meanwhile, Hagenmaier et al. (2016) also observed no differences in growth performance between shaded and non-shaded calves, although they did observe an increase in dry matter intake for shaded animals compared with non-shaded animals. These results are often confounded with environmental factors such as THI and days above a THI of 74. Although studies showing performance differences in shaded versus non-shaded cattle occur, these studies typically occur during periods of high THI or during experiments when THI goes above 74 for multiple days. In our experiments THI averaged greater than 76 for the duration of the study, representing periods of elevated THI in both years.

Animal Comfort

Shade had lower ($P < 0.01$) mean panting score compared with NSH at each time point and overall. Sullivan et al. (2011) measured the panting score in shaded and non-shaded cattle. During periods of elevated heat load, cattle in non-shaded areas exhibited greater panting behavior compared with cattle in shaded areas. Previous studies conducted by Mitlöhner et al. (2001) and Mader et al. (2006) demonstrated reduced panting scores when animals were exposed to lower THI and lower solar radiation levels. Reducing heat load experienced by the animal may reduce the use of panting to expel excess heat.

Water Usage

Water usage was less ($P < 0.01$) for SH compared with NSH throughout the study. Arias and Mader (2011) demonstrated similar results where cattle provided shade had a lower water intake compared with non-shaded cattle. Mader and Davis (2004) also observed reductions in water intake when heat stress mitigation strategies were applied. By reducing the heat load of cattle during periods of heat stress, water loss primarily due to increased panting and respiration rate can be reduced.

Experiment 2-Year 1

Effects of diet

Data from experiment 2 year 1 are presented in Tables 2.11 and 2.12. By design dry matter intake was greater ($P < 0.01$) for ADLIB compared with LIM, although differences in dry matter intake between ADLIB and LIM were not large as for the digestibility study. Individual housing the likely was a factor in self-limiting intake of ADLIB. Organic matter, NDF, and ADF intake were greater ($P < 0.01$) for ADLIB compared with LIM. Apparent total tract digestibility of DM did not differ ($P = 0.15$) between dietary treatments; however, apparent total tract OM digestibility tended to be lesser ($P = 0.07$) for ADLIB compared with LIM treatments. Greater OM digestibility could be correlated to decreases in passage rate which is in agreement with Galyean et al. (1979) and Murphy et al. (1994) when calves were limit-fed. Total tract digestibilities of NDF and ADF were greater ($P < 0.01$) for LIM compared with ADLIB.

Ruminal pH (Table 2.12 and Figure 2.5) tended to be greater ($P = 0.09$) in ADLIB compared with LIM. There was also a diet × hour tendency ($P = 0.09$) for ruminal pH to decrease to a greater extent from 2 to 8 h after feeding for LIM compared with ADLIB. From 12 to 24 hours post-feeding pH did not differ ($P > 0.05$) between dietary treatments. Spore et al. (2019) detected differences in ruminal pH of calves fed increasing dietary energy levels. By increasing the proportion of concentrate in the diet, pH will often decrease more than for a roughage-based diet. Tomczak et al. (2019) evaluated different dietary management strategies for newly received cattle. Authors found a greater reduction in ruminal pH when calves were provided diets with a greater proportion of concentrate. Our results are in agreement with Spore et al. (2019) who showed limiting intake allows ruminal pH to return to basal levels prior to the next day’s feeding since limit-fed animals generally consume their feed within 6 h.

Ruminal ammonia concentrations did not differ (*P* = 0.12; Table 2.12) for ADLIB compared with LIM. The lack of differences between dietary treatments is possibly due to the variation within each time point reducing the ability to detect differences between treatments. A diet × hour effect was observed where at hour 12 and 18 ADLIB tended to have greater ($P \leq 0.06$; Figure 2.8) ruminal ammonia concentrations compared with LIM then at hour 24 ADLIB had lesser ($P < 0.01$) ruminal ammonia concentrations compared with LIM. These hourly differences result from greater crude protein availability and intake of ADLIB compared with LIM.

Total ruminal VFA concentrations did not differ ($P = 0.41$; Table 2.12) between dietary treatments. Acetate concentration and proportion was greater ($P < 0.01$) in ADLIB compared with LIM. Propionate concentration and proportion decreased ($P < 0.01$) in ADLIB compared with LIM. As evaluated by Bauman et al. (1971), increased dietary concentrate can shift VFA concentration from acetate towards propionate. In our experiment, propionate concentration tended to increase following feeding to a greater extent in LIM compared with ADLIB (diet × hour $P = 0.07$; Figure 2.11). This shift also resulted in a decrease ($P < 0.01$) in acetate: propionate (A: P) which may help explain improved performance in cattle fed high-energy corn-based diets compared with traditional high-roughage diets. The shift towards increased propionic acid concentrations would promote improvements in animal efficiency and energy utilization (Ørskov, 1978). Butyrate concentration was greater ($P = 0.02$) in ADLIB compared with LIM. Butyrate proportion tended to be greater ($P = 0.09$) in ADLIB compared with LIM. Valerate concentration and proportion was lesser ($P \leq 0.01$) for ADLIB compared with LIM. Isobutyrate concentration and proportions were unaffected ($P \geq 0.59$). Isovalerate concentrations and proportions tended to be lesser ($P \leq 0.07$) for ADLIB compared with LIM.

Liquid passage rate (Table 2.11) was greater (P < 0.01) in ADLIB compared with LIM. Previously, Galyean et al. (1979) demonstrated differences in diet digestibility when feeding steers at increasing levels above maintenance. Authors noted that steers fed at levels closer to maintenance had slower passage rates than those fed above maintenance. Reduced liquid passage rate can be associated with greater total tract digestibility. For example, Murphy et al. (1994) demonstrated increased diet digestibility and decreased liquid passage rate for calves a rolled corn diet fed at 70% of ad libitum intake compared with cattle fed the same diet for ad libitum intake. Authors also noted decreased ruminal liquid volume when reducing intake levels. Ruminal liquid volume in our study was greater (P = 0.02) in ADLIB compared with LIM, possibly resulting from the greater dry matter intake for ADLIB compared with LIM.

Effects of shade

No diet × shade interactions ($P \geq 0.38$) were observed for intakes, diet digestibilities, liquid passage, or ruminal liquid volume. No differences ($P \geq 0.85$) were observed between shaded treatments for DM, OM, NDF, or ADF intake. In addition, apparent total tract digestibilities of DM, OM, NDF, and ADF did not differ ($P \geq 0.55$) between SH and NSH treatments.

Ruminal pH of SH tended to be greater (P = 0.07) compared with NSH. When cattle experience heat stress salivation and drool often increase as a result of increased panting and respiration rates (Gaughan et al., 2008). Saliva serves as a buffer in the rumen through the addition of bicarbonate to the rumen environment. We hypothesize that increased salivation and drooling may reduce the amount of saliva reaching the reticulum and rumen reducing the buffering capacity in heat stressed animals. Increased water consumption during periods of heat stress could potentially reduce the amount of saliva being produced by heat stressed animals contributing to lower pH of NSH animals. Although water intake was not measured during our digestibility studies, NSH had greater water usage compared with SH during year 1 of the receiving trial.

Ruminal ammonia concentrations were lower ($P = 0.02$) in SH compared with NSH. Ruminal ammonia concentration and ruminal pH have an inverse relationship where an increase in ruminal pH leads to higher absorption of ammonia resulting in lower ruminal ammonia concentration. Greater ruminal pH of SH animals, possibly resulting from decreased saliva and bicarbonate reaching the rumen, may alter microbial populations and absorption rates of ammonia.

A diet × shade interaction ($P = 0.04$) was observed for propionate concentration of ADLIB SH to be greater compared with ADLIB NSH; conversely, LIM SH concentration was lesser compared with LIM NSH. A diet × shade interaction ($P \leq 0.04$) was observed for acetate and propionate proportions. Acetate proportions of ADLIB SH was lesser than ADLIB NSH; however, LIM SH had greater proportions compared with LIM NSH. The inverse was true for propionate proportions. No differences ($P \geq 0.15$) were observed between VFA concentrations of acetate, butyrate, isobutyrate, or isovalerate; however, valerate concentrations were lower ($P = 0.05$) for SH compared with NSH. Molar proportions of acetate tended to be greater ($P = 0.09$) for SH compared with NSH. Molar proportions of propionate were lesser ($P = 0.04$) for SH compared with NSH. Molar proportions of butyrate and isovalerate did not differ ($P \geq 0.37$) between shade treatments. Valerate and isobutyrate proportions were lesser ($P \leq 0.01$) for ADLIB compared with LIM.

Digestibility Trial-Year 2

Effect of diet

Intake and diet digestibility data for year 2 are presented in Table 2.13. Dry matter intake, by design, was greater ($P < 0.01$) for ADLIB compared with LIM; intakes of OM, NDF, and ADF were similar greater for ADLIB than LIM. Apparent tract digestibility of DM and OM were lesser ($P < 0.01$) for ADLIB compared with LIM. Acid detergent fiber digestibility was greater ($P = 0.05$) for ADLIB compared with LIM, whereas NDF digestibility was unaffected by diet ($P = 0.94$).

Ruminal pH data are presented in Table 2.14 and Figure 2.6. Ruminal pH did not differ overall between dietary treatments; however, a diet × hour interaction ($P < 0.01$) was observed for ruminal pH to be greater in ADLIB from 2 to 6 hours after feeding but not at later time points. The difference in ruminal pH may be a result of greater availability of fermentable starch in LIM compared with ADLIB. Increasing availability of dietary starch has been shown to decrease ruminal pH immediately post-feeding (Spore et al., 2019). This decrease is short lived however, likely a result of differences between treatments in temporal patterns of feed intake; LIM consumed their feed within 6 h of feeding, whereas ADLIB consumed feed throughout the day.

Ruminal ammonia concentrations are presented in Table 2.14 and Figure 2.9. Concentrations were greater ($P < 0.01$) for ADLIB compared with LIM. This relationship is in contradiction with Clark et al. (2007) in which animals were fed for ad libitum intake and at 80% of ad libitum levels. Authors observed increased ammonia concentration when intakes were reduced. As ruminal pH increases the concentration of ruminal ammonia decreases due to an increased rate of absorption from the rumen epithelium (Lana et al., 1998). In our study, both the amount fed and the composition of the diets differed between treatments; notably the greater amount of starch in the LIM diet relative to the ADLIB diet, could have led to greater microbial fermentation with the resultant greater microbial uptake of carbohydrates. Slight differences in crude protein content and protein degradability also may have also contributed to differences in ruminal ammonia concentrations.

Volatile fatty acid concentrations are presented in Table 2.14. Concentrations over 24-h sampling periods are presented in Figure 2.12. Total VFA concentrations were greater ($P = 0.03$) for ADLIB compared with LIM. Acetate concentration and proportion were greater for ADLIB compared with LIM. Propionate concentration and proportion was lesser ($P < 0.01$) for ADLIB compared with LIM. Acetate:propionate was greater ($P < 0.01$) in ADLIB compared with LIM. This finding is likely the result of greater acetate produced in high roughage diets whereas propionate production is increased in high-starch diets (Clark et al., 2007). Butyrate concentration was greater ($P < 0.01$) for ADLIB compared with LIM; however, butyrate proportion did not differ ($P = 0.52$). Valerate concentration and proportion did not differ ($P \geq 0.32$) between dietary treatments. Isobutyrate and isovalerate concentrations and proportions were lesser ($P \leq 0.05$) for ADLIB compared with LIM.

Liquid passage rate and ruminal liquid volume data are presented in Table 2.13. Liquid passage rate was greater ($P < 0.01$) for ADLIB compared with LIM. Murphy et al. (1994) found limiting intake to 70% of ad libitum intake also decreased passage rate. Murphy et al. (1994) found limiting intake led to reductions in ruminal volume which is in disagreement with our observation that ruminal liquid volume tended to be greater ($P = 0.09$) for LIM compared with ADLIB. Differences in ruminal osmotic pressure could explain some differences between our findings and that of Murphy et al. (1994). Decreased ruminal pH of LIM would be associated with increased ruminal osmotic pressure which could increase ruminal liquid volume.

Effect of shade

Intake of DM and OM tended to be lesser (P = 0.09) for SH compared with NSH, although the difference was only 0.04 kg/d for dry matter intake. There were no differences in NDF or ADF intake between SH and NSH calves. Apparent total tract digestibility of DM, OM, NDF, and ADF did not differ ($P \geq 0.22$) between SH and NSH.

Ruminal pH was greater ($P < 0.01$) for SH compared with NSH. A possible explanation for lower rumen pH would be less saliva reaching the rumen to serve as a buffer. During periods of heat stress cattle experience increased drooling resulting from increased panting and respiration rates and increased water consumption potentially allowing less saliva to reach the rumen. A reduction in the amount of bicarbonate that reached the rumen decreasing rumen pH. Ruminal ammonia concentrations were unaffected (P = 0.87) by shade allocation.

Volatile fatty acid concentrations are presented in Table 2.14. Concentrations over 24-hour sampling periods are presented in Figure 2.12. Total VFA concentrations did not differ (P = 0.15) between shade treatments. Concentrations of acetate, butyrate, valerate, isobutyrate, and isovalerate did not differ ($P \geq 0.18$) between shade treatments. Acetate proportion was lesser (P = 0.01) for SH compared with NSH. Propionate concentration was lesser ($P < 0.01$) for SH compared with NSH, and the proportion of propionate also tended to be lesser (P = 0.07) for SH compared with NSH. Acetate: propionate was greater for SH compared with NSH. Proportions of butyrate, valerate, isobutyrate, and isovalerate did not differ ($P \geq 0.25$) between shade treatments.

Liquid passage rate and ruminal liquid volume were unaffected ($P \geq 0.32$) by shade treatment. Although intake tended to be greater for NSH compared with SH, the small difference in amount was unlikely to alter liquid passage rate or ruminal liquid volume.

Combined years

Effect of diet

Digestibility and intake data for Years 1 and 2 are presented in Table 2.15. A diet × year interaction ($P \leq 0.03$) was observed for intake of DM and OM as well as diet digestibility of DM and OM. A tendency for a diet × year interaction ($P = 0.08$) for NDF was also observed. Intake of DM, OM and NDF were greater for LIM in year 1 compared with LIM in year 2. By design, dry matter intake was greater ($P < 0.01$) for ADLIB compared with LIM. Organic matter, NDF, and ADF intakes were greater ($P < 0.01$) for ADLIB compared with LIM as a result of greater intake of a diet containing greater proportions of roughage. Apparent total tract digestibility of DM and OM was lesser ($P < 0.01$) for ADLIB compared with LIM. Conversely, apparent digestibility of NDF tended to be greater ($P = 0.06$) and apparent ADF digestibility was greater ($P < 0.01$) for ADLIB compared with LIM. Ruminal pH differences may explain the differences in NDF and ADF digestibility. At higher pH fibrolytic bacteria are more active and prevalent; therefore, the ADLIB diet, which had greater ruminal pH, may have increased activity of fiber digesting bacteria which may lead to increased fiber digestion.

Ruminal pH data are presented in Table 2.16 and Figure 2.7. A diet × year interaction was observed for LIM and ADLIB to tend to have greater ($P = 0.07$) ruminal pH in year 2 compared with year 1. Ruminal pH was greater ($P = 0.03$) for ADLIB compared with LIM. A diet × hour interaction was observed for LIM to have lower ($P < 0.01$) pH between 2 and 8 hours after feeding, then pH was similar between dietary treatments between 12 and 24 hours after feeding. Lana et al. (1998) described the relationship between concentrate level and ruminal pH. Ruminal pH was lower when a 90% concentrate diet was fed compared with 100% or 55% forage based diets. These findings are also in agreement with Spore et al. (2019) where increasing levels of dietary energy in the form of dry-rolled corn resulted in decreasing ruminal pH. Rapid intake of dietary starch would lead to decreased ruminal pH; however, limiting intake would allow ruminal pH to stabilize post-feeding.

No diet × year interactions for ruminal ammonia were observed. Ruminal ammonia concentrations (Table 2.16) were greater ($P < 0.01$) for ADLIB compared with LIM. A diet × hour interaction where ADLIB had greater ($P \leq 0.02$; Figure 2.10) ruminal ammonia concentrations at hours 2, 8, 12, 18 compared with LIM. Lana et al. (1998) also reported a positive relationship between ruminal pH and ruminal ammonia concentration. Increasing levels of concentrate in the diet, such as our LIM diet, may provide more fermentable carbohydrates compared with roughage based diets, such as our ADLIB diet, to support microbial population growth. A shift in bacteria populations when feeding higher concentrate diets may contribute to a greater uptake of ruminal ammonia by the microbial population. A comparison of the dietary protein concentration provided between the ADLIB and LIM diet suggests the ADLIB treatment also had a higher protein concentration. As pH increases in forage-based diets such as our ADLIB diet, deamination of amino acids increases compared with a concentrate diet such as LIM.

Volatile fatty acid concentrations are presented in Table 2.16. Concentrations over 24-hour sampling periods are presented in Figure 2.13. No diet × year interactions were observed for isobutyrate concentration, butyrate concentration, acetate concentration, Isovalerate concentration, total VFA concentration, isobutyrate proportion, and isovalerate proportion. A diet × year interaction was observed for acetate: propionate, propionate, valerate, acetate proportion, propionate proportion, and valerate proportion.

Total VFA concentrations tended to be greater (*P* = 0.06) for ADLIB compared with LIM. Spore et al. (2019) observed a decrease in total VFA concentrations when calves were limit-fed compared with calves fed for ad libitum intake. Acetate concentration and proportion was greater, whereas propionate concentration and proportion was less, for ADLIB compared with LIM (*P* < 0.01). These differences can be attributed to greater dietary roughage inclusion and less starch-containing concentrates for the ADLIB diet than for the LIM diet. Butyrate concentration was greater (*P* < 0.01) for ADLIB compared with LIM; however, butyrate proportion did not differ (*P* = 0.11) between dietary treatments. Increased forage inclusion and increased ruminal pH of ADLIB could contribute to a shift in butyrate producing bacteria and increased concentration of butyrate for ADLIB compared with LIM. Valerate concentration and proportion was lesser (*P* < 0.01) for ADLIB compared with LIM. Isobutyrate concentration did not differ (*P* = 0.17); however, proportion of isobutyrate was lesser (*P* < 0.01) for ADLIB compared with LIM. Isovalerate concentration and proportion was lesser (*P* < 0.01) for ADLIB compared with LIM.

Liquid passage rate (Table 2.15) was greater (*P* < 0.01) for ADLIB compared with LIM. These results are in agreement with Spore et al. (2019) who observed decreases in ruminal passage rate with decreasing intake and increasing dietary energy levels. Ruminal liquid volume did not differ (*P* = 0.25) for ADLIB compared with LIM. A diet × year interaction was observed (*P* < 0.01) during year 1, ADLIB had larger ruminal liquid volumes compared with LIM and this effect was reversed in year 2.

Effect of shade

No shade × year interactions were observed for intake, diet digestibility, liquid passage rate, ruminal pH, ruminal ammonia, acetate concentration, butyrate concentration, butyrate proportion, or isovalerate proportion.

No effect of shade was observed for DM, OM, NDF, or ADF intake or diet digestibility (Table 2.15; $P \geq 0.70$). Bernabucci et al. (1999) evaluated diet digestibility in cattle housed in thermoneutral conditions for 25 d compared with cattle housed in a hot environment (THI = 84) for 40 d. Heifers housed in thermal neutral conditions were transitioned for 3 d into the hot environment where cattle spent 13 d; then they were maintained in the hot environment for an additional 24-d trial. Dry matter intake was lower for calves housed in a hot environment compared with those in thermoneutral conditions. The authors observed an increase in diet digestibility when cattle were placed in the hot environment for 13 d, then during the final 4-d trial digestibility returned to the initial level observed when cattle were housed in thermoneutral conditions. These data suggest cattle can adapt to some extent during hot conditions which could possibly explain our observations in diet digestibility. Dry matter intake was not affected by shade in our study therefore any expected change in diet digestibility was not observed.

Ruminal pH was greater ($P < 0.01$) for SH compared with NSH. As discussed previously, the relationship between water intake and ruminal pH has not been explored extensively. Previous research has shown water intake increased during periods of heat stress (Arias and Mader, 2011; Mensching et al., 2020). We hypothesize the increase in water intake that results from heat stress may lead to a reduction in ruminal pH. Increased drool due to increased panting and respiration rate during periods of heat stress may reduce the amount of bicarbonate reaching the rumen during periods of heat stress. Increased water intake may decrease saliva production and also contribute to less buffering capacity in the rumen resulting in greater ruminal pH. In addition, ruminal ammonia concentration tended to be lesser (P = 0.10) for SH compared with NSH. During periods of heat stress blood flow is shifted from the gastrointestinal tract to the extremities to aid in heat loss (Lees et al., 2019). This shift in blood flow could potentially result in reduced absorption of VFA's causing an observed reduction in ruminal pH in NSH animals compared with SH animals. At lower ruminal pH, ammonia absorption rate would decrease due to the increased protonation of ruminal ammonia (Lana et al., 1994). This could lead to a higher concentration of ammonia in NSH animals compared with SH animals.

Volatile fatty acid concentrations are presented in Table 2.16. Shade did not affect the pattern of VFA concentrations over time (P = 0.94; Figure 2.13). No diet × shade interactions (P ≥ 0.15) were observed for concentrations of acetate, butyrate, valerate, isobutyrate, or isovalerate. A diet × shade interaction was observed for propionate concentration and proportion for SH to reduce propionate concentrations in LIM to a greater extent than ADLIB. Total VFA concentrations tended to be lesser (P = 0.08) for SH compared with NSH. This is likely a result of LIM SH having numerically the lowest total VFA concentration of all treatments. Acetate, butyrate, isobutyrate, and isovalerate concentrations did not differ ($P \geq 0.43$) between shaded treatments, but propionate and valerate concentrations were lesser ($P \leq 0.01$) for SH compared with NSH. Acetate proportion was greater ($P < 0.01$) in SH compared with NSH. Propionate proportion was lesser ($P < 0.01$) in SH compared with NSH. Propionate production and absorption was measured by Bedford et al. (2020) in Holstein heifers housed in 20 °C and 30 °C environments. The heat stress treatments were introduced during period one then animals were housed at 20 °C and pair fed to match heat stressed dry matter intake during period 2. Authors fed for ad libitum intake and during heat challenge dry matter intake was reduced. While authors did not find a change in propionate absorption or production due to heat stress they did find that at reduced intake propionate absorption was increased. We did not observe reductions in dry matter intake for SH compared with NS; however, there was a decrease in propionate concentration in SH compared with NSH possibly a result of different absorption rates. Valerate proportions were lesser (P = 0.01) for SH compared with NSH. Butyrate, isobutyrate, and isovalerate proportions did not differ (P = 0.15) between shade treatments.

Liquid passage rate and ruminal liquid volume did not differ ($P \geq 0.19$) between shaded treatments. A tendency for a shade × year interaction was observed (P = 0.10) where shaded animals SH and NSH animals in year 1 tended to have greater ruminal volumes compared with SH and NSH animals in year 2. Allocation of shade during periods of heat stress can increase dry matter intake in animals fed for ad libitum intake which may be associated with differences in liquid passage rate and ruminal liquid volumes (Mitlöhner et al., 2001). There were no differences in intake between shaded treatments which may explain the lack of differences in liquid passage rate and ruminal liquid volume.

CONCLUSIONS

Minimization of heat load experienced by growing calves during summer months is beneficial from both a performance and animal comfort perspective. Implementation of shade increased animal body weight, average daily gain, and feed efficiency during two consecutive summer trials. In addition, water usage and panting scores were reduced when calves were provided access to shade. Although shade allocation will not improve performance in all climates, shade access can have a beneficial impact on animal welfare during periods of heat stress. When growing calves were limit-fed a high-energy diet compared with feeding for ad libitum intake, feed efficiency was better and both body weight and average daily gain were greater. Rumination was reduced and activity was greater for limit-fed calves compared with calves fed for ad libitum intake. Water usage and panting scores were lesser for limit-fed calves compared with calves fed for ad libitum intake. In addition, limit feeding improved diet digestibility which may explain improved feed efficiency of growing calves. Shade altered ruminal pH which could possibly be explained by a variety of factors including buffering capacity of saliva reaching the rumen. Limit feeding and implementing shade independently improved animal performance, water usage, and animal comfort; however, improvements in ad libitum dry matter intake can be achieved with the use of shade compared with limit feeding as a result of feeding strategy.

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Table 2.1 Composition and nutrient analysis of experimental diets in years 1 and 2. Exp. 1.

	Diet	
Item,	ADLIB	LIM
Ingredient	% of dry matter	
Dry-rolled corn	8.6	38.8
Wet corn gluten feed[1]	40.0	40.0
Alfalfa hay	22.5	6.5
Chopped prairie hay	22.5	6.5
Supplement[2]	6.4	8.2
Year 1, nutrient composition		
Dry matter, % as fed	76.9	75.8
Organic matter	92.5	94.0
Crude protein	16.6	16.0
Neutral detergent fiber	40.9	26.1
Acid detergent fiber	20.9	9.6
Calcium	0.9	1.0
Phosphorus	0.6	0.6
Year 2, nutrient composition		
Dry matter, % as fed	77.2	76.1
Organic matter	92.3	94.1
Crude protein	15.3	14.3
Neutral detergent fiber	41.1	26.3
Acid detergent fiber	20.5	9.7
Calcium	1.0	0.8
Phosphorus	0.5	0.5

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% of body weight daily (dry matter basis).

[2] Sweet Bran (Cargill Corn Milling, Blair, NE).

[3]Supplement pellet formulated to contain (dry matter basis) 8.4% Ca, 5% NaCl, and 360 mg/kg monensin. Supplement ingredients: 72.15% wheat middlings, 22.0% calcium carbonate, 5% NaCl, 0.35% soybean oil, 0.18% Rumensin 90 (Elanco, Greedfield, IN), 0.11% zinc sulfate, 0.08% manganese (Mn) sulfate (32% Mn), 0.06% vitamin E premix (500,000 IU/kg), 0.05% copper sulfate, 0.01% selenium premix (0.99% Se), 0.007% ethylenediamine dihydriodide (EDDI) premix (11.4% EDDI), and 0.004% vitamin A (650,000 IU/g).

Table 2.2 Composition and nutrient analysis of experimental diets, gut-fill equilibration diet. Exp. 1

Item	% of dry matter
Ingredient	
Dry-rolled corn	23.8
Wet corn gluten feed[1]	40.7
Alfalfa hay	14.2
Chopped prairie hay	14.4
Supplement[2]	6.9
Nutrient composition	
Year 1	
Dry matter, % as fed	76.2
Organic matter	93.7
Crude protein	15.7
Neutral detergent fiber	33.7
Acid detergent fiber	15.2
Calcium	0.8
Phosphorus	0.6
Year 2	
Dry matter, % as fed	76.5
Organic matter	93.3
Crude protein	14.8
Neutral detergent fiber	33.6
Acid detergent fiber	15.0
Calcium	0.8
Phosphorus	0.5

[1]Sweet Bran (Cargill Corn Milling, Blair, NE)

[2] Supplement pellet formulated to contain (dry matter basis) 8.4% Ca, 5% NaCl, and 360 mg/kg monensin. Supplement ingredients: 72.15% wheat middlings, 22.0% calcium carbonate, 5% NaCl, 0.35% soybean oil, 0.18% Rumensin 90 (Elanco, Greedfield, IN), 0.11% zinc sulfate, 0.08% manganese (Mn) sulfate (32% Mn), 0.06% vitamin E premix (500,000 IU/kg), 0.05% copper sulfate, 0.01% selenium premix (0.99% Se), 0.007% ethylenediamine dihydriodide (EDDI) premix (11.4% EDDI), and 0.004% vitamin A (650,000 IU/g).

Table 2.3 Panting score evaluation

Panting Score[1]	Breathing Conditions
0	No panting. Respiration <60 breaths per minute.
1.0	Slight panting, mouth closed, no drool, easy to see chest movement. Respiration ~60 to 90 breaths per minute.
1.5	Moderate panting, no drool present, easy to see chest movement, mouth closed. Respiration ~60 to 90 breaths per minute.
2.0	Fast Panting, drool present, mouth closed. Respiration ~90 to 120 breaths per minute.
2.5	Fast Panting, drool present, occasional mouth panting. Respiration ~90 to 120 breaths per minute.
3.0	Occasional open mouth panting, excessive drooling, neck extended, head held up. Respiration ~120 to 150 breaths per minute.
3.5	Open mouth panting, excessive drooling, tongue slightly extended or occasionally extended for short periods. Respiration ~120 to 150 breaths per minute.
4.0	Open mouth with extended tongue for a prolonged period, excessive drooling, neck extended, and head up. Respiration may decrease. Respiration ~120 to 150 breaths per minute.
4.5	Open mouth with extended tongue for a prolonged period, excessive drooling, neck extended, head up, visible breaths from the flank, drooling may be ceased. Respiration may decrease. Respiration ~120 to 150 breaths per minute.

[1]Panting score evaluation was adapted from Gaughan et al. (2008).

Table 2.4 Composition and nutrient analysis of experimental diets in years 1 and 2. Exp. 2.

	Diet	
Item,	ADLIB	LIM
Ingredient	% of dry matter	
Dry-rolled corn	8.6	38.8
Wet corn gluten feed[1]	40.0	40.0
Alfalfa hay	22.5	6.5
Chopped prairie hay	22.5	6.5
Supplement[2]	6.4	8.2
Year 1, nutrient composition		
Dry matter, % as fed	77.6	76.9
Organic matter	92.3	93.9
Crude protein	17.2	16.3
Neutral detergent fiber	40.0	25.4
Acid detergent fiber	19.6	9.3
Calcium	1.0	0.9
Phosphorus	0.6	0.6
Year 2, nutrient composition		
Dry matter, % as fed	78.2	77.0
Organic matter	92.9	94.5
Crude protein	15.4	14.5
Neutral detergent fiber	41.3	26.7
Acid detergent fiber	20.9	10.0
Calcium	0.9	0.7
Phosphorus	0.5	0.5

[1]SweetBran (Cargill Corn Milling, Blair, NE)

[2] Supplement pellet formulated to contain (dry matter basis) 8.4% Ca, 5% NaCl, and 360 mg/kg monensin. Supplement ingredients: 72.15% wheat middlings, 22.0% calcium carbonate, 5% NaCl, 0.35% soybean oil, 0.18% Rumensin 90 (Elanco, Greedfield, IN), 0.11% zinc sulfate, 0.08% manganese (Mn) sulfate (32% Mn), 0.06% vitamin E premix (500,000 IU/kg), 0.05% copper sulfate, 0.01% selenium premix (0.99% Se), 0.007% ethylenediamine dihydriodide (EDDI) premix (11.4% EDDI), and 0.004% vitamin A (650,000 IU/g).

Table 2.5 Weather data collected during year 1.

Item[1]	May	June	July	August	September	Overall
Temperature, C°						
Mean	19.9 ± 4.2	28.2 ± 4.5	28.3 ± 4.0	28.9 ± 4.2	25.8 ± 4.4	26.6 ± 5.2
Maximum	30.6	38.3	37.2	36.7	35.0	38.3
Minimum	8.9	15.0	18.3	17.2	10.0	8.9
Relative Humidity,%						
Mean	76.7 ± 13.9	66.4 ± 7.0	68.4 ± 6.9	69.8 ± 5.6	61.4 ± 8.9	68.0 ± 9.7
Maximum	96.0	88.0	79.0	81.0	74.0	96.0
Minimum	33.0	32.0	25.0	26.0	26.0	25.0
Wind Speed, km/h						
Mean	12.4 ± 6.3	9.4 ± 6.2	9.2 ± 4.8	12.1 ± 6.0	12.2 ± 6.2	10.9 ± 6.1
Maximum	30.6	27.4	29.0	35.4	37.0	37.0
Minimum	0	0	0	0	0	0
Solar Radiation, W/m^2						
Mean	310 ± 236	510 ± 265	498 ± 254	456 ± 258	382 ± 242	445 ± 262
Maximum	1186	1104	1201	1060	902	1201
Minimum	0	15	1	0	0	0
THI[2]						
Mean[3]	66.5 ± 6.3 (1)	78.2 ± 6.8 (24)	78.7 ± 6.3 (27)	79.8 ± 6.7 (26)	74.3 ± 6.5 (12)	76.1 ± 7.9 (90)
Maximum	77.7	93.4	93.1	92.1	96.6	96.6
Minimum	49.2	58.7	63.4	61.8	52.6	49.2

[1]Weather data collected by Davis weather station (Vantage Pro 2, Davis Instruments Corporation, Hayward, CA).
[2] THI equation adapted from Thom (1959). THI = 0.8 × ambient temperature + ((relative humidity/100) × (ambient temperature - 14.3)) + 46.4.
[3] Numbers within parentheses denote days during the trial when THI reached above 72.

Table 2.6 Effect of shade and limit-fed high-energy diets on animal performance, rumination, activity, and water usage. Exp.1 Year 1.

	Treatment[1]							
	No Shade		Shade			*P*-value		
Item	ADLIB	LIM	ADLIB	LIM	SEM[2]	Diet	Shade	D×S
Number of pens	10	10	10	10				
Number of animals	105	100	106	102				
Body weight, kg								
day 0	256	256	254	255	1.3	0.46	0.28	0.72
day 14	280	278	282	277	1.8	< 0.01	0.89	0.29
day 90	368	366	374	369	3.0	0.10	0.04	0.40
day 97	367	378	371	380	3.1	< 0.01	0.19	0.47
Average daily gain, kg/d								
day 0-14	1.78	1.57	1.99	1.54	0.12	< 0.01	0.28	0.16
day 0-90	1.25	1.22	1.34	1.27	0.03	0.04	< 0.01	0.03
day 0-97	1.14	1.26	1.21	1.28	0.03	< 0.01	0.06	0.35
Dry matter intake, kg/d								
day 0-14	6.16	5.52	6.12	5.50	0.092	< 0.01	0.65	0.91
day 0-90	9.44	7.06	9.69	7.05	0.119	< 0.01	0.17	0.12
day 0-97	9.44	7.23	9.68	7.23	0.114	< 0.01	0.15	0.15
day 90-97	9.44	9.39	9.52	9.51	0.098	0.71	0.19	0.82
Gain:feed, kg/kg								
day 0-14	0.293	0.285	0.325	0.284	0.021	0.08	0.24	0.22
day 0-90	0.132	0.174	0.138	0.179	0.004	< 0.01	0.07	0.87
day 0-97	0.121	0.174	0.124	0.177	0.004	< 0.01	0.29	0.99
NE_m[3], Mcal/kg dry matter	1.38	1.81	1.39	1.82	0.028	< 0.01	0.35	0.91
NE_g[3], Mcal/kg dry matter	0.79	1.17	0.81	1.19	0.024	< 0.01	0.35	0.91
Rumination[4], min/day	474	424	476	399	19.4	< 0.01	0.02	< 0.01
Activity[4], min/day	313	317	313	323	2.7	< 0.01	0.10	0.14
Water Usage[5], L/d	44.7	40.5	39.8	35.6	1.14	< 0.01	< 0.01	0.86

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% body weight daily (dry matter basis).
[2]Largest SEM is reported.
[3]Net energy calculations based on equations from NRC (1996).
[4]Measured using 3-axial accelerometer ear tags (Allflex Livestock Intelligence, Madison, WI).
[5]Measured using iPERL water meters (SENSUS, Morrisville, NC).

Table 2.7 Mean panting scores[1] collected during Year 1 and 2.

	Treatment[2]							
	No Shade		Shade			*P*-value		
Item,	ADLIB	LIM	ADLIB	LIM	SEM[3]	Diet	Shade	D×S
Year 1								
0930 h	0.41	0.46	0.22	0.21	0.031	0.39	< 0.01	0.13
1330 h	2.14	2.15	1.10	1.05	0.059	0.56	< 0.01	0.44
1730 h	2.04	1.98	1.06	1.02	0.054	0.19	< 0.01	0.88
Overall	1.53	1.53	0.80	0.76	0.040	0.51	< 0.01	0.48
Year 2								
0930 h	0.54	0.35	0.26	0.16	0.029	< 0.01	< 0.01	0.03
1330 h	2.16	2.11	1.29	1.19	0.038	< 0.01	< 0.01	0.49
1730 h	2.23	2.17	1.34	1.23	0.032	< 0.01	< 0.01	0.26
Overall	1.64	1.54	0.96	0.86	0.028	< 0.01	< 0.01	0.99
Combined								
0930 h	0.47	0.41	0.24	0.18	0.037	< 0.01	< 0.01	0.70
1330 h	2.15	2.13	1.20	1.12	0.069	0.05	< 0.01	0.31
1730 h	2.13	2.08	1.20	1.13	0.064	< 0.01	< 0.01	0.65
Overall	1.59	1.54	0.87	0.81	0.051	< 0.01	< 0.01	0.57

[1]Panting score evaluation adapted from Gaughan et al. (2008).

[2]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% of body weight daily (dry matter basis).

[3]Largest SEM reported.

Table 2.8 Weather data collected during year 2

Item,[1]	May	June	July	August	September	Overall
Temperature, C°						
Mean	21.1 ± 7.1	27.0 ± 4.9	28.4 ± 4.4	28.7 ± 4.5	27.3 ± 4.1	27.5 ± 5.2
Maximum	31.7	36.7	38.3	37.8	33.3	38.3
Minimum	11.1	13.9	17.8	18.9	16.1	11.1
Relative Humidity,%						
Mean	67.9 ± 14.3	64.2 ± 13.4	62.7 ± 14.6	59.2 ± 13.6	55.2 ± 15.2	62.1 ± 14.3
Maximum	93.0	90.0	87.0	86.0	87.0	93.0
Minimum	33.0	32.0	25.0	23.0	28.0	23.0
Wind Speed, km/h						
Mean	19.2 ± 11.5	11.2 ± 7.1	9.8 ± 6.0	9.2 ± 5.2	9.1 ± 3.6	10.7 ± 7.1
Maximum	49.9	46.7	32.2	27.4	17.7	49.9
Minimum	0.0	0.0	0.0	0.0	0.0	0.0
Solar Radiation, W/m^2						
Mean	377 ± 291	506 ± 275	456 ± 273	467 ± 267	440 ± 245	467 ± 274
Maximum	1015	1112	1174	955	926	1174
Minimum	0	0	4	0	2	0
THI[2,3]						
Mean	67.0 ± 9.92 (3)	75.9 ± 6.5 (18)	77.7 ± 5.3 (26)	77.6 ± 5.4 (28)	75.0 ± 4.7 (3)	76.2 ± 6.7 (78)
Maximum	80.3	87.0	87.9	87.4	81.5	87.9
Minimum	52.5	57.2	62.4	63.0	60.8	52.5

[1]Weather data collected by Davis weather station (Vantage Pro 2, Davis Instruments Corporation, Hayward, CA)

[2] Numbers within parentheses denote days during the trial when THI reached above 72

[3] THI equation adapted from Thom 1959. THI = 0.8 × ambient temperature + ((relative humidity/100) × (ambient temperature - 14.3)) + 46.4.

Table 2.9 Effect of shade and limit-fed high-energy diets on animal performance, and water usage. Exp. 1 Year 2.

	Treatment[1]							
	No Shade		Shade			*P*-value		
Item,	ADLIB	LIM	ADLIB	LIM	SEM[2]	Diet	Shade	D*S
Number of pens	10	10	10	10				
Number of animals	109	113	109	108				
Body Weight, kg								
day 0	243	242	241	241	2.4	0.79	0.43	0.89
day 14	268	260	269	262	2.9	< 0.01	0.71	0.83
day 90	339	331	348	341	4.7	0.03	0.01	0.82
day 97	343	344	353	353	4.4	0.99	< 0.01	0.85
Average Daily Gain, kg/d								
day 0-14	1.83	1.31	1.97	1.47	0.124	< 0.01	0.09	0.89
day 0-90	1.07	0.98	1.19	1.12	0.039	< 0.01	< 0.01	0.84
day 0-97	1.03	1.04	1.16	1.15	0.382	0.84	< 0.01	0.71
Dry Matter Intake, kg/d								
day 0-14	5.98	5.11	6.07	5.10	0.079	< 0.01	0.41	0.38
day 0-90	8.77	6.34	9.71	6.44	0.197	< 0.01	< 0.01	< 0.01
day 0-97	8.75	6.49	9.64	6.59	0.189	< 0.01	< 0.01	< 0.01
day 90-97	9.41	9.42	9.53	9.49	0.108	0.85	0.22	0.71
Gain to Feed, kg/kg								
day 0-14	0.304	0.257	0.325	0.289	0.022	0.01	0.10	0.73
day 0-90	0.122	0.154	0.123	0.172	0.004	< 0.01	0.01	0.01
day 0-97	0.118	0.160	0.120	0.174	0.004	< 0.01	0.01	0.04
NE_m[3], Mcal/kg dry matter	1.34	1.71	1.33	1.78	0.036	< 0.01	0.09	< 0.01
NE_g[3], Mcal/kg dry matter[3]	0.77	1.09	0.75	1.15	0.031	< 0.01	0.09	< 0.01
Water Usage[4], L/d	45.0	39.4	40.1	33.7	2.16	< 0.01	< 0.01	0.84

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% body weight (dry matter basis).
[2]Largest SEM is reported.
[3]Net energy calculations based on equations from NRC (1996).
[4]Measured using iPERL water meters (SENSUS, Morrisville, NC)

Table 2.10 Effect of shade and limit-fed high-energy diets on animal performance, and water usage. Combined years.

	Treatment[1]							
	No Shade		Shade			*P*-value		
Item,	ADLIB	LIM	ADLIB	LIM	SEM[2]	Diet	Shade	D*S
Number of pens	20	20	20	20				
Number of animals	214	213	215	210				
Body Weight, kg								
day 0	251	251	249	250	3.4	0.96	0.62	0.90
day 14	275	270	276	270	3.3	0.02	0.84	0.84
day 90	354	349	362	356	4.5	0.08	0.03	0.88
day 97	355	361	362	366	4.3	0.10	0.04	0.72
Average Daily Gain, kg/d								
day 0-14	1.69	1.33	1.87	1.40	0.099	< 0.01	0.09	0.45
day 0-90	1.15	1.09	1.25	1.18	0.035	0.01	< 0.01	0.72
day 0-97	1.07	1.14	1.17	1.20	0.031	0.03	< 0.01	0.51
Dry Matter Intake, kg/d								
day 0-14	6.11	5.36	6.14	5.35	0.095	< 0.01	0.91	0.75
day 0-90	9.13	6.73	9.73	6.77	0.158	< 0.01	< 0.01	0.02
day 0-97	9.12	6.88	9.69	6.94	0.153	< 0.01	< 0.01	0.02
day 90-97	9.42	9.41	9.52	9.50	0.074	0.70	0.07	0.91
Gain to Feed, kg/kg								
day 0-14	0.277	0.249	0.306	0.265	0.019	0.01	0.10	0.61
day 0-90	0.125	0.162	0.129	0.173	0.004	< 0.01	0.02	0.20
day 0-97	0.118	0.165	0.120	0.174	0.004	< 0.01	0.04	0.30
NE_m[3], Mcal/kg dry matter	1.36	1.76	1.36	1.80	0.033	< 0.01	0.06	0.05
NE_g[3], Mcal/kg dry matter	0.78	1.13	0.78	1.17	0.029	< 0.01	0.06	0.05
Water Usage[4], L/d	45.0	39.7	40.1	34.8	1.17	< 0.01	< 0.01	0.92

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% body weight (dry matter basis).
[2]Largest SEM is reported.
[3]Net energy calculations based on equations from NRC (1996).
[4]Measured using iPERL water meters (SENSUS, Morrisville, NC)

Table 2.11 Effect of shade and limit-fed high-energy diets on intake, diet digestibility, liquid passage, and ruminal liquid volume. Year 1.

	Treatment[2]							
	No Shade		Shade			*P*-value		
Item,	ADLIB	LIM	ADLIB	LIM	SEM[2]	Diet	Shade	D × S
Number of Observations	7	7	8	8				
Intake, kg/d								
Dry matter	7.67	6.24	7.68	6.17	0.273	< 0.01	0.85	0.78
Organic matter	7.08	5.85	7.09	5.80	0.268	< 0.01	0.86	0.78
Neutral detergent fiber	3.07	1.58	3.07	1.57	0.102	< 0.01	0.95	0.89
Acid detergent fiber	1.51	0.58	1.51	0.57	0.049	< 0.01	0.95	0.92
Liquid passage rate, %/h[3]	7.2	4.5	8.6	4.7	0.52	< 0.01	0.30	0.40
Ruminal liquid volume, L[3]	62.8	45.8	52.6	44.2	5.71	0.02	0.24	0.38
Apparent total tract digestibility, %								
Dry matter	73.9	75.3	74.2	75.9	1.46	0.15	0.64	0.87
Organic matter	76.3	78.0	76.6	78.6	1.32	0.07	0.64	0.88
Neutral detergent fiber	68.7	53.3	69.0	54.4	1.95	< 0.01	0.60	0.77
Acid detergent fiber	74.4	48.8	74.7	50.1	1.82	< 0.01	0.55	0.70

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% of body weight daily (dry matter basis).

[2] Largest SEM reported

[3] Calculated from samples collected from 0, 2, 4, 6, 8, 12, 18 hours after dosing Co-EDTA at feeding

[4]Average values collected at 0, 2, 4, 6, 8, 12, 18, 24 hours after feeding

Table 2.12 Effect of shade and limit-fed high-energy diets on ruminal VFA and ammonia concentrations. Year 1

	Treatment[1]							
	No Shade		Shade			*P*-value		
Item,	ADLIB	LIM	ADLIB	LIM	SEM[2]	Diet	Shade	D × S
Number of Observations	7	7	8	8				
Ruminal[3]								
pH[4]	5.79	5.56	5.90	5.80	0.14	0.09	0.07	0.16
Ammonia, m*M*	5.84	5.22	4.95	4.58	0.75	0.12	0.02	0.69
Acetate:propionate, mol/mol	2.60	1.67	2.55	1.95	0.15	< 0.01	0.12	0.03
Total VFA, m*M*	104.7	107.0	107.2	98.9	3.64	0.41	0.44	0.14
Acetate, m*M*	61.9	53.8	63.2	52.3	1.80	< 0.01	0.95	0.43
Propionate, m*M*	25.0	34.9	25.9	29.0	1.75	< 0.01	0.15	0.04
Butyrate, m*M*	13.2	12.3	13.7	11.8	0.61	0.02	0.95	0.39
Valerate, m*M*	2.27	3.21	2.17	2.36	0.24	0.01	0.05	0.10
Isobutyrate, m*M*	0.88	0.91	0.91	0.91	0.04	0.68	0.66	0.69
Isovalerate, m*M*	1.63	2.00	1.80	2.09	0.19	0.07	0.50	0.86
Ruminal VFA, molar % of total								
Acetate	59.3	50.7	59.0	53.8	1.33	< 0.01	0.09	0.04
Propionate	23.8	32.2	23.9	29.7	1.35	< 0.01	0.04	0.03
Butyrate	12.4	11.4	12.6	12.0	0.55	0.09	0.37	0.66
Valerate	2.16	2.93	2.00	2.27	0.25	< 0.01	< 0.01	0.09
Isobutyrate	0.96	0.92	1.00	1.08	0.05	0.59	0.01	0.09
Isovalerate	1.61	1.92	1.68	2.20	0.26	0.06	0.47	0.67

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% body weight daily (dry matter basis).
[2] Largest SEM reported.
[3]Average of samples collected at 0, 2, 4, 6, 8, 12, 18, 24 hours after feeding

Table 2.13 Effect of shade and limit-fed high-energy diets on intake, diet digestibility, liquid passage, and ruminal liquid volume. Year 2.

	Treatment[1]							
	No Shade		Shade			*P*-value		
Item,	ADLIB	LIM	ADLIB	LIM	SEM[2]	Diet	Shade	D × S
Number of Observations	8	8	8	8				
Intake, kg/d								
Dry matter	7.62	6.57	7.58	6.53	0.373	< 0.01	0.09	0.86
Organic matter	7.08	6.21	7.05	6.17	0.349	< 0.01	0.09	0.75
Neutral detergent fiber	3.15	1.75	3.13	1.74	0.135	< 0.01	0.68	0.82
Acid detergent fiber	1.60	0.65	1.58	0.65	0.064	< 0.01	0.79	0.83
Liquid passage rate, %/h[3]	10.5	5.8	10.7	6.4	0.6	< 0.01	0.42	0.66
Ruminal liquid volume, L[3]	31.8	35.6	33.7	39.2	2.9	0.09	0.32	0.75
Apparent total tract digestibility, %								
Dry matter	74.4	78.3	71.7	78.8	1.4	<0.01	0.28	0.12
Organic matter	76.8	80.7	74.3	81.3	1.3	<0.01	0.34	0.12
Neutral detergent fiber	71.5	70.0	68.1	69.3	2.2	0.94	0.23	0.43
Acid detergent fiber	69.5	64.5	66.0	63.2	2.5	0.05	0.22	0.55

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% body weight daily (dry matter basis).

[2] Largest SEM reported.

[3] Calculated from samples collected from 0, 2, 4, 6, 8, 12, 18 hours after dosing Co-EDTA at feeding

[4]Average values collected at 0, 2, 4, 6, 8, 12, 18, 24 hours after feeding

Table 2.14 Effect of shade and limit-fed high-energy diets on ruminal VFA and ammonia concentrations. Year 2

	Treatment[1]							
	No Shade		Shade			*P*-value		
Item,	ADLIB	LIM	ADLIB	LIM	SEM[2]	Diet	Shade	D × S
Number of Observations	8	8	8	8				
Ruminal[3]								
pH[4]	5.93	5.88	6.10	6.01	0.07	0.18	< 0.01	0.66
Ammonia, m*M*	5.33	4.28	5.03	4.50	0.41	< 0.01	0.88	0.37
Acetate:propionate, mol/mol	2.21	1.83	2.40	1.97	0.10	<0.01	0.02	0.70
Total VFA, m*M*	90.2	84.7	86.3	82.7	2.98	0.03	0.15	0.65
Acetate, m*M*	51.6	44.7	50.6	44.3	1.74	< 0.01	0.55	0.79
Propionate, m*M*	23.9	26.8	21.8	25.1	1.22	< 0.01	0.03	0.78
Butyrate, m*M*	11.0	9.5	10.1	9.3	0.61	< 0.01	0.18	0.50
Valerate, m*M*	2.01	1.89	1.80	1.97	0.13	0.77	0.49	0.09
Isobutyrate, m*M*	0.67	0.69	0.64	0.70	0.03	0.05	0.74	0.43
Isovalerate, m*M*	1.15	1.30	1.13	1.27	0.10	0.02	0.66	0.87
Ruminal VFA, molar % of total								
Acetate	57.2	53.3	58.8	54.3	0.70	< 0.01	0.01	0.54
Propionate	26.6	30.9	25.4	29.5	0.96	< 0.01	0.07	0.87
Butyrate	11.9	11.3	11.4	11.5	0.58	0.52	0.80	0.39
Valerate	2.23	2.14	2.04	2.29	0.12	0.32	0.83	0.06
Isobutyrate	0.77	0.84	0.78	0.91	0.05	< 0.01	0.25	0.29
Isovalerate	1.30	1.58	1.39	1.62	0.09	< 0.01	0.32	0.72

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% body weight (dry matter basis

[2] Largest SEM reported

[3]Average values collected at 0, 2, 4, 6, 8, 12, 18, 24 hours after feeding

Table 2.15 Effect of shade and limit-fed high-energy diets on intake, diet digestibility, liquid passage, and ruminal liquid volume. Combined years.

	Treatment[1]							
	No Shade		Shade			*P*-value		
Item,	ADLIB	LIM	ADLIB	LIM	SEM[2]	Diet	Shade	D × S
Number of observations	15	15	16	16				
Intake, kg/d								
Dry matter	7.64	6.40	7.63	6.35	0.240	< 0.01	0.71	0.81
Organic matter	7.08	6.03	7.07	5.98	0.218	< 0.01	0.73	0.81
Neutral detergent fiber	3.11	1.67	3.10	1.66	0.086	< 0.01	0.80	0.99
Acid detergent fiber	1.55	0.62	1.55	0.61	0.040	< 0.01	0.83	0.94
Liquid passage rate, %/h[3]	8.93	5.15	9.65	5.56	0.463	< 0.01	0.19	0.71
Ruminal liquid volume, L[3]	46.95	40.86	42.86	41.41	3.767	0.25	0.62	0.49
Apparent total tract digestibility, %								
Dry matter	74.10	76.77	72.93	77.36	0.959	< 0.01	0.70	0.25
Organic matter	76.70	79.41	75.76	80.10	0.912	< 0.01	0.86	0.26
Neutral detergent fiber	70.21	61.71	69.46	62.32	1.514	0.06	0.84	0.28
Acid detergent fiber	69.86	57.87	70.36	56.20	1.808	< 0.01	0.96	0.39

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% body weight (dry matter basis)

[2] Largest SEM reported

[3] Calculated from samples collected from 2, 4, 6, 8, 12, 18 hours after dosing Co-EDTA at feeding

Table 2.16 Effect of shade and limit-fed high-energy diets on ruminal VFA and ammonia concentrations. Combined years.

	Treatment[1]							
	No Shade		Shade			*P*-value		
Item,	ADLIB	LIM	ADLIB	LIM	SEM[2]	Diet	Shade	D × S
Number of Observations	15	15	16	16				
Ruminal[3]								
pH[4]	5.86	5.71	5.99	5.89	0.08	0.02	< 0.01	0.71
Ammonia, m*M*	5.57	4.73	5.01	4.52	0.34	< 0.01	0.07	0.40
Acetate:propionate, mol/mol	2.41	1.74	2.46	1.97	0.07	< 0.01	< 0.01	0.08
Total VFA, m*M*	97.1	96.7	96.5	90.5	2.77	0.09	0.08	0.15
Acetate, m*M*	56.6	49.7	56.7	48.3	1.48	< 0.01	0.54	0.44
Propionate, m*M*	24.5	31.0	23.9	26.8	1.19	< 0.01	< 0.01	0.02
Butyrate, m*M*	12.0	11.0	11.9	10.5	0.51	< 0.01	0.43	0.60
Valerate, m*M*	2.16	2.53	2.00	2.15	0.14	< 0.01	0.01	0.27
Isobutyrate, m*M*	0.78	0.80	0.77	0.81	0.03	0.17	0.86	0.88
Isovalerate, m*M*	1.40	1.64	1.43	1.69	0.12	< 0.01	0.60	0.94
Ruminal VFA, molar % of total								
Acetate	58.2	52.1	58.8	53.2	0.62	< 0.01	< 0.01	0.07
Propionate	25.2	31.5	24.8	29.8	0.75	< 0.01	< 0.01	0.03
Butyrate	12.1	11.4	12.0	11.8	0.46	0.11	0.60	0.42
Valerate	2.20	2.49	2.04	2.27	0.11	< 0.01	0.01	0.62
Isobutyrate	0.82	0.84	0.81	0.93	0.04	< 0.01	0.18	0.07
Isovalerate	1.49	1.68	1.58	1.89	0.11	< 0.01	0.15	0.52

[1]ADLIB = 0.99 Mcal NE_g/kg dry matter fed for ad libitum intake. LIM = 1.32 Mcal NE_g/kg dry matter fed at 2.2% body weight (dry matter basis

[2] Largest SEM reported

[3]Average values collected at 0, 2, 4, 6, 8, 12, 18, 24 hours after feeding

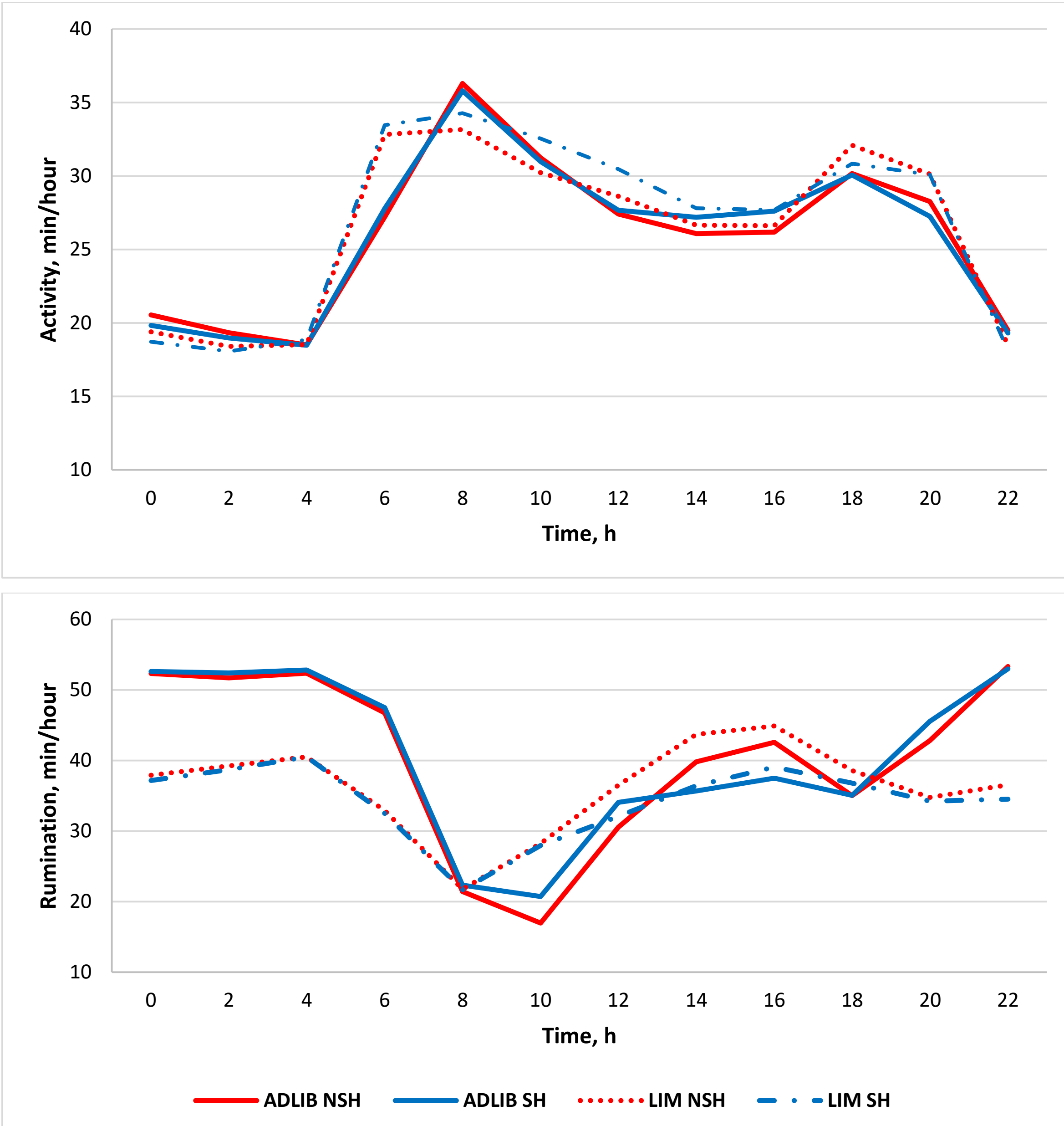

Figure 2.1 Effect of shade and dietary treatment on hourly activity and rumination (Exp. 1 Year 1).

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Top graph: Diet (P = 0.04, Shade (P = 0.39), diet × shade (P = 0.43), hour (P < 0.01), hour × shade (P = 0.18), hour × diet (P < 0.01), hour x diet x shade (P = 0.65). SEM = 0.41. Bottom graph: Diet (P < 0.01), Shade (P = 0.31), diet × shade (P = 0.17), hour (P < 0.01), hour × shade (P < 0.01), hour × diet (P < 0.01) hour × diet × shade (P = 0.55) SEM = 1.01.

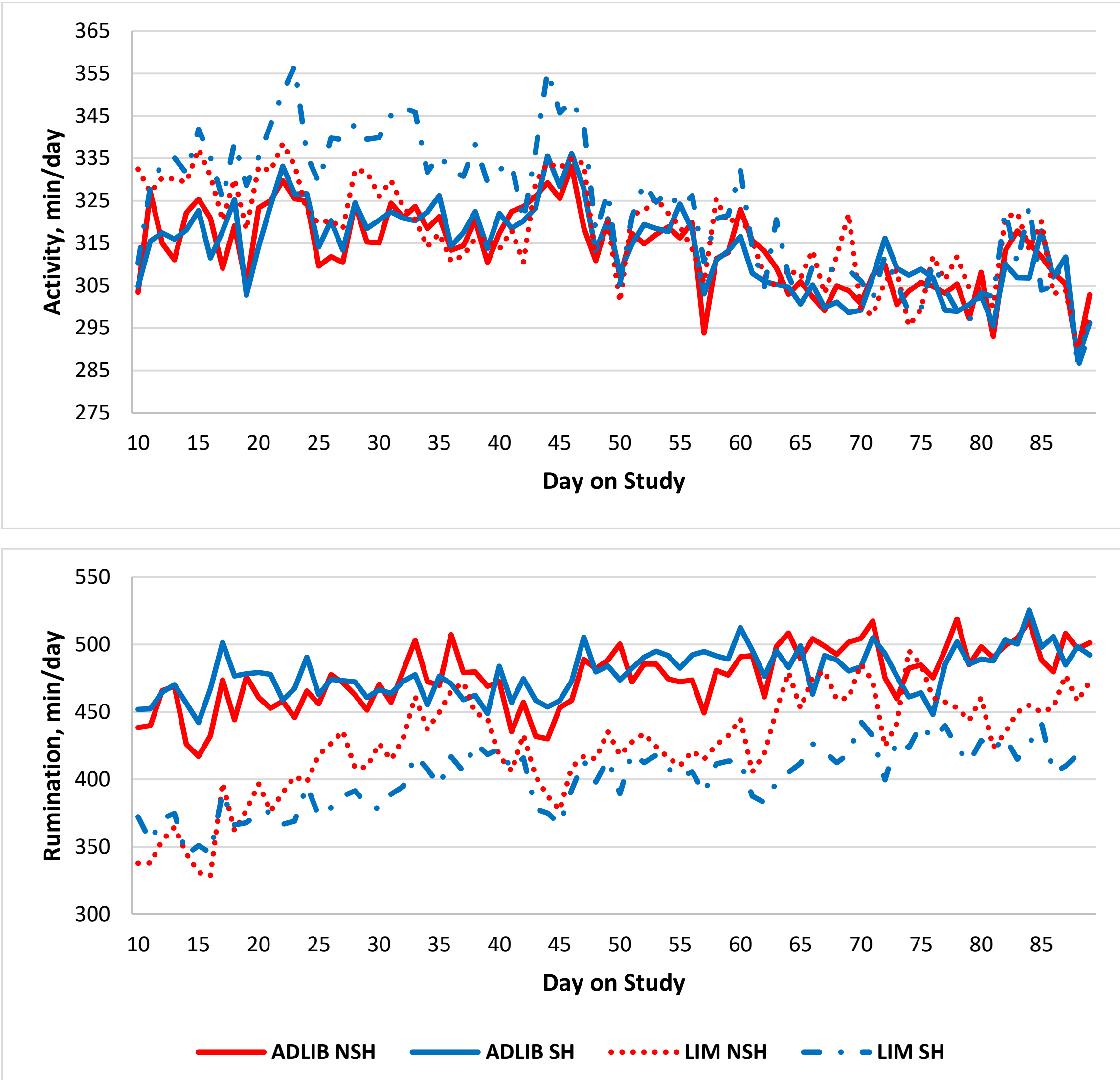

Figure 2.2 Effect of shade and dietary treatment on daily activity and rumination.

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Top graph: Diet ($P < 0.01$), Shade ($P = 0.10$), diet × shade ($P = 0.14$), day ($P < 0.01$), day × shade ($P = 0.99$), day × diet ($P = 0.98$), diet × shade × day ($P = 1.00$) SEM = 2.71. Bottom graph: Diet ($P < 0.01$), Shade ($P = 0.02$), diet × shade ($P < 0.01$), day ($P < 0.01$), day × shade ($P = 0.02$), day × diet ($P = 0.01$), diet × shade × day ($P = 0.99$) SEM = 19.40

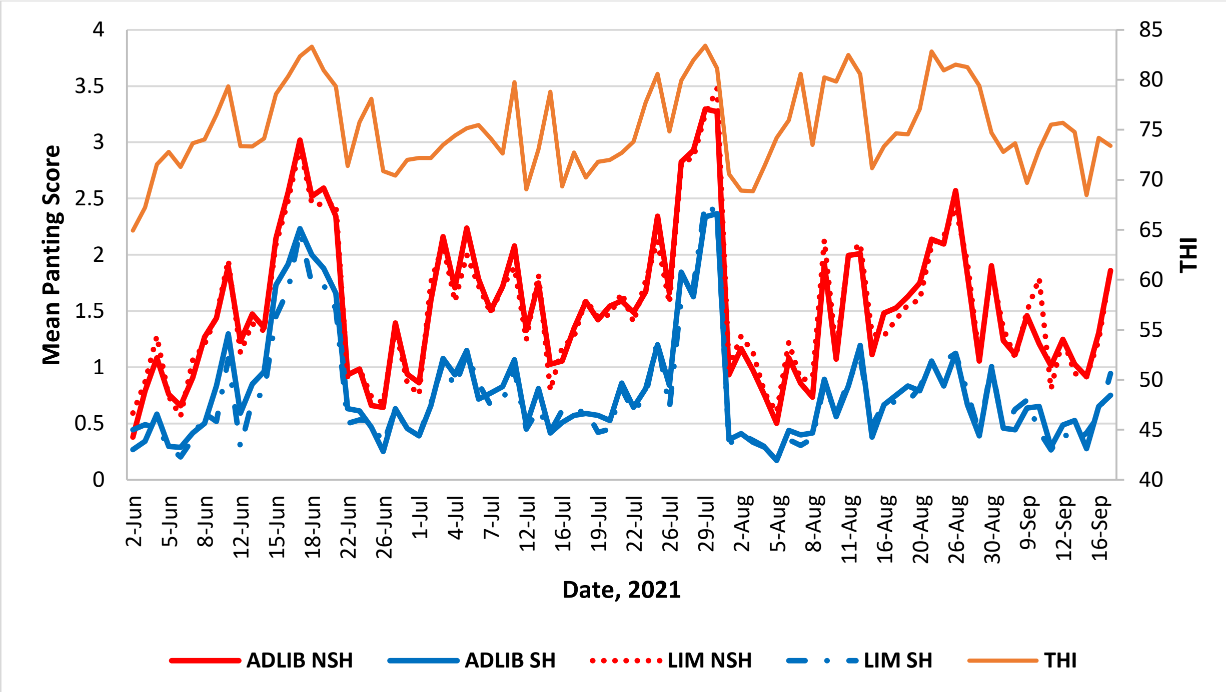

Figure 2.3 Effects of shade and dietary treatment on mean panting score (Year 1).

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Diet (P = 0.09), Shade ($P < 0.01$), diet × shade (P = 0.06), day ($P < 0.01$), day × shade ($P < 0.01$), day × diet (P = 0.81), day × diet × shade (P = 0.76) SEM = 0.10.

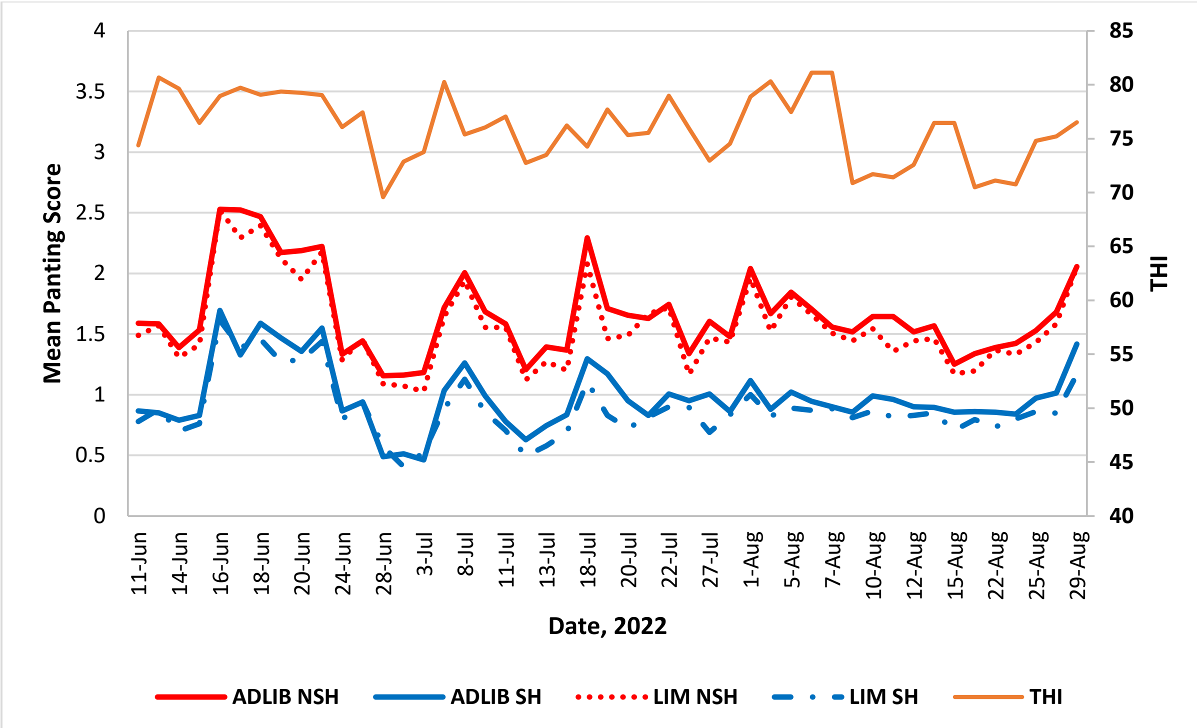

Figure 2.4 Effects of shade and dietary treatment on mean panting score. Year 2

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Diet ($P < 0.01$), Shade ($P < 0.01$), diet × shade ($P = 0.77$), day ($P < 0.01$), day × shade ($P < 0.01$), day × diet ($P = 0.18$), day × diet × shade ($P = 0.83$) SEM = 0.06

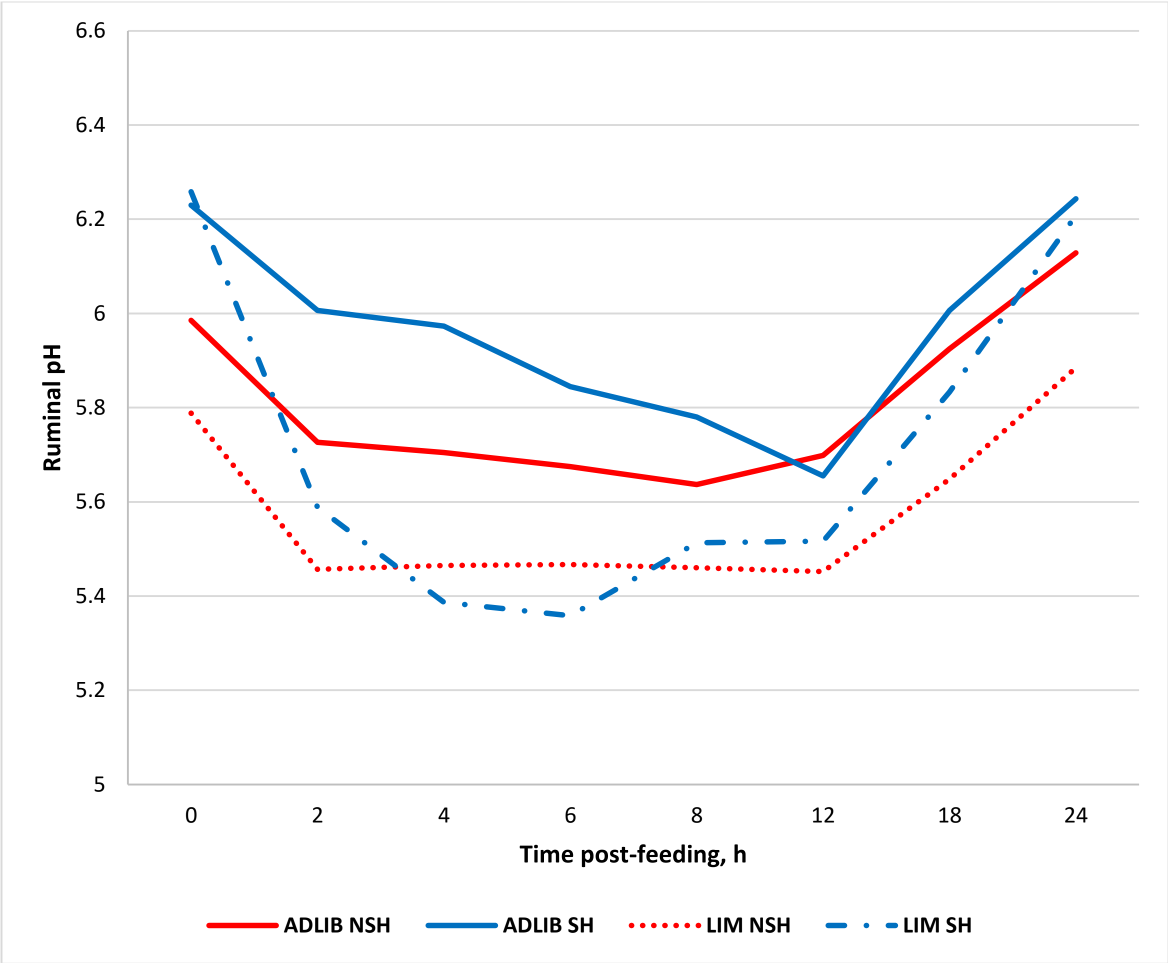

Figure 2.5 Effects of shade allotment and dietary treatment on ruminal pH across 24 hours. Year 1

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Diet ($P = 0.09$), shade ($P = 0.07$), shade × diet ($P = 0.16$), hour ($P < 0.01$), diet × hour ($P = 0.09$), shade × hour ($P = 0.30$), diet × shade × hour ($P = 0.30$) SEM = 0.14.

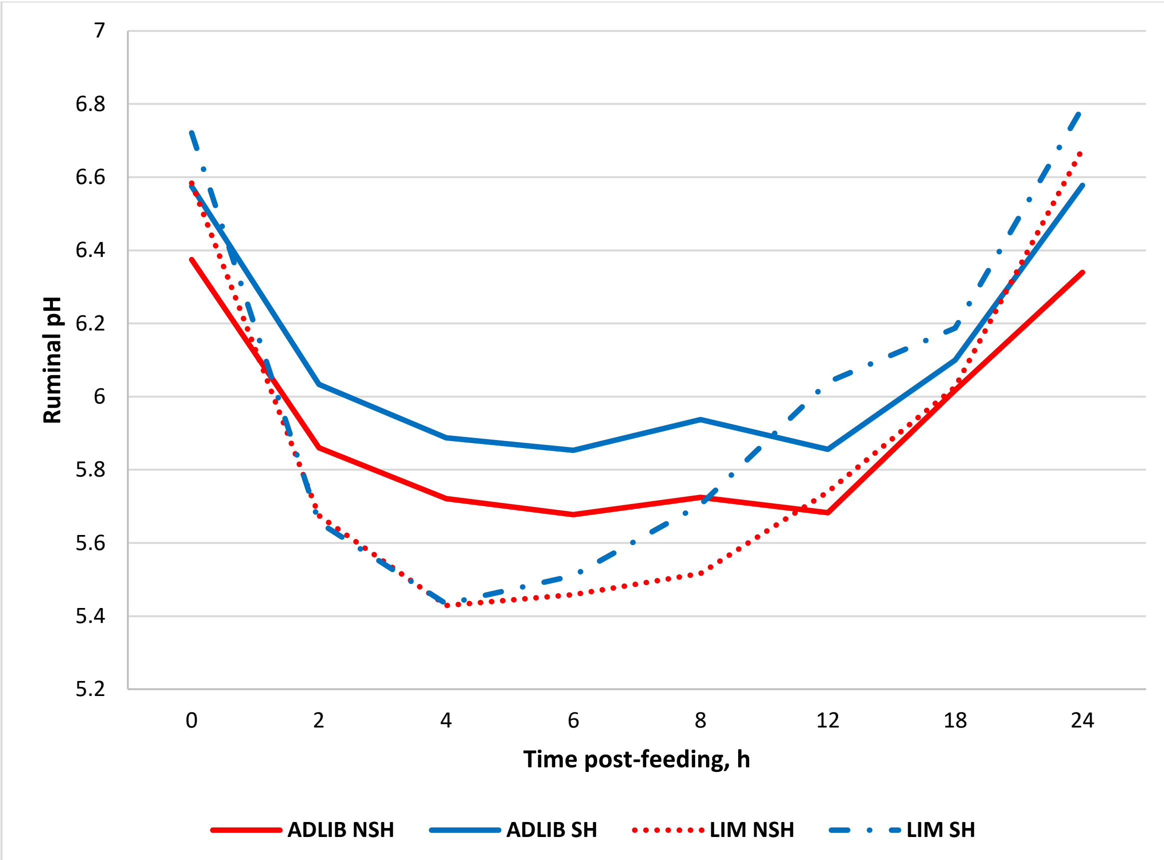

Figure 2.6 Effects of shade allocation and dietary treatment on ruminal pH across 24 hours Year 2.

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Diet (P = 0.18), shade (P < 0.01), shade × diet effect (P = 0.66), hour (P < 0.01), diet × hour (P < 0.01), shade × hour (P = 0.75) diet × shade × hour (P = 0.56). SEM = 0.07.

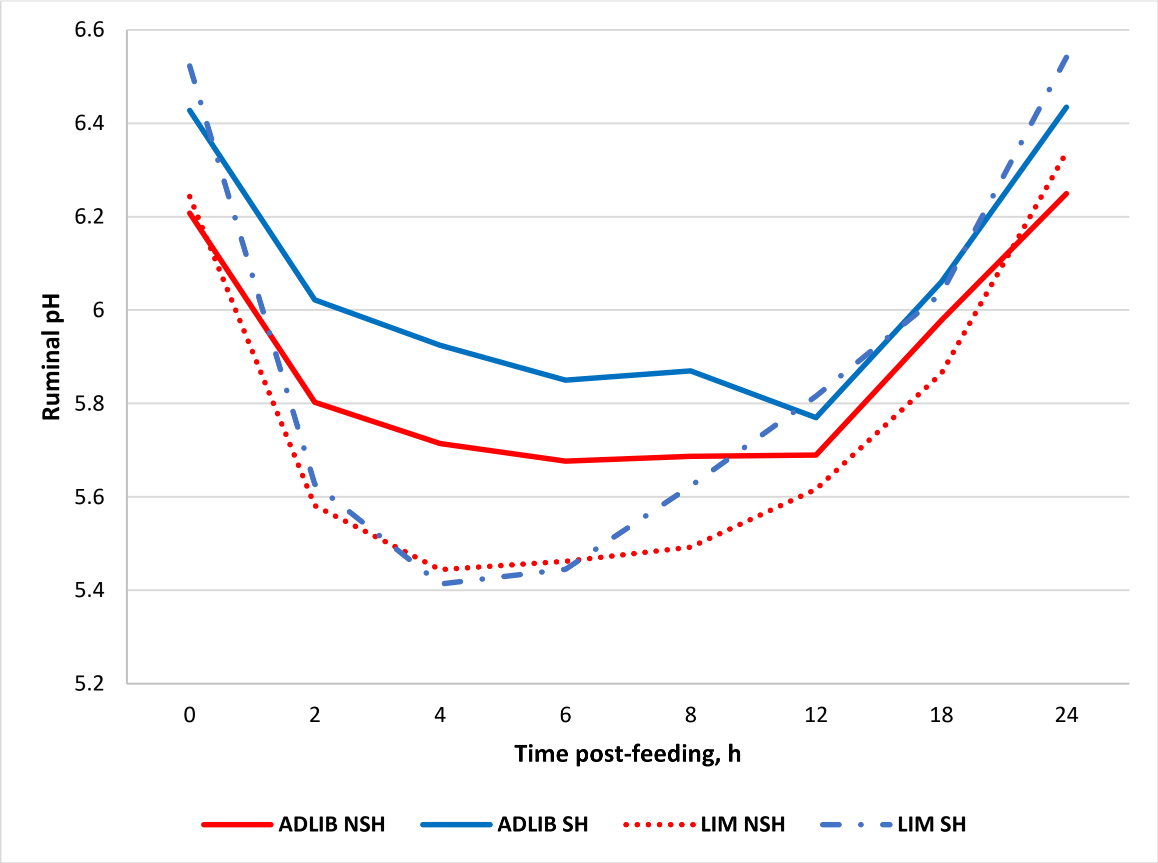

Figure 2.7 Effects of shade allocation and dietary treatment on ruminal pH across 24 hours Combined Years.

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Diet ($P = 0.02$), shade ($P < 0.01$), shade × diet ($P = 0.71$), hour ($P < 0.01$), diet × hour ($P < 0.01$), shade × hour ($P = 0.46$) diet × shade × hour ($P = 0.44$). SEM = 0.08.

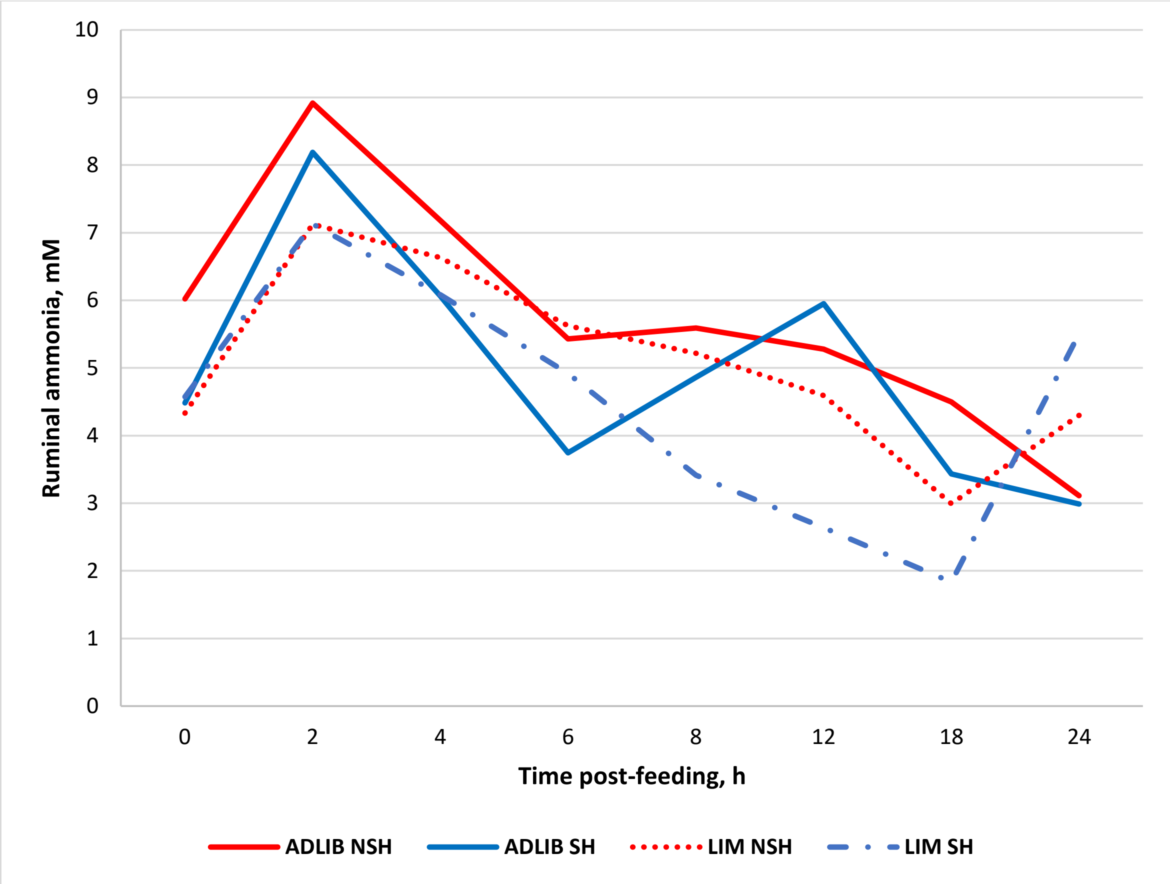

Figure 2.8 Effects of shade allocation and dietary treatment on ruminal ammonia concentration across 24 hours Year 1.
ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Diet (P = 0.12), Shade (P = 0.02), Shade × diet (P = 0.69), Hour (P < 0.01), diet × hour (P < 0.01), Shade × hour (P = 0.35), shade × diet × hour (P = 0.22). SEM = 0.74.

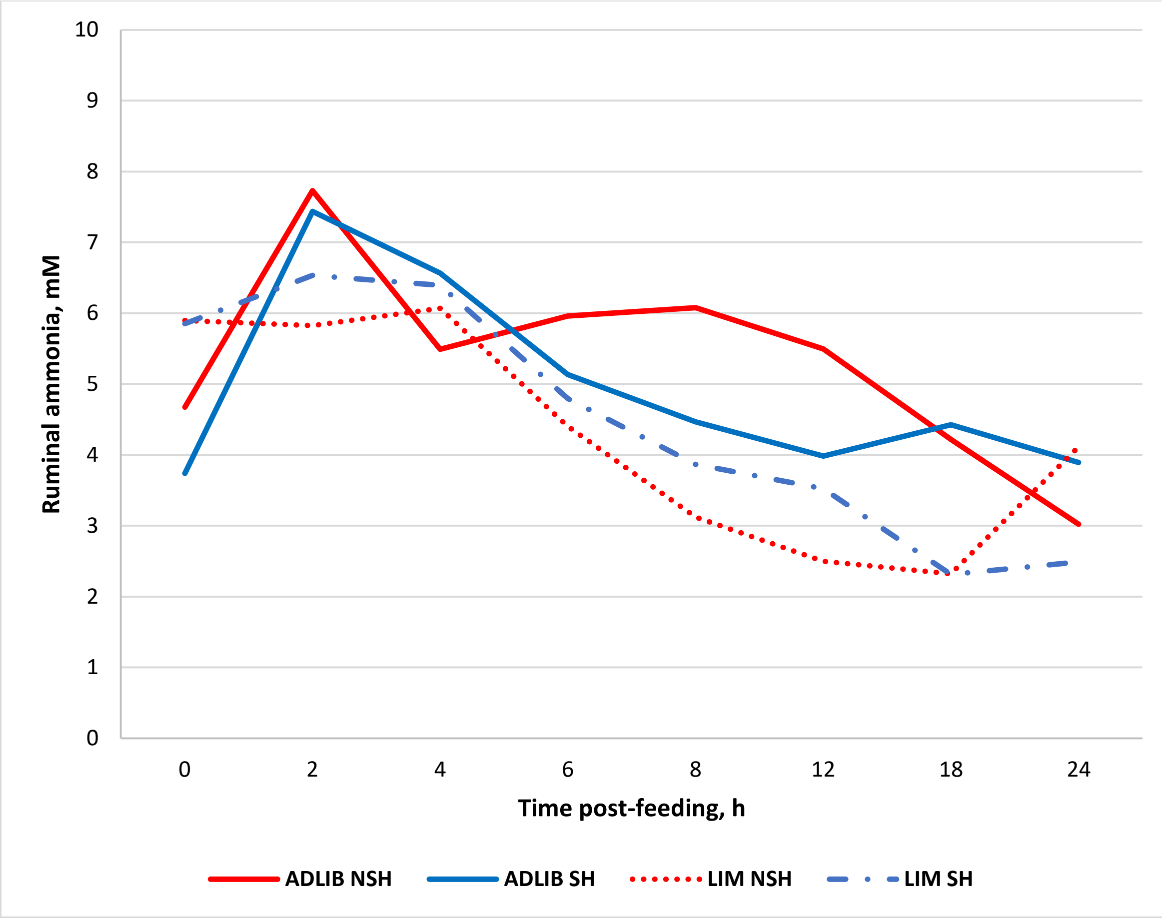

Figure 2.9 Effects of shade allocation and dietary treatment on ruminal ammonia concentration across 24 hours. Year 2

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Diet (P < 0.01), Shade (P = 0.88), Shade × diet (P = 0.37), Hour (P < 0.01), diet × hour (P < 0.01), Shade × hour (P = 0.97), Shade × diet × hour (P = 0.38). SEM = 0.41.

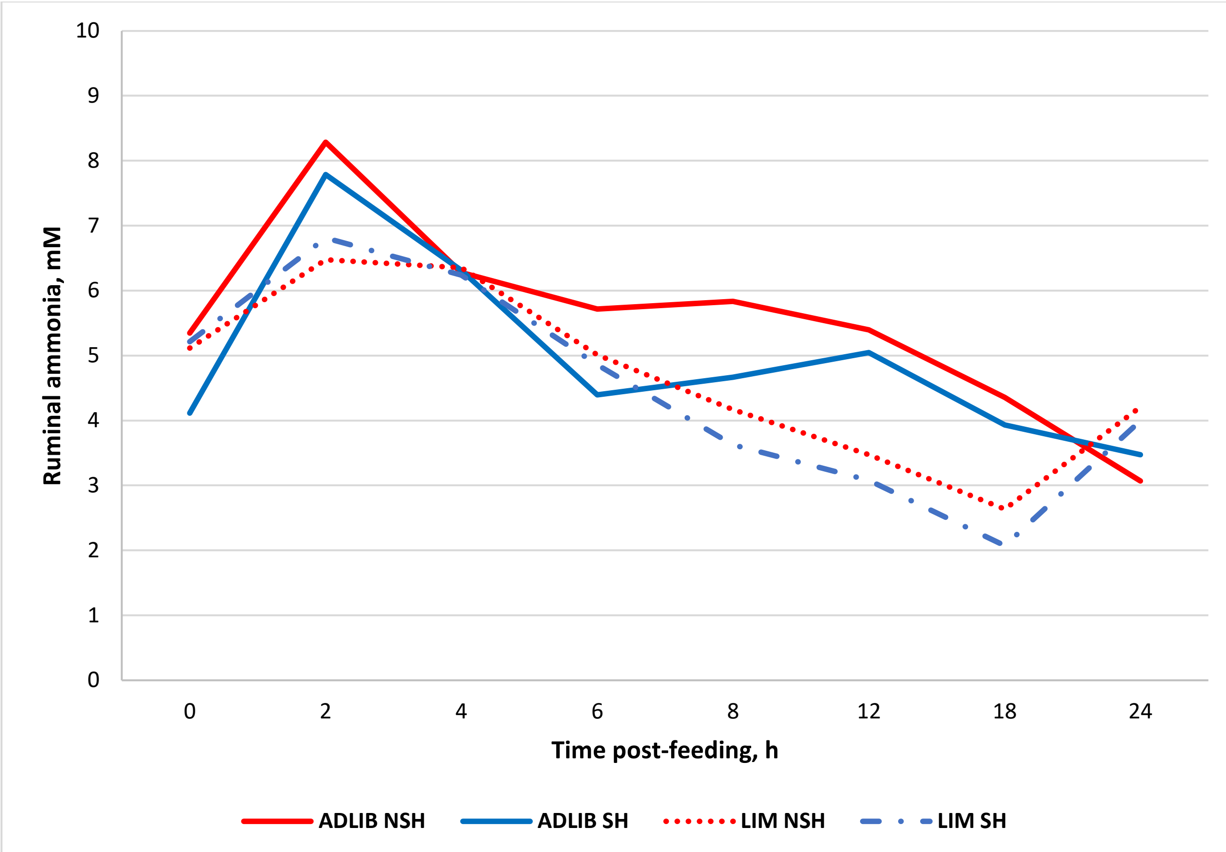

Figure 2.10. Effects of shade allocation and dietary treatment on ruminal ammonia concentration across 24 hours. Combined Years.
ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Diet (P < 0.01), Shade (P = 0.07), Shade × diet (P = 0.40), Hour (P < 0.01), diet × hour (P < 0.01), Shade × hour (P = 0.84) diet × shade × hour (P = 0.77). SEM = 0.34.

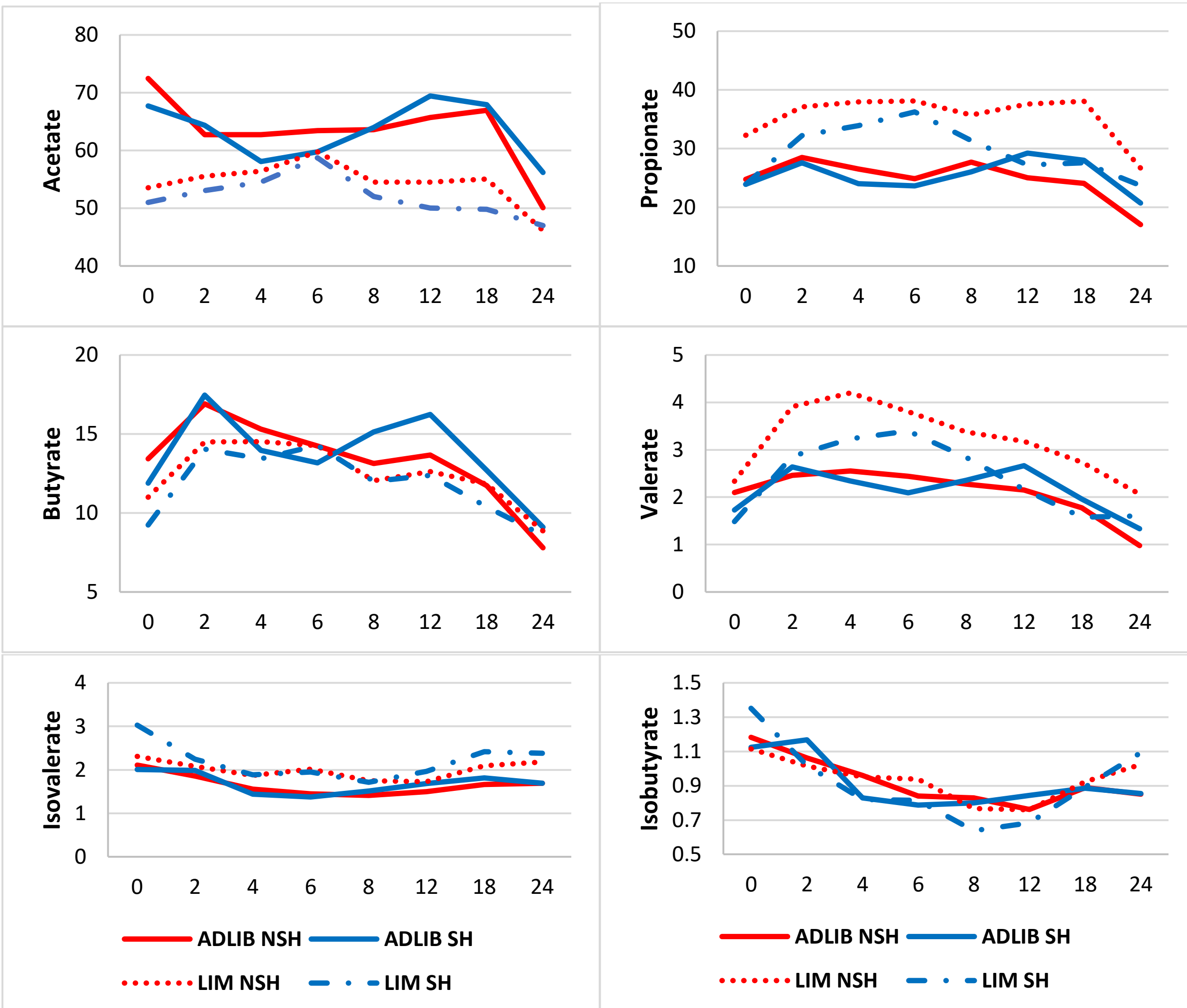

Figure 2.11 Effects of shade allocation and dietary treatment on ruminal VFA concentrations across 24 hours. Year 1

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Acetate: diet (P < 0.01), shade (P = 0.95), diet × shade (P = 0.43), hour (P < 0.01), diet × hour (P < 0.01), shade × hour (P = 0.43) SEM = 3.18. Propionate: diet (P < 0.01), shade (P = 0.15), diet × shade (P = 0.04), hour (P < 0.01), diet × hour (P < 0.01) shade × hour (P = 0.74) SEM = 2.73. Butyrate: diet (P = 0.02), shade (P = 0.95), diet × shade (P = 0.39), hour (P < 0.01), diet × hour (P = 0.07) shade × hour (P = 0.39) SEM = 0.97. Valerate: diet (P = 0.01), shade (P = 0.05), diet × shade (P = 0.10), hour (P < 0.01), diet × hour (P = 0.05) shade × hour (P = 0.72) SEM = 0.33. Isovalerate: diet (P = 0.07), shade (P = 0.51), diet × shade (P = 0.86), hour (P < 0.01), diet × hour (P = 0.04) shade × hour (P = 0.71) SEM = 0.21. Isobutyrate: diet (P = 0.68), shade (P = 0.66), diet × shade (P = 0.69), hour (P < 0.01), diet × hour (P = 0.01) shade × hour (P = 0.29) SEM = 0.08.

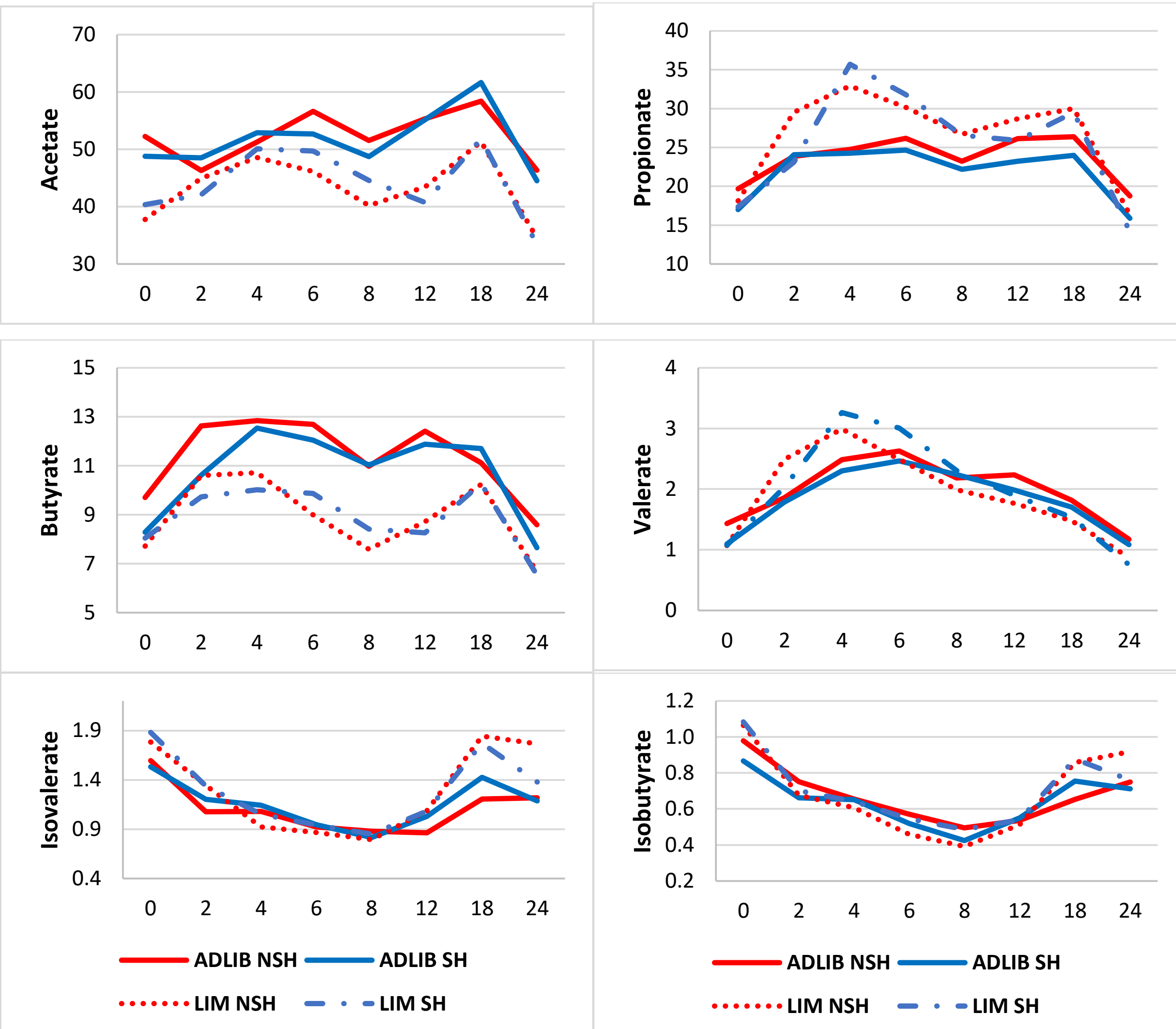

Figure 2.12 Effects of shade allocation and dietary treatment on ruminal VFA concentrations across 24 hours. Year 2.

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Acetate: diet ($P < 0.01$), shade ($P = 0.55$), diet × shade ($P = 0.79$), hour ($P < 0.01$), diet × hour ($P = 0.01$), shade × hour ($P = 0.99$) SEM = 1.74. Propionate: diet ($P < 0.01$), shade ($P = 0.03$), diet × shade ($P = 0.78$), hour ($P < 0.01$), diet × hour ($P < 0.01$) shade × hour ($P = 0.91$) SEM = 1.22. Butyrate: diet ($P = 0.01$), shade ($P = 0.18$), diet × shade ($P = 0.50$), hour ($P < 0.01$), diet × hour ($P = 0.20$) shade × hour ($P = 0.88$) SEM = 0.61. Valerate: diet ($P = 0.01$), shade ($P = 0.05$), diet × shade ($P = 0.10$), hour ($P < 0.01$), diet × hour ($P < 0.01$) shade × hour ($P = 0.72$) SEM = 0.13. Isovalerate: diet ($P = 0.07$), shade ($P = 0.50$), diet × shade ($P = 0.86$), hour ($P < 0.01$), diet × hour ($P = 0.04$) shade × hour ($P = 0.71$) SEM = 0.10. Isobutyrate: diet ($P = 0.05$), shade ($P = 0.74$), diet × shade ($P = 0.43$), hour ($P < 0.01$), diet × hour ($P = 0.10$) shade × hour ($P = 0.70$) SEM = 0.03

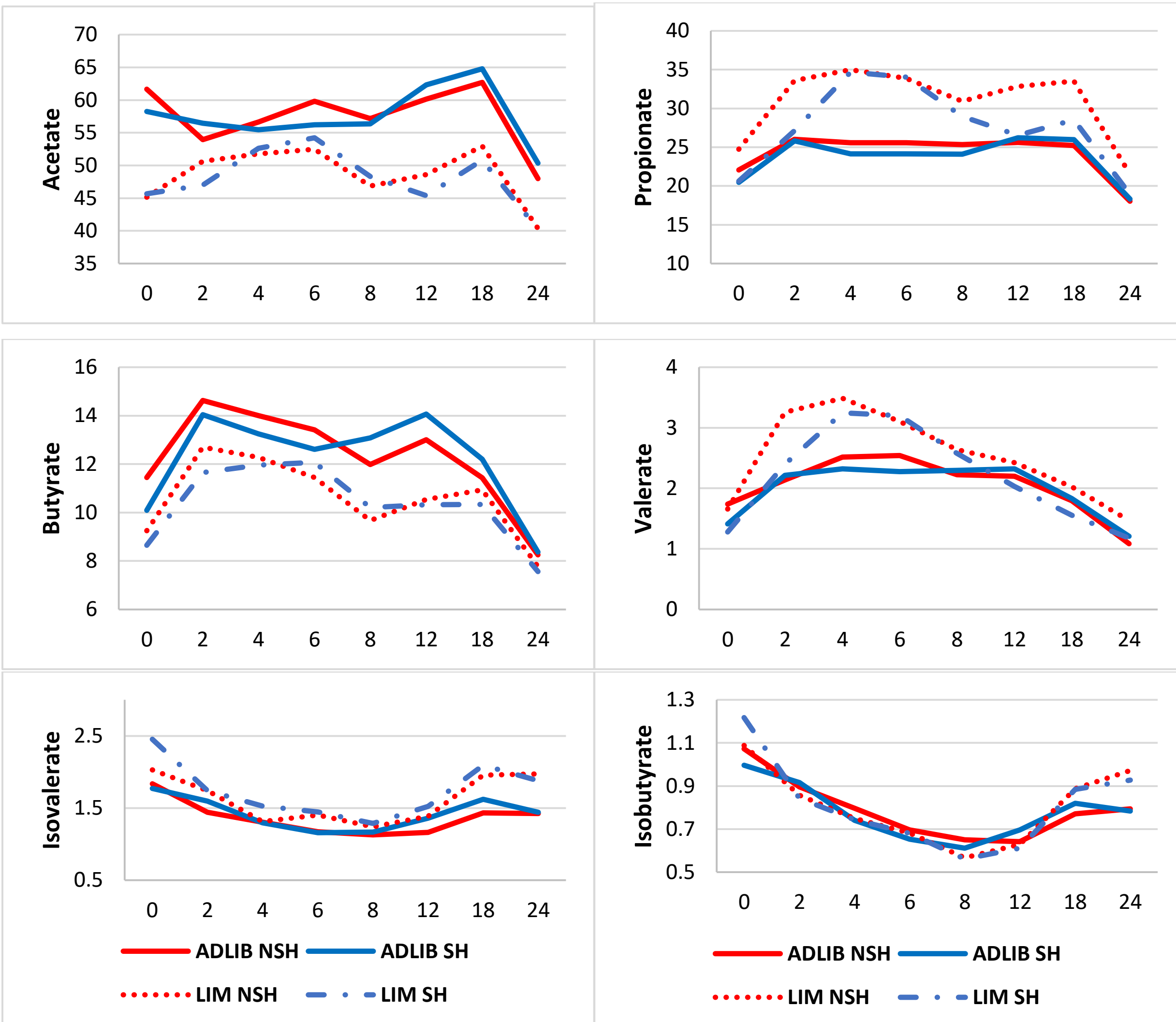

Figure 2.13 Effects of shade allocation and dietary treatment on ruminal VFA concentrations across 24 hours. Combined Years.

ADLIB = heifers fed a 0.99 Mcal NEg/kg DM diet for ad libitum intake. LIM = heifers limit-fed a 1.32 Mcal NEg/kg DM diet at 2.2% body weight daily. SH = shade. NSH = no shade. Acetate: diet ($P < 0.01$), shade ($P = 0.54$), diet × shade ($P = 0.44$), hour ($P < 0.01$), diet × hour ($P < 0.01$), shade × hour ($P = 0.94$) diet × shade × hour ($P = 0.41$) SEM = 1.45. Propionate: diet ($P < 0.01$), shade ($P < 0.01$), diet × shade ($P = 0.02$), hour ($P < 0.01$), diet × hour ($P < 0.01$) shade × hour ($P = 0.94$), diet × shade × hour ($P = 0.30$) SEM = 1.20. Butyrate: diet ($P < 0.01$), shade ($P = 0.43$), diet × shade ($P = 0.60$), hour ($P < 0.01$), diet × hour ($P = 0.20$) shade × hour ($P = 0.64$) diet × shade × hour ($P = 0.76$) SEM = 0.50. Valerate: diet ($P < 0.01$), shade ($P = 0.01$), diet × shade ($P = 0.27$), hour ($P < 0.01$), diet × hour ($P < 0.01$) shade × hour ($P = 0.88$), diet × shade × hour ($P = 0.02$) SEM = 0.14. Isovalerate: diet ($P < 0.01$), shade ($P = 0.60$), diet × shade ($P = 0.94$), hour ($P < 0.01$), diet × hour ($P = 0.01$) shade × hour ($P = 0.89$) diet × shade × hour ($P = 0.31$) SEM = 0.11. Isobutyrate: diet ($P < 0.01$), shade ($P = 0.86$), diet × shade ($P = 0.88$), hour ($P < 0.01$), diet × hour ($P < 0.01$) shade × hour ($P = 0.89$) diet × shade × hour ($P = 0.41$) SEM = 0.03