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Impact of Shade on Performance and Heat Stress of Finishing Cattle and Pooled Analysis of Individually Fed Finishing Trials

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IMPACT OF SHADE ON PERFORMANCE AND HEAT STRESS OF FINISHING CATTLE AND POOLED ANALYSIS OF INDIVIDUALLY FED FINISHING TRIALS

by

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Impact of Shade on Performance, Body Temperature, and Heat Stress of Finishing Cattle in Eastern Nebraska and Pooled Analysis of Individually Fed Finishing Trials at the University of Nebraska-Lincoln

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A commercial feedyard trial in Eastern Nebraska evaluated the effect of shade vs no shade on cattle performance, ear temperature, and panting scores. No differences in overall performance (final BW, DMI, ADG, and G:F) or carcass characteristics (HCW, 12th rib fat thickness, marbling, LM area, and calculated YG) were observed. Cattle that were provided shade had lower panting scores and ear temperatures, and greater DMI, compared to cattle that had no shade during heat events. Also, a treatment by hour interaction for movement of cattle occurred for one of the heat events. In comparison, the cool event had greater DMI and lower panting scores for the cattle that were provided shade compared to the cattle without shade, but ear temperature and movement were not different. Providing shade to cattle in southeast Nebraska reduced measures of heat stress for feedyard cattle.

A pooled-analysis of individually fed cattle was conducted to determine the relationships of metabolizable energy (ME), DMI, ADG, G:F, and carcass traits. Increased amounts of ME increased G:F. Animal ADG had a strong correlation (R^2 = 0.72) with G:F, while the correlation between DMI and G:F (R^2 = 0.02) was not as

strong. Animal G:F was poorly correlated with 12th rib fat thickness (R^2 = 0.01) and marbling (R^2 = 0.01).

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INTRODUCTION

Seventy percent of all finished cattle are fed in Texas, Kansas, and Nebraska, all of which have a THI load above the average of other beef producing states (St-Pierre et al., 20003). Heat stress in beef feedyards has negative impacts on feed intake, growth, efficiency, and in extreme cases can cause death (Fuquay, 1981; Busby and Loy, 1996; Hubbard et al., 1999; St-Pierre et al., 2003; Mader, 2006). Also, with demand from consumers to improve animal welfare, shade could also become a consumer demand for their beef products.

Feeding cattle in individually fed pens allows us the opportunity to collect individual feed intake and G:F. With this information, relationships between individual DMI and G:F can be made with other traits that are routinely measured in pen studies.

The objectives of these experiments were to: 1) determine the effect of shade on cattle performance, body temperature, and cattle activity of cattle in southeast Nebraska, and 2) determine relationships of ADG, DMI, and metabolizable energy, and determine the effectiveness of the NASEM (2016) at predicting intake of individually fed animals.

CHAPTER I. REVIEW OF LITERATURE

Factors Affecting Heat Stress

Heat stress in feedlot cattle has been shown to reduce productive efficiency and cause death of animals on feed (Fuquay, 1981; Hubbard et al., 1999; Busby and Loy, 1996; St-Pierre et al., 2003; Mader et al., 2006). Several climatic factors should be considered when determining potential heat stress in feedlots. An accepted model to predict heat stress in cattle is through the Temperature-Humidity Index (THI; Hahn and Mader, 1997). The THI scale for cattle has been adapted from the Thom (1959) equation, which is an adjustment of temperature based on humidity. Further adjustment for THI is accomplished by adjusting for solar radiation, a measure of heat flux density, and wind speed (Davis and Mader, 2003a; Mader et al., 2006). These four measurements (ambient temperature, humidity, wind speed, and solar radiation) can be used to accurately determine when animals are stressed (Du Preez et al., 1990; Armstrong, 1994; Mader et al., 1999a; Davis and Mader, 2003a) and when producers need to act to prevent losses in their feed yard.

Various THI models have been created recently and have been re-evaluated to determine the best way to predict heat stress. Gaughan et al. (2008) wanted to account for cumulative effects of heat load and natural cooling on feedlot cattle. Cattle will accumulate heat during the day and their body temperature may rise. During the night, ambient temperatures drop and the heat that was accumulated by the cattle during the day is then dissipated. If there is insufficient night cooling, then the cattle will enter the next day with an accumulated heat load (Hahn and Mader, 1997). Since THI only accounts for

the effects of heat at a specific time point, a model for accumulated effects of heat on cattle was established. The accumulated heat load or accumulated heat load unit (AHL or AHLU) for cattle uses several factors to determine heat stress and the accumulation of heat. The AHL is based on a heat load index (HLI). The HLI has two models, one for black globe temperature above 25°C and one for below 25°C. Black globe thermometers consist of a black globe that has a thermometer in the center. Black globe thermometers are used to measure radiant heat. The models by Gaughan et al. (2008) account for black globe temperature, humidity, and wind speed. The AHL has adjustments for genotype (e.g. *Bos taurus* or *Bos indicus*), coat color, health status, acclimatization, amount of shade, days on feed, manure management, and drinking water temperature. The main purpose of the AHL is to account for the amount of heat that accumulates over time.

Other considerations for determining heat stress in feedlots is visual appraisal of animals. Stressed animals will show visual signs such as panting and increased respiration rates (Gaughan et al., 2000; Mader et al., 2006). Many studies have used panting scores and respiration rates to quantify heat stress in cattle (Gaughan et al., 2000; Eigneberg et al., 2005; Mader et al., 2006; Hahn et al., 2009).

Ambient Temperature

Ambient air temperature is the temperature of a dry-bulb thermometer. The thermoneutral zone (TNZ) has been described relative to production animals as the optimum thermal environment in which the animal enjoys optimum health and maximum performance (Mount, 1974). In other words, when an animal is in the TNZ, its NE_m requirement is at its least and more energy is allocated toward NE_g (in the case of feedlot cattle). At the bounds of the TNZ are the lower and the upper critical temperatures.

Outside of these bounds, the efficiency of production decreases. Below the lower critical temperature is referred to as cold stress and above the upper critical temperature in referred to as heat stress. Visual representation of temperatures effect on efficiency is shown in Figure 1.1.

When animals become cold stressed they will increase intake and NE_m will increase linearly. In extreme cold stress situations, intakes will plateau and NE_m will continue to increase. The NE_m requirement can become greater than kilocalories consumed which will result in lost weight in feedlot animals. Potentially, animals can die if not removed from this state of hypothermia.

When animals become heat stressed, typically around 25 to 27°C for feed lot cattle (Beede and Collier, 1986), they will decrease intake and NE_m will increase. However, NE_m of heat stressed cattle increases quadratically instead of linearly. Similar to cold stressed animals, in extreme heat stress situations, animals can have NE_m requirements greater than kilocalories consumed, which will result in lost weight from feedlot animals. If not removed from this state of hyperthermia, death can potentially occur.

When considering the TNZ for cattle on feed, we must also consider how much energy they are consuming. Lofgreen and Garrett (1968) showed that heat production of cattle and metabolizable energy intake per unit of metabolic body size had a positive linear relationship. Knowing this, we can conclude that as cattle consume more energy per unit of metabolic body, the TNZ is shifted to lower temperatures (Ames, 1980). Therefore, under hot climatic conditions, cattle intake is a function of body temperature (Hahn, 1995). When temperatures during the day are high and little or no night cooling

occurs, cattle will reduce intakes in order to limit heat produced. The TNZ is not the same for every animal but the relationships shown in Figure 1.1 remain the same. For instance, a black hided *Bos taurus* steer would typically have a lower TNZ compared to that of a white hided *Bos indicus* steer. Many factors can affect an animal's individual TNZ (hair density, coat color, breed, age, diet).

When ambient air temperature approaches and exceeds body temperature, animals must find a way to dissipate the heat, reduce heat production, or increase dissipation of heat by evaporation of water from the respiratory tract, or from the skin by sweating (Lee, 1967). Of the four measures commonly used by cattle producers to predict heat stress, ambient temperature is the easiest to obtain and is the basis of all measures of heat stress. Dikmen and Hansen (2008) conducted an experiment at three dairies in central Florida and found that dry-bulb temperature (r^2 = 0.41) was nearly as good as THI (r^2 = 0.42) at predicting rectal temperature of lactating Holstein cows in a subtropic climate. The range of rectal temperatures for the experiment were from 37 to 41.5°C, temperatures ranged from 18 to 39°C, and THI ranged from 65 to 88. However, this high correlation could be due to the consistently high humidity of the tropic climate. The various heat stress indices will vary with climate.

Humidity

High humidity is a concern for livestock when it is combined with high temperature. High humidity decreases the animal's ability to lose heat through evaporative cooling. There are two types of evaporative cooling in cattle: perspiration and panting. Perspiration works by secreting sweat through pores on the surface of the animal which will then evaporate. This transfers the heat from the animal to the

environment. If humidity is high, the perspiration will not evaporate as effectively due to the lower concentration gradient of sweat on the animal compared to the moisture surrounding the animal. However, the transfer of heat by evaporation occurs despite an equal or reversed thermal gradient between the animal and its surrounding environment (Arkin et al., 1991). This means that the only way an animal may dissipate heat in extreme conditions is by evaporative transfer (Davis et al., 2003b).

If cattle are not able to cool themselves by sweating alone they will begin to pant. Panting is another way for cattle to lose body heat. Similar to sweating, evaporative cooling and air flow are used to remove heat from the animal. Hales (1973) found that blood flow was increased 3 to 4-fold to the respiratory muscles and the nasal passages in sheep that were exposed to mild heat stress (approximately 40°C dry bulb and 26°C wet bulb) with an approximately 7-fold increase when exposed to severe heat stress (approximately 42°C dry bulb and 39°C wet bulb) following a control period in a thermoneutral environment (15°C). This was offset by a reduction in blood flow and metabolic rate in non-respiratory and visceral organs. This decreased blood flow in visceral organs can cause decreased efficiency in animals on feed and will increase days on feed (St-Pierre et al., 2003). Similar to when cattle sweat, a concentration gradient between the air surrounding the animal and the air being exhaled by the animal is needed for the cattle to efficiently release heat by panting.

Air Movement

Increased wind speed increases the amount of heat that is removed from the animal by convective cooling. Convective cooling occurs when the heat from the animal is removed by the air flowing around the animal. This can only occur when the ambient

temperature is less than the temperature of the animal. However, wind can also aid in evaporative cooling. As the animal perspires or pants, the wind increases the rate of evaporation.

Solar Radiation

Solar radiation (or irradiance) is a measure of heat flux density. In some branches of physics, solar radiation is referred to as “intensity”. The units associated with solar radiation are watts per square meter (W/m^2). Solar radiation ranges from 0 to 1362 W/m^2 on the earth’s surface. There are three main factors that affect solar radiation: elevation, angle of the sun, and scattering elements such as clouds. Higher elevation results in a shorter path from the atmosphere which means higher solar radiation. When the sun is at its zenith, solar radiation will be at its highest. When the sun is lower in the sky it has more of the ozone to travel through. Seasonality will also have an effect on solar radiation. Cloud coverage can also reduce the amount of solar radiation in a particular area. Because clouds will diffuse solar radiation, angle of the sun is less important on cloudy days. Solar radiation will decrease with increased cloud cover or by providing shade. An increase in solar radiation will decrease the ability of an animal to cool. Mader et al. (2006) suggested increasing THI 0.68 units for every 100 W/m^2 increase in solar radiation.

Management Strategies for Reducing Heat Stress in Feedlots

There are four ways to transfer heat: evaporation, conduction, convection, and radiation. Because producers can’t control the weather, they must control some of the factors that allow an animal to dissipate heat. Some things producers and researchers have done to prevent and alleviate heat stress are: select for heat tolerant cattle, provide

shade for cattle, water feedlot pens on hot days, and use different feeding strategies.

Genetics

Coat color of cattle can have a significant effect on heat tolerance of an animal. Black coat color can increase the surface temperature compared to red and white cattle by as much as 5.6°C and 11.7°C, respectively (Arp et al., 1983a). Finch et al. (1984) observed that white shorthorn steers had a 0.3°C lower rectal temperature compared to dark-red shorthorn steers. The white shorthorn steers also gained 0.13 kg/d more than dark-red shorthorn steers. The difference was attributed to greater heat flux present at the skin of the darker haired animals. A lower rectal temperature for lighter colored animals has been observed in other studies (Davis et al., 2003b; Arp et al., 1983a; Arp et al., 1983b).

Using certain breeds of cattle that are known to have a higher heat tolerance in hotter climates is a common practice. It has been shown that *Bos indicus* breeds of cattle have lower rectal temperature and respiration rates compared to *Bos taurus* breeds of cattle during heat events (Beatty et al., 2006; Gaughan et al., 1999). *Bos indicus* cattle also are less prone to decreased feed intake during heat events compared to *Bos taurus* cattle (Beatty et al., 2006). The ability of Bos *indicus* cattle to dissipate heat is attributed to their greater surface area per mass to dissipate heat and their lower metabolic rates (Gaughan et al., 1999). The effects of a heat event continue for some days after a heat event. Beatty et al. (2006) observed that after a heat event, in a climate-controlled room, blood pH dropped in both types of cattle, *Bos taurus* and *Bos indicus*. This would indicate a state of metabolic acidosis. The heat did affect both types of cattle, but it was more pronounced in the *Bos taurus* cattle.

Perspiration rates also differ between the two types of cattle. Finch et al. (1982) found that in *Bos indicus* cattle, sweating rates increase exponentially while in *Bos taurus* cattle, sweating rates plateau after an initial increase. In extreme heat events where only evaporative transfer is possible, *Bos indicus* cattle have a significant advantage over *Bos taurus* cattle.

Shade

Providing shade will decrease the solar radiation experienced by the cattle (Mader et al., 1999a; Brosh et al., 1998; Mitlöhner et al., 2001), significantly reduce the ground temperature (Mitlöhner et al., 2002), and increase ground moisture (Mitlöhner et al., 2002), but will have little or no effect on the ambient temperature (Morrison, 1983). All of these effects of shade on the microenvironment in the pen can increase the performance of cattle.

Shade structures have been shown to reduce the heat load of cattle by as much as 30% for cattle in low humidity conditions (Bond et al., 1966). However, benefits of shade are diminished in high-humidity climates. This decreased effect in high-humidity environments has been contributed to radiation sources related to cloud cover (Hahn et al., 1970).

Mitlöhner et al. (2002) fed 168 heifers in 12 pens with 6 pens having galvanized steel roof shades during the summer in West Texas. Shaded heifers had 2.9% greater DMI, 6.1% greater ADG, and final BW was 11.3 kg/heifer greater compared to unshaded heifers. However, the G:F ratio did not differ between the two treatments. Similar results have been observed in other shade studies (Ittner et al., 1954; Boren et al., 1961; Mitlöhner et al., 2001). Sullivan et al. (2011) performed a study to determine the correct

amount of shade to supply to feedlot pens. Shade was provided at 3 different levels (2.0, 3.3, and 4.7 m^2/animal) and a control that had no shade. Their results showed that cattle with shade had better G:F than cattle without shade. However, cattle with the lower and intermediate amounts of shade (2.0 and 3.3 m^2/animal) had better G:F than cattle with large amounts of shade (4.7 m^2/animal). In this case, DMI was the same across all treatments. The ADG was greatest for the highest level of shade provided at 1.06 kg/day and the least for the cattle with no shade at 0.93 kg/day. The ADG for the 2.0 and 3.3 m^2 of shade were intermediate to the highest level (4.7 m^2) of shade and the no shade treatments at 1.02 kg/day and 1.03 kg/day, respectively.

Although there are studies that have observed benefits of shade for feedlot cattle, there are also some that have reported no benefits. Mader et al. (1999a) compiled data from three trials that had 110 to 112 animals for 3 consecutive years fed during the summer in Northeast Nebraska. The trials were all 2 × 2 factorials with shade or no shade treatment and wind barrier and no wind barrier treatments. When the wind barrier was provided, F:G was significantly improved for the shade compared to no shade at 5.96 and 6.31, respectively, for the first 56 days on feed. For the cattle without a wind barrier, F:G was also significantly improved for the shade compared to no shade at 5.59 and 5.91, respectively, for the first 28 days. These benefits for shade were not significantly different by the end of the feeding period. Boyd et al. (2016) reported no differences between shade and no shade cattle for DMI and G:F but did see a tendency for non-shaded cattle to have greater ADG and final live BW compared to shaded cattle. Cattle were on feed during the summer in Central Nebraska. McCormick et al. (1963) also did not observe any performance differences in cattle fed in Southern Georgia which was

likely due to moderate temperatures during the experiment.

When looking at the effect of shade on cattle we must not only look at performance. Shade can also act as an insurance policy against catastrophic heat events. For example, on July 11 and 12, 1995 an extreme heat wave occurred in the Mid-West. The weather on July 11 was a high of 104°F with a 50% relative humidity, no cloud cover, and no wind from 3 p.m. until 12 p.m. on July 12. A producer survey was conducted by Busby and Loy (1996) in west-central Iowa. Thirty-six producers were surveyed, which covered 13 counties in West Central Iowa. The data include 81 lots of cattle with 9,830 head. Thirty-five of the 81 lots provided shade for the cattle and 46 did not. The lots that provided shade had a 0.2% death loss and the lots without shade had a 4.8% death loss. Eighty-six percent of the lots with shade and 19% of the lots without shade had no death loss at all. These results illustrate that shade can prevent death loss of cattle in extreme heat waves.

Other than performance and death loss, shades can be used to positively impact the welfare of animals in feedlots. Consumers are interested in how production animals are treated. Shades can reduce the effects of a hot environment on the animals even if performance differences are not realized at the conclusion of the feeding period.

The effects of shade on cattle performance is highly dependent on location and on the severity of the summer in a given year. In summers with low to moderate heat, providing shade may not provide any benefits. However, during unusually hot summers, cattle can be negatively affected. Reductions in DMI, ADG, and feed efficiency are all possibilities. In extreme cases, death can occur. Providing shade can alleviate these negative effects and provide insurance against death loss.

Watering

Watering cattle and feedlot pens is an inexpensive way to cool cattle during heat events. The objective of directly watering cattle is to increase evaporative cooling. Sprinklers are the primary source of watering feedlot cattle. Sprinklers have been found to increase gains of cattle on feed (Kelly et al., 1955; Garner et al., 1988; Gaugan et al., 2001; Lofgreen et al., 1973; Davis et al. 2003b).

Watering feedlot cattle has also been evaluated by using misters. Misters provide a smaller water droplet compared to sprinklers which generally will evaporate more quickly and cool the air quicker but will raise the humidity. Mitlöhner et al. (2001) found that misting was largely ineffective at decreasing heat stress and lowering its negative effects. It is believed that fine water droplets cling to the outer hair of the cattle and a majority of the water does not reach the skin. This may build up an insulation layer which acts as an insulation barrier and can actually increase heat stress. However, proof of insulation due to smaller water droplet size has not been established.

Cooling the surface of the pen is the main benefit of watering. When the ground temperature of the feedlot pen is greater than body temperature of the animal then the animal is absorbing heat from the ground. The objective of watering the pen surface is to provide an area conducive to conductive heat exchange between the animal and the feedlot surface (Davis et al., 2003b). This can be achieved through watering the feedlot pens.

Watering of feedlot cattle and pens can be effective in reducing excessive heat load of cattle (Gaughan et al., 2001; Davis et al., 2003b; Morrison et al., 1973). However, the time of day at which water is applied is significant (Gaughan et al., 2001; Davis et al.,

2003b). Davis et al. (2003b) sprinkled mounds for 2 hours in the morning, 2 hours in the afternoon or not at all as a control during 3 days of severe heat stress (THI ≥ 77). Tympanic temperatures of morning watered cattle were lower than afternoon watered cattle from 1300 to 1400 hours and 2300 to 0800 hours with control cattle being intermediate. All other times of day were not significantly different. Gaugan et al. (2001) held 6 heifers in climate-controlled rooms for a week at thermoneutral conditions. Then for 6 days they raised the temperature to 35°C from 0800 to 1500 hours and allowed it to gradually drop to 26°C after 1600 hours to simulate summer time conditions. One treatment was sprinkled each of the 6 hot days and double sprinkled on day 4 and 5 and one treatment was sprinkled every day except for day 4 and 5 of the hot days. This was to demonstrate the effects of inconsistent watering. Rectal temperature, respiration rate, and pulse rate were greater on days 4 and 5 for the cattle that did not get sprinkled. However, with the return of once a day sprinkling to both treatments on day 6, the cattle that were double sprinkled on day 4 and 5 had a tendency to have higher respiration rates than cattle that did not get sprinkled on day 4 and 5. Also, respiration rates for cattle that were double watered were highest on day 6 while cattle that did not receive water on days 4 and 5 were highest on those days. This demonstrates that consistent sprinkling of cattle is important during hot periods. Lofgreen et al. (1973) found that sprinkling more often in shorter intervals increased DMI 0.95 kg/day and ADG by 0.16 kg/day compared to cattle sprinkled less often in longer intervals. Similar results were also reported by Garner et al. (1988).

Similar to shade, location and severity of summer time conditions play major roles in the effect of watering on animals. Benefits have been observed by increasing

DMI and ADG; however, this is not always the case. Feedlots may apply water to prevent death loss of cattle. Watering of cattle may just be a means of alleviating heat stress in some cases with no performance advantages. How water is applied (sprinkled or misting), time of day it is applied, and intervals of when it is applied are all important factors to consider when watering cattle.

Feeding Strategies

Another strategy to reduce heat stress in cattle is managing feed intake and roughage concentration in the diet. As discussed before, heat is produced in the rumen due to fermentation of feedstuffs by ruminal microbes. A reduction in substrate available for metabolism within the rumen reduces this heat load. Another explanation is the potential for decreased organ size in response to low levels of intake (Koong et al., 1985; Burrin et al., 1990; Davis et al., 2003b).

Instead of feeding the cattle ad libitum as is usual with feedlot cattle, before and during heat events, animals can be limit fed. Mader et al. (2002b) compared cattle restricted to 75% of ad libitum with ad libitum fed cattle and reported 0.2 to 0.4°C lower tympanic temperatures in cattle on restricted feed compared to ad libitum. This suggests that restricting feed to feedlot animals is a viable option to reduce heat stress. However, reducing feed will decrease ADG. For this reason, intentionally reducing feed to cattle is not a popular option among producers.

Rates of ruminal contractions are reduced at high temperature (Attebery and Johnson, 1969). This will decrease the rate of passage of feed in the rumen. In cattle being fed a high roughage diet, intakes are limited by gut fill. If the rate of passage is decreased then intakes will drop (Collier et al., 1982a). Also, for a given amount of

digestible energy, roughages have a greater heat increment compared to concentrates in ruminant diets (Sudarman and Ito, 2000; Kleiber, 1975).

Monitoring Heat Stress in Feedlots

Producers can use many tools to know when cattle are stressed from heat, even without visual appraisal of the animals. Knowing the temperature, relative humidity, solar radiation, and wind speed are useful. Other information to consider when identifying heat stressed animals are intake, panting scores, and respiration rates.

Intakes

Cattle and other ruminants produce large amounts of heat due to fermentation of feed by microbes in the rumen. The crude fiber content of the diet is directly proportional to the heat increment (Kleiber, 1975). This has been attributed to the acetate:propionate ratio. Relative to a diet that is high in concentrate, forage diets elicit a greater acetate:propionate ratio. Hungate (1966) fermented 1 mole of hexose to 2 moles of acetate and 1 mole of hexose to 2 moles of propionate. In the fermentation of acetate, 252 kcal were lost as heat. However, in the fermentation of propionate 62 kcal were gained.

Heat produced by the rumen is problematic for ruminants during heat events. A major way for cattle in feedlots to reduce their heat load is to reduce feed intake (Fuquay, 1981; Baccari, 1983; Morrison, 1983; Ray, 1989; Mitlöhner et al., 2002; Mader, 2003; Beatty, 2006; Beatty, 2008). By doing this, the cattle reduce heat of fermentation that takes place in the rumen.

Panting Scores and Respiration Rates

Respiration rates are simply the number of breaths an animal takes in a certain amount of time (breaths/minute). There are many studies that show a positive correlation

between respiration rate and ambient air temperature ($r^2 \geq 0.41$; Hahn et al., 1997; Mader et al., 1999a; Gaughan et al., 2000; Mitlöhner et al, 2001; Brown-Brandl et al., 2005; Eigenberg et al., 2005). Models have been developed with respiration rate as the dependent variable. Eigenberg et al. (2005) created regression equations with variables of dry-bulb temperature, relative humidity (or dew point), wind speed, and solar radiation ($r^2 = 0.45$). Respiration rate is a good indicator of heat stress, but there is a lag time involved. Gaughan et al. (2000) suggest recording respiration rate two to three hours after the hottest part of the day because it takes time for the animals to "warm up". In thermoneutral conditions cattle respiration rate is normally 40 breaths/minute. During heat events respiration rate can increase up to 120 breaths/minute.

Another heat stress indicator used in many research trials is panting scores. Panting scores are on a scale of 0 to 4. A panting score of 0 would indicate no panting while a score of 4 would indicate severe panting that would be accompanied by a protruding tongue, excessive salivation, and the neck extended forward. Mader et al. (2006) established several models for heat stress in cattle based on panting scores with variables for temperature, relative humidity, wind speed, and solar radiation. These models were created from previous trials that used predominantly black hided animals, therefore should exclusively be used for those animals.

The models created that correlate panting scores or respiration rate to heat stress in feedlot cattle show strong correlations. The purpose of these models is to give real-time updates to producers so they can act to prevent losses from at-risk animals (Brown-Brandl, 2007).

Response of Cattle to Heat Stress

Cattle can become acclimated to heat via acclamatory homeostasis (Horowitz, 2002) or more recently, it has been referred to as a homeorhetic mechanism (Collier et al., 2008) because it appears to alter the set-points of homeostatic-related systems (Bernabucci et al., 2010). When cattle are heat stressed, we observe increased respiration rate, panting scores, and water intake and decreased feed intake. This process is categorized as short-term heat acclimation (Horowitz et al., 1996). Long-term heat acclimation is defined by a reprogrammed gene expression and cellular response which improves efficiency signaling pathways and metabolic processes (Horowitz, 2002). The first responder to elevated temperature is a family of transcription factors know as heat shock transcription (Trinklein et al., 2004; Page et al., 2006). These transcription factors affect expression of genes including heat shock proteins (Akerfelt er al., 2007). Currently it is believed that in a non-stressed cell, a folded heat shock transcription factor 1, a major heat shock transcription factor, is bound to heat shock proteins. When a heat stimulus is applied, heat shock transcription factor 1 dissociates from the heat shock protein and unfolds. Then two unfolded heat shock transcription factor 1 monomers attach to a heat shock protein. This trimer is translocated to the nucleus to activate heat stress target gene transcription (Collier et al., 2008). This long-term heat acclimation presumably has the goal of decreasing metabolic heat production and increasing heat dissipation.

A few noted adaptations to heat stress in the endocrine system are decreases in aldosterone secretion (Collier et al., 1982a), glucocorticoid secretion (Collier et al., 1982b; Ronchi et al., 2001), somatotropin secretion (McGuire et al., 1991), thyroxine secretion (Collier et al., 1982 b; Nardone et al., 1997), estrone sulfate secretion (Collier et

al. 1982b) and increases in epinephrine secretion (Alvarez and Johnson, 1973), progesterone secretion (Collier et al., 1982b; Ronchi et al., 2001), leptin secretion (Bernabucci et al., 2006), and prolactin secretion (Wetteman and Tucker, 1979; Ronchi et al., 2001). Acclimation is a process of altered expression of pre-existing features and is driven by the hormones mentioned above (Bernabucci et al., 2010).

Diet and Growth Parameters for Feedlot Cattle

Individually Fed Cattle

Feeding cattle in a pen setting limits our understanding of how individual animals perform. In studies that are performed in pens, our experimental unit is the pen because treatments are imposed on the pen. Furthermore, feeding cattle individually gives us the opportunity to collect individual DMI and G:F which in turn makes the experimental unit the animal instead of the pen. When using data from individually fed animals we observe individual animal variation that may be masked on not evident from a pen of animals. Stock et al. (1995) studied the effect of monensin and tylosin on feed intake of feedlot steers and found that the magnitude of intake variance was 5 to 10 times greater with individually fed steers than with commercial feedlot pens. When looking at DMI of individually fed cattle with treatments of 27 mg/kg of monensin vs a control of 0 mg/kg of monensin, the authors observed greater variation in DMI of the control cattle compared to the cattle being fed monensin ($P < 0.10$). In fact, when the individually fed steers were statistically treated as a pen, they observed no differences between treatments. From this example, individually fed animals give a better understanding of individual animal performance where it would be lost in pen settings.

Metabolizable Energy

Metabolizable energy (ME) is the gross energy consumed by an animal minus the energy in the feces, urine, and gas emissions (primarily methane). When ME concentration of a diet is increased, the amount of feed required to maintain equilibrium is reduced (Lofgreen and Garrett, 1968). There are several ways to increase ME of finishing beef cattle diets; adding a higher proportion of grain to roughage, degree of processing of feed ingredients, fat supplementation, and addition of byproducts are some common ways to do so. Typical finishing diets for beef cattle range from 2.70 to 3.45 Mcal/kg of ME/kg of DM (Krehbiel et al., 2006). Effects of ME concentration on performance of feedlot animals has not been well studied. Effects such as roughage source and level in finishing diets (Gaylean and Dufoor, 2003), grain source and processing (Owen et al., 1997), byproduct inclusion in beef finishing diets (Stock et al., 1999; Klopfenstein et al., 2008), and fat supplementation (Hess et al, 2008) are all well documented. The concentration of ME has also been used along with BW to predict DMI (Plegge et al., 1984).

More recently the effect of ME concentration on carcass characteristics and some metabolic factors has been studied. Krehbiel et al. (2006) looked at ME concentrations of 69 different trials with 243 treatment observations and compared the ME concentrations to different performance parameters. Concentration of ME was calculated from NRC (1996) equations and also from literature (Zinn, 1989; Zinn, 1994; Owen et al., 1997). The range of ME concentration for the NRC (1996) values were from 2.66 to 3.29 Mcal/kg of DM. For the NRC (1996) values for ME concentration the authors observed a linear decrease in DMI, as a percent of BW as concentration of ME increased. Intake of

ME did not differ across different ME concentrations, resulting in constant energy intake. As ME concentrations increased, ADG and G:F increased at decreasing rates. The greatest ADG was at 3.16 Mcal/kg of DM and the greatest G:F was at 3.46 Mcal/kg of DM. However, the authors cautioned that the maximum G:F was an extrapolation above the upper range of data and would likely be untenable.

Residual Feed Intake

Residual feed intake (RFI) is defined as the difference in actual DMI and predicted DMI. Koch et al. (1963) first observed RFI (described as gain adjusted for feed consumption and body weight) and noted it was the most accurate mathematical description of the cause and effect relationships of body weight gain and feed consumed. They also noted RFI was more heritable than feed consumption adjusted for differences in weight gain or G:F adjusted for body weight. Residual feed intake has been reported to be correlated with several traits relating to performance and carcass characteristics. Feed conversion ratio (F:G; kg of feed/kg of gain) has typically been used by producers to determine efficiency of cattle. Some researchers have warned that selection for F:G might have unfavorable effects on overall production system efficiency (Archer et al., 1999; Nkrumah et al., 2004). Also, F:G is greatly influenced by rate of growth and composition of gain (Nkrumah et al., 2004). Residual feed intake has been shown to be a better index of energetic efficiency for beef cattle (Herd and Bishop, 2000; Arthur et al., 2001; Nkrumah et al., 2004).

Nkrumah et al. (2006) fed 3 groups of cattle based on RFI. The three groups were labeled high, medium, and low RFI. Three hundred and six animals were fed using the GrowSafe automated feeding system. Animals were placed in respective RFI groups

based on SD from the mean RFI. Of the 306 animals they selected 8 animals with low RFI (RFI < 0.5 SD below the mean), 8 animals with medium RFI (RFI ± 0.5 SD above and below the mean), and 11 animals with high RFI (RFI > 0.5 SD above the mean). The high RFI cattle consumed more feed than predicted based on their contemporaries while the low RFI cattle consumed less feed than predicted. Animals were fed a common diet. The authors fed animals in metabolic crates once they were on full feed (2.5 × NRC (2006) maintenance requirement). Animals in the low RFI group had the lowest F:G (6.53), and the lowest DMI (9.62 kg/d) while the high RFI group had the greatest F:G (7.98) and the greatest DMI (11.62 kg/d). The ADG for all three groups was not different. Methane production of the low RFI group was the least (1.28 L/kg of $BW^{0.75}$ or 3.19% of GE) and the high RFI group was the greatest (1.71 L/kg of $BW^{0.75}$ or 4.28% of GE). High RFI animals produced the most heat (164 kcal/kg of $BW^{0.75}$) and the low RFI animals produced the least amount of heat (129 kcal/kg of $BW^{0.75}$). Digestibility of DM, CP, NDF, and ADF was not different between the groups. Hegarty et al. (2007) also observed a reduction in methane production for low RFI cattle (142 g/d) compared to high RFI cattle (190 g/d). The ADG was not different between the low and high RFI groups so methane production/unit of gain tended to be lower for low RFI cattle ($P = 0.09$).

Nkrumah et al. (2007) selected animals the same way as Nkrumah et al. (2006) with the same RFI groups of high (n = 139), medium (n = 183), and low (n = 142). The authors of this study were interested in feeding behavior of the different groups of RFI cattle. Phenotypic RFI was positively correlated with daily feed duration (r = 0.49), head down time (r = 0.50), and feeding frequency (r = 0.18), but no differences were observed with flight speed of the animals. Low RFI cattle had 24 and 14% lesser feeding duration,

29 and 18% lesser head down time, and 14 and 10% lesser feeding frequency compared to high and medium RFI cattle, respectively.

Robinson et al. (2004) compared cattle that were feedlot finished for three different markets (domestic (Australian), Korean, and Japanese). Cattle weight averaged 300 kg for domestic (n = 75), 400 kg for Korean (n= 401), and 400 kg for Japanese (n = 309) markets when cattle were transferred to the feedlot. The cattle finished at an average of 400 kg, 520 kg, and 600 kg for domestic, Korean, and Japanese markets, respectively. The authors wanted to study RFI across greater range of cattle BW compared to previous research. Genetic correlation of RFI (r) with rump fat, rib fat, and intramuscular fat adjusted for age were 0.72, 0.48, and 0.22, respectively. The authors want to make sure that the relationships were unrelated to weight so a second analysis was carried out with carcass weight as a covariate. In this analysis, genetic correlation of RFI (r) to rump, rib, and intramuscular fat was 0.79, 0.58, and 0.25, respectively. These results indicate that selection for cattle with lower RFI will result in reduced subcutaneous fat but will not have a great effect on intramuscular fat. In fact, the authors concluded that selection for reduced rump fat thickness would result in a greater reduction in RFI (0.25 kg/d) than direct selection of reduced RFI (0.20 kg/d).The authors attributed the reduced efficiency of high RFI cattle to an increase in fat deposition. Nkrumah et al. (2004) also observed a lower back fat thickness for low RFI cattle (8.83 mm) compared to medium (10.55 mm) and high RFI cattle (11.56 mm). Nkrumah et al (2004) also noted differences in lean meat yield. The high, medium, and low RFI cattle had 57.04, 58.48, and 59.26% lean meat yield, respectively. Robinson et al. (2004) noted that depositing 1 kg of fat requires more energy than 1 kg of lean tissue (SCA, 1990).

Cruz et al. (2010) observed a similar phenotypic correlation between RFI and G:F. However, their analysis showed that G:F explained much more of the variation in cost of gain (98.5%) compared to RFI alone (18%). The authors also noted that RFI is a more desirable selection criteria (Arthur et al., 2001a) and adopting a multivariate approach for analyzing RFI would perhaps be a better approach. Another issue for using RFI is that individual feed intake data are not available for animals fed in a pen setting and models used to predict RFI are not adequate (Cruz et al., 2011).

Ramos and Kerley (2013) found in four separate experiments comparing low and high RFI cattle, DMI was greater for high RFI cattle compared to low RFI cattle ($P < 0.05$) and ADG was not different ($P > 0.16$). However, instead of looking at G:F of cattle, they were interested in mitochondrial function and more specifically mitochondrial complex 1 protein, which is responsible for electron transport and the generation of a proton gradient across the mitochondrial inner membrane to drive ATP production. In three of the four experiments they found that low RFI cattle had significantly ($P < 0.02$) more mitochondrial complex I protein compared to high RFI cattle. In the fourth experiment they observed a trend ($P = 0.07$) for greater concentration of Band I (protein S1) which belongs to mitochondrial complex I protein. The authors concluded that mitochondrial function was at least in part responsible for differences among animals in metabolic efficiency.

Effect of Performance on Carcass Characteristics.

Cattle feedlot producers ideally would like to have cattle that perform well in the feedlot (high G:F) with high quality beef at the conclusion of the feeding period. For this reason, it is desirable to know if increased performance leads to better carcass

characteristics. Models to predict feedlot performance have been effective when using initial BW and sex (Galyean et al., 2010). However, attempts to predict carcass characteristics have not been as successful. Reinhardt et al. (2009) found a poor correlation between marbling score and ADG (r = 0.077) in 15,631 steer and 5,897 heifers fed at 18 different feedlots in southwest Iowa from 2002 to 2006. The author noted that calculated yield grade (r = 0.324), percent Angus genetics (r = 0.315), frame score upon arrival (r = 0.145), and initial BW upon arrival (r = -0.094) had greater correlation than ADG with marbling score. Since the cattle were fed in feedlot pens individual DMI and G:F were not available. Perhaps one of the most influential determinants of carcass characteristics is genetics of the animal. Reinhardt et al. (2012) observed similar ADG of cattle (n = 17,919) that graded Prime, Choice, or Select and suggested that performance and quality grade are not genetically linked.

Most models predict average performance over the entire feeding period. However, changes in growth rate happen across the feeding period, and the number of days cattle are fed will impact these estimates. Wilken et al. (2015) describe performance of finishing cattle across the finishing period two separate ways: live BW basis and HCW basis. The DMI of cattle increased quadratically at an increasing rate, with the greatest intake at the end of the feeding period. When they evaluated performance on a live BW basis, cattle BW increased quadratically at a decreasing rate as days on feed increased with the greatest BW at the end of the feeding period. The ADG and G:F on a live BW basis decreased linearly with increasing days on feed. When the authors evaluated performance on a HCW basis, HCW increased quadratically at an increasing rate as days on feed increased with the greatest HCW the end of the feeding period. The ADG on a

HCW basis was a quadratic response that increased at a decreasing rate, peaking at 62.5% of days on feed at which point it started to decrease. The G:F on a HCW basis was a quadratic response that peaked at approximately 41% of days on feed, at which point it started to decrease. As cattle on feed increase BW, NE_m increases which explains the increase in DMI. However, the authors noted that previous research observed an initial increase in DMI followed by a plateau and an eventual decrease (Hicks et al., 1990a, b). The authors contribute the increase in intake at the end of the feeding period to cooler fall temperatures. Transfer of live BW to carcass weight increased linearly as days on feed increased from approximately 61 to 90%, demonstrating that late in the feeding period nearly all of the BW gain is also carcass weight gain. The authors contribute this increase to type of gain (protein and bone vs fat) and a lower visceral organ weight-to-BW ratio of cattle fed high-energy diets (Johnson et al., 2003; Hersom et al., 2004).

Marbling and Fat Deposition

Marbling of meat is known as the amount of visible intramuscular fat and is important in determining the quality grades of beef cattle (Cianzio et al., 1985). Increased amounts of marbling increase the sensory quality traits of meat such as taste and flavor (Hocquette et al., 2010). Marbling has also been shown to explain 10 to 15% of the variation in palatability of beef (Dikeman, 1987) and 38.4% of variation in juiciness (Jeramiah et al., 2003). Fat cell numbers/g of tissue and average fat cell diameter are equally important in determining marbling score (Moody and Cassens, 1968; Hood and Allen, 1973; Cianzio et al., 1985). It has been shown that intramuscular fat is not late maturing relative to other fat depositions such as subcutaneous fat (Johnson et al., 1972; Trenkle et al., 1978; Cianzio et al., 1985). This has been shown by describing each fat

depot (i.e. subcutaneous, intramuscular, and KPH) as a percent of total fat. When described this way, the percent of fat in each portion remains constant over different amounts of total fat of cattle. However, the amount of intramuscular fat content expressed as a percent of fat has been shown to increase linearly from carcass weights of 200-400 kg at a rate of 0.47% increase in intramuscular fat/10 kg of HCW gain (Duckett et al., 1993; Pugh et al., 2002). Aoki et al. (2001) showed that this increase does not continue once carcasses reach approximately 420 kg. Marbling score has also been shown to increase linearly as days on feed increase (Camfield et al., 1997) as well as exponentially (Brethour et al., 2000). Pethick et al. (2004) suggest that the final marbling score of cattle is determined by their amount of intramuscular fat at the beginning of the feeding period. The linear increase of intramuscular fat relative to HCW is explained by the decreased rate of muscle deposition and the increased rate of fat deposition as time on feed increases (Owens et al., 1995). This also would explain in part the decrease in G:F on a HCW basis observed by Wilken et al. (2015). Cianzio et al. (1982) observed that deposition of intramuscular fat is not late maturing but the expression of marbling is. This was also in agreement with Pethick et al. (2004).

Marbling is difficult to predict based on feedlot performance as shown by Reinhardt et al. (2009) and Brethour (2000). Brethour (2000) attempted to predict marbling scores and back fat of animals using ultrasound and prediction equations. Two groups of cattle were used for the experiment. Each time ultrasounding was done, a prediction for marbling and back fat thickness at harvest was made. Plots of actual relative to predicted marbling and fat thickness were created. Ultrasounding of fat thickness and marbling for the first group was done 43 days before harvest and the

second group was 58 days before harvest. For fat thickness, the prediction for the first and second group accounted for 70 and 68% of the variation, respectively. Marbling score predictions account for the first and second group accounted for 51 and 34% of the variation respectively. However, the accuracy at which they predicted choice vs select carcasses was 75 and 81% for the first and second group, respectively. This shows that even with ultrasound imaging of animals marbling score is much more difficult to predict than back fat thickness, but it would be possible to distinguish between choice and select quality grade.

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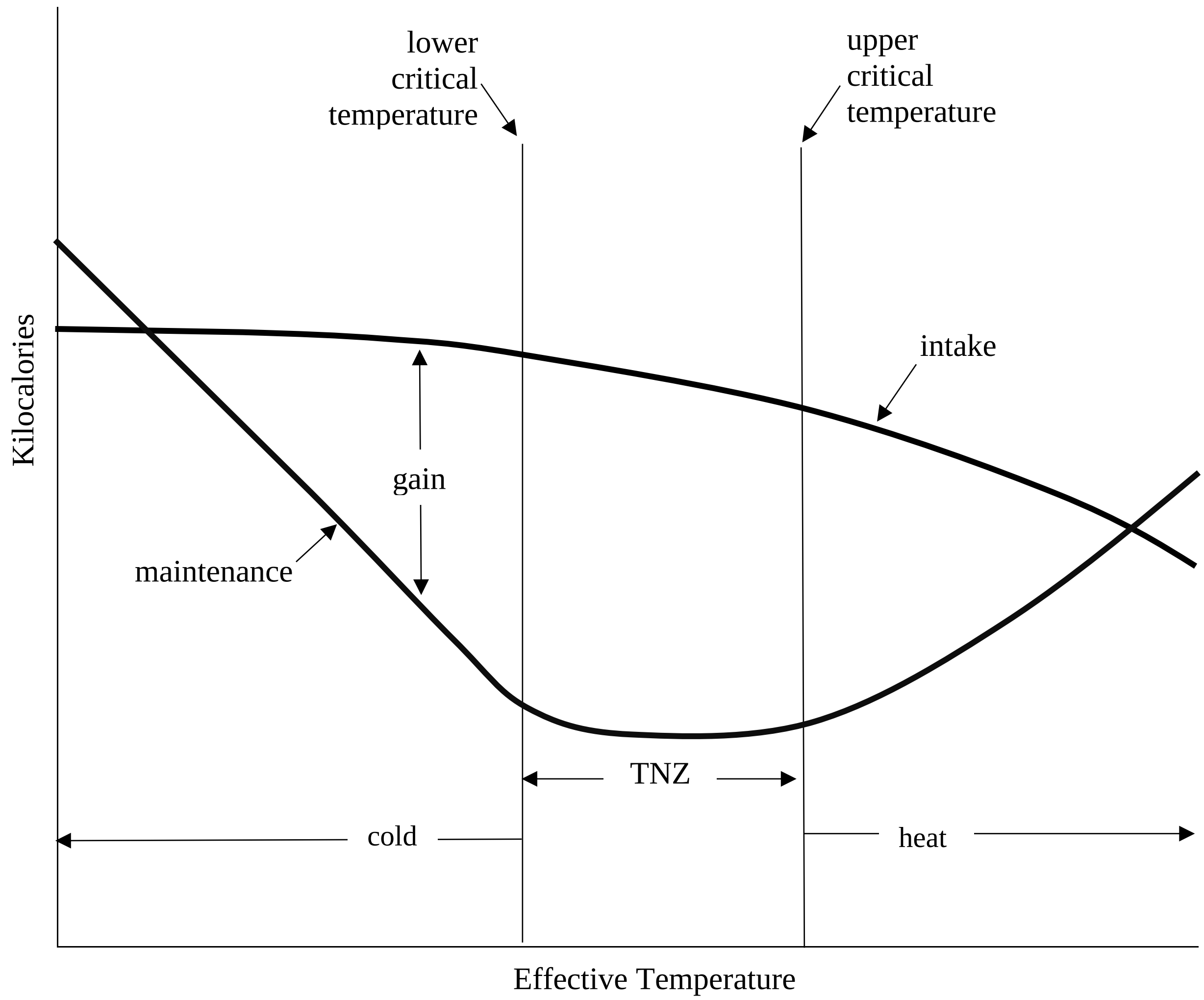

Figure 1.1. General structure of the efficiency of feedlot animals relative to temperature (adapted from Ames, 1980**)**

CHAPTER II. IMPACT OF SHADE ON PERFORMANCE, BODY TEMPERATURE, AND HEAT STRESS OF FINISHING CATTLE IN EASTERN NEBRASKA

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Abstract

A study using crossbred steers (n= 1677; initial BW = 372 kg, SD = 47) was conducted at a commercial feedyard in Eastern NE to determine the effects of shade on cattle performance, body temperature, and cattle activity. Two treatments were evaluated using a randomized complete block design (n = 5 blocks based on arrival). Treatments were assigned randomly to pen and consisted of 5 pens without shade (OPEN) and 5 pens with shade (SHADE). Steers were allowed 38 m^2/steer of pen space and shaded area was 2.8 to 4.2 m^2/steer. Cattle were assigned to pen based on processing order, switching the sort gate after every third steer. Body temperatures were collected throughout the trial using the Quantified Ag biometric sensing ear tags on a subset of cattle (20 to 30 steers per pen based on pen size). Panting scores were collected on those same subsets of steers a minimum of twice weekly from June 8 until August 21. No significant differences were observed for ADG ($P = 0.29$), DMI ($P = 0.31$), G:F ($P = 0.85$), or carcass characteristics ($P \geq 0.24$). Two heat events and one cool event were defined for the feeding period based on adjusted temperature-humidity index (THI), with Event 1 from July 3 to July 7, Event 2 from July 18 to July 22, and the cool event from August 3 to August 7. In addition, overall trial data (April 28 to September 8) were compared for temperature and activity when all cattle were in pens simultaneously. During Event 1, SHADE cattle had lower panting scores ($P < 0.01$), but DMI was not different between treatments ($P = 0.32$). During Event 2, SHADE cattle had greater DMI ($P < 0.01$) and lower panting scores ($P < 0.01$). The cool event resulted in greater DMI ($P < 0.01$) for SHADE cattle, but no difference in panting scores ($P = 0.99$). Ear temperature was not different due to treatment for heat Event 1 ($P = 0.24$) and the cool event ($P = 0.11$), but was greater for

OPEN cattle compared to SHADE cattle for Event 2 ($P < 0.01$). This suggests that cattle in shaded pens were cooler during Event 2. Movement of cattle had an interaction between hour and treatment for Event 1 ($P < 0.01$) and Event 2 ($P < 0.01$), but there was no effect of treatment on movement for the cool event ($P = 0.76$). During the entire feeding period, OPEN cattle ear temperature was greater than SHADE cattle ($P < 0.01$) while movement was not different between the two treatments ($P = 0.38$).

Key Words: Biometric sensing, Heat stress, Shade, Feedyard, Beef cattle

Introduction

Heat stress in beef feedyards has been shown to reduce feed intake, growth, efficiency, and in extreme cases can cause death (Fuquay, 1981; Busby and Loy, 1996; Hubbard et al., 1999; St-Pierre et al., 2003; Mader, 2006). Heat stress occurs when heat produced by the animal exceeds the ability of the animal to dissipate heat. The four main factors to consider when determining heat stress are: ambient temperature, relative humidity, wind speed, and solar radiation. Producers must find a way to alleviate the negative effects of heat stress for cattle on feed.

One of the most commonly used practices for abating heat stress is the use of shades. Providing shade for cattle will decrease the solar radiation experienced by the cattle (Mader et al., 1999a; Brosh et al., 1998; Mitlöhner, et al., 2001), significantly reduce the ground temperature (Mitlöhner et al., 2002), and increase ground moisture (Mitlöhner et al., 2002), but will have little or no effect on the ambient temperature (Morrison, 1983). Using shades in feed lot pens can increase feed intake (Ittner et al., 1954; Boren et al., 1961; Mitlöhner et al., 2002), increase ADG (Ittner et al., 1954; Boren

et al., 1961; Mitlöhner et al., 2002; Sullivan et al., 2011), improve carcass traits (Mitlöhner et al., 2002), and reduce the risk of death (Busby and Loy, 1996). There are conflicting reports of the benefits of shade on cattle performance during an entire feeding period. Some studies have reported greater feed efficiency of cattle with shade compared to cattle without shade (Sullivan et al., 2011). Other studies have observed greater DMI, ADG and final BW (Ittner et al., 1954; Mitlöhner et al., 2001; Mitlöhner et al., 2002). Other studies have reported no benefits at all (Boren et al., 1961; McCormick et al., 1963; Mader et al., 1999a).

The objective of this study was to determine the effects of shade on performance, body temperature, and activity of cattle in southeast Nebraska using a high density polyethylene monofilament (NetPro; Stanthorpe, Qld, Australia) that excluded 70% of sunlight. These shade structures are different than much of the previous research that used sloped steel structures. The monofilament is higher off the ground and will potentially allow more air flow through the pens. Sensing Tags (Quantified Ag; Lincoln, NE) were used to measure ear temperature as well as quantify movement of the animals. Movement of the animals was quantified with accelerometers in the sense tags. Panting scores were visually measured as heat stress behavior.

Materials and Methods

Cattle

A study with crossbred steers (n=1677; initial BW = 372 kg, SD = 47) was conducted at a commercial feedyard in Eastern NE to determine the effects of shade on cattle performance, panting, body temperature, and activity. All research activities followed the guidelines stated in the Guide for the Care and Use of Agricultural Animals

in Agricultural Research and Teaching (FASS, 2010) and procedures were approved by University of Nebraska-Lincoln IACUC.

Cattle were received from March 17 to April 21. Upon arrival at the feedyard cattle were weighed, vaccinated for Infectious Bovine Rhinotracheitis (IBR), Bovine Virus Diarrhea (Types 1 and 2), Bovine Parainfluenza3 (PI3), and Bovine Respiratory Syncytial Virus (BRSV) (Titanium 5; Elanco Animal Health; Greenfield, IN), injected with 1% ivermectin and 10% clorsulon solution for gastrointestinal roundworms, lungworms, adult flukes, cattle grubs, suckling lice, and sarcoptic mange mites (Ivermax Plus; Aspen Veterinary Resources; Greeley, CO), poured with 5mg/mL ivermectin solution for gastrointestinal roundworms, lungworms, cattle grubs, horn flies, suckling and biting lice, and sarcoptic mange mites (Ivermmax Pour On; Aspen Veterinary Resources), and implanted with 100 mg trenbolone acetate and 14 mg estradiol benzoate (Synovex Choice; Zoetis; Parsippany, New Jersey). Cattle were assigned to treatment as they exited the chute by switching a sort gate after every third animal. Cattle were fed a common diet during the trial (Table 2.1) with twice per day feeding. All cattle were stepped up to the finishing ration in three steps over a twenty-one day period. Bunk space was provided at 0.31 to 0.34 linear m/animal. When the corn silage supply was gone, cattle were switched to the second diet on July 3. Cattle were re-implanted with 200 mg trenbolone acetate, 20 mg estradiol, and 29 mg tylosin (Component TE-200; Elanco Animal Health) from June 7 to June 27 depending on start date and body weight. The color distribution of all cattle was 70% black, 26% red, and 4% white.

During the study, if the feedlot owner deemed it necessary to sprinkle cattle with water to reduce the risk of death due to severe heat stress, all cattle were sprinkled evenly across treatments.

The first block of cattle was shipped on September 8 and the final block was shipped on September 20. Pen live weights were collected by using a truck scale. Trucks were weighed prior to loading the cattle and once again after loading and live weight was assumed to be the difference which was then shrunk 4%. Cattle were harvested at Cargill Meat Solutions (Schuyler, NE). Hot carcass weight was collected at time of harvest. Longissimus muscle area, 12th rib fat thickness, and marbling score were collected following a 32 to 34-hour chill. All carcass data were collected and provided by the packing plant by pens marketed as separate lots.

Experimental Design

The experimental design was a randomized complete block with two treatments. Arrival date was used as the blocking effect. On each date that cattle were received they were equally divided into 2 pens within 1 block until pens were full, then the next block would be filled. Ten pens were assigned randomly to a treatment as either having shade (SHADE) or no shade (OPEN) with five pens per treatment. The color distribution of the SHADE cattle was 71% black, 25% red, and 4% white. The color distribution of the OPEN cattle was 69% black, 27% red, and 4% white. Six of the pens were 61 by 122 m and four of the pens were 41 by 122 m. Each pen had approximately 39 m^2/animal. The shades in all the shaded pens were the same size. Shade material was composed of high density polyethylene monofilament (NetPro; Stanthorpe, Qld, Australia) that excluded approximately 70% of sunlight and was approximately 5.5 m off the ground. Shades were

held up by cables that ran the entire length and width of the pens. The cables were attached to poles that were cemented in the ground on the outside of the pens. The larger pens supplied 2.8 m^2 of shade for each animal and the smaller pens supplied 4.2 m^2/animal.

A subset of 20 (small pens) or 30 steers (large pens) were selected randomly using Excel random number generator which was applied to each animal based on the order they went through the chute. Selected cattle were given a biometric sensing tag (Quantified Ag). The color distribution of the subset of selected cattle within the SHADE treatment was 73% black, 24% red, and 3% white. The color distribution of the OPEN subset was 66% black, 32% red, and 2% white. Coat color of cattle is important when studying heat stress. The Quantified Ag sense tag recorded movement every hour and ear temperature 5 times every hour. Movement of animals was quantified using accelerometers within the sense tags. The accelerometers measured total movement as well as velocity of the movement in a 3-demensional space. There are no units associated with this measurement of movement. Temperature of the animal was obtained from an infrared reader aimed down the inner ear canal of the animal. The data were sent to an antenna located at the feed mill. The antenna was connected to the internet and to Quantified Ag's cloud database.

Panting scores were assigned as: 0 = No panting; 1 = Slight panting, mouth closed, no drool, and slight chest movements; 2 = Fast panting, drool present, and no open mouth; 3 = open mouth and excessive drooling, neck extended, and head held up; 4 = open mouth with tongue fully extended for prolonged periods with excessive drooling, neck extended with and head up; 4.5 = same as 4, but head held down, cattle breath from

the flank, and drooling may cease. Half scores were used if the panting scores of the animals appeared between 2 whole number scores. Panting scores were recorded on the same subset of animals that had the biometric sensing ear tag at least twice every week from June 8 to August 21 between 1300 and 1700 hours. All panting scores were collected by one trained individual.

Environmental Temperature Recordings

After the trial, two heat events were defined according to adjusted temperature-humidity index (adjusted THI). The values used for adjusted THI were from the weather station located one mile south of the location of the study. The weather station recorded weather data every 30 minutes. The recordings of maximum and minimum temperature, humidity, wind speed, and adjusted THI as well as daily average adjusted THI for each day of the trial are in Table A2.1. The weather station did not record solar radiation, so a constant (250 W/m^2) was used for the adjusted THI equation. Figure 2.1 shows the Maximum, minimum, and daily average adjusted THI. The Livestock Weather Safety Index uses an adjusted THI of 74 as the threshold for heat stress in cattle. The first heat event (Event 1) was the first 5 days of the trial that had a daily average adjusted THI of greater than 75 for each day. Event 1 was July 3 to June 7. The second heat event (Event 2) was the 5 consecutive days with the greatest average daily THI. Event 2 was from July 18 to July 22. A cool event was also defined as the first 5 days following Event 2 that had a daily average adjusted THI below 70 for each day. The cool event was from August 3 to August 7. The cool event was used as a comparison to the heat events.

Six temperature and humidity recording devices (Kestrel DROP; KestrelMeter.com; Minneapolis, MN) were placed in two blocks of pens on July 7th until

the end of the trial. One device was placed in the open pens. Two devices were placed in the shaded pens; one under the shade and one in the open. The devices were hung from a wire and attached to the cable that held the shades up. Devices were approximately 3 meters off the ground to prevent cattle from coming in contact with them. The meters recorded temperature and humidity every 10 minutes. Data were then uploaded to a mobile phone via Bluetooth.

Ground temperatures were recorded with an infrared gun (Extech; Nashua, NH) in each pen on 5 separate days between 1300 and 1600 hours. Temperatures were recorded in 10 separate locations each time. In the shaded pens, 5 of the recordings were recorded under the shade and 5 were in the open.

Statistical Analysis

Carcass characteristics (HCW, LM area, 12th rib fat, marbling score, and calculated yield grade) and carcass adjusted performance (ADG, DMI, G:F, initial BW, and final BW) were analyzed using the MIXED procedure of SAS (SAS Institute Inc. Cary, NC) with pen as the experimental unit. Block was included in the model as a fixed effect. Calculated yield grade was calculated as 2.50 + (6.35* 12th rib fat, cm) - (2.06*LM area, cm2) + (0.2*2.5 KPH) + (0.0017*HCW, kg). Panting scores, biometric ear tag data, and rumen bolus data were analyzed using the GLIMMIX procedure of SAS with pen as the experimental unit and block as a fixed effect. Biometric sensing ear tag data were analyzed with a treatment by hour interaction sliced by hour (each hour of the day were analyzed together). For example, any recording from 0000 to 0100 hours would be analyzed together and be known as hour 0. This was to determine if there were any

differences during specific hours of the day. Differences were considered significant at $P \leq 0.05$ and trends are discussed with $P \leq 0.10$.

Results

There were no differences in SHADE cattle compared to OPEN cattle for DMI, ADG, and G:F ($P \geq 0.29$; Table 2.2). Carcass characteristics (HCW, 12th rib fat thickness, marbling, LM area, and calculated yield grade) were not different due to treatment ($P \geq 0.24$). Figure 2.2 shows the ear temperature of the cattle (n = 131 SHADE; n = 130 OPEN) measured with the biometric sensing ear tag across all days of the trial (April 28 to September 8). A treatment by hour interaction ($P < 0.01$) was observed for ear temperature, with OPEN cattle being significantly hotter than the SHADE cattle from 1300 to 1800 hours ($P \leq 0.05$), but not different during the other hours of the day. Movement was not significantly different between the OPEN and SHADE cattle ($P = 0.38$) across all days (Table 2.3) but did differ by time of day ($P < 0.01$). The difference in movement of cattle by time of day was due to the behavior of the cattle at different times of the day. This difference in behavior was also observed in finishing heifers in northwest Texas by Mitlöhner et al. (2002).

During heat event 1, there were no differences due to treatment for DMI ($P = 0.32$). During this heat event, panting scores were lower for SHADE cattle compared to OPEN cattle ($P < 0.01$; Table 2.4). Ear temperature of cattle was not different ($P = 0.24$). A treatment by hour interaction for movement occurred during Event 1 ($P < 0.01$). During hour 11 and hour 20 through 23 SHADE cattle had more movement compared to OPEN cattle ($P \leq 0.05$; Figure 2.3).

During heat event 2, SHADE cattle had greater DMI compared to the OPEN cattle ($P < 0.01$). Panting scores for SHADE cattle were lower than OPEN cattle ($P < 0.01$). There was a treatment by hour interaction for movement during Event 2 ($P < 0.01$; Figure 2.4). From 1300 to 1400 hours OPEN cattle had greater movement than SHADE cattle ($P \leq 0.05$). During 1900, 2000, 2200, and 2300 hours SHADE cattle had greater movement than OPEN cattle ($P \leq 0.05$). The behavior during the middle of the day may be explained by the SHADE cattle laying down in the shade. Also during Event 2, ear temperature was greater for the OPEN cattle compare to the SHADE cattle ($P <0.01$).

During the cool event SHADE cattle had greater DMI compared to OPEN ($P < 0.01$). Panting scores of cattle were not different during the cool event (P = 0.99). There were no differences due to treatment (OPEN vs. SHADE) for ear temperature ($P = 0.34$) or movement ($P = 0.93$) during the cool event (Table 2.4). Both movement and ear temperature did vary across hours of the day ($P < 0.01$). The cool event demonstrates that under thermoneutral conditions SHADE cattle behave the same and have similar body temperature as OPEN cattle. Despite the fact that Event 2 and the cool event had greater DMI for SHADE compared to OPEN there was no difference ($P = 0.31$) for DMI for the entire feeding period.

The temperature and humidity recording devices did not differ by day for maximum, minimum, or average temperature or THI due to treatment ($P > 0.46$). Infrared ground temperatures across the five days of recordings were least underneath the shade ($P < 0.05$) and not different for the open pens or the open portion of the shaded pens. Although solar radiation data was not collected in the pens, it is assumed to be blocked

by the shades. It is evident that the reduced ear temperature is due to the shade treatment and not due to other environmental differences between the pens.

Seventeen steers (n = 8 SHADE, n = 9 OPEN) were removed from the study due to death or health issues. None of the deaths or health issue were believed to be related to heat stress.

Discussion

The effect of shade on the performance of feedlot animals has been inconsistent across experiments. However, there is general agreement that shade reduces heat stress on animals. This reduction in heat stress does not always result in improved performance at the conclusion of the feeding period.

In the current study we observed no performance benefits at the conclusion of the trial with the use of shades. However, decreased panting scores and ear temperature were observed for cattle that were provided shade compared to cattle without shade during heat events. Mader et al. (2006) created 4 models for predicting panting scores. These equations were modeled using primarily black cattle. Mader et al. (2002) observed that dark-colored cattle tended to bunch more ($P = 0.07$), pant more ($P < 0.01$), and had higher tympanic temperatures ($P < 0.05$) than light-colored cattle.

Intakes were greater for cattle that were provided shade compared to cattle without shade during heat events. Reduced daily DMI for OPEN cattle compared to SHADE was 0.6 kg/animal for Heat Event 2. Mitlöhner et al. (2001) fed 77 heifers in New Deal, TX from June 23 to October 13. Half of the animals were provided shade and half were without shade. The heifers without shade ate 0.65 kg/day less than heifers with shade during the entirety of the trial which is comparable to the heat events of the current

study. Mader et al. (1999a) compiled data from three trials of predominantly black cattle fed in Northeast Nebraska. Cattle were fed from late June until mid-September. Over the three trials, no differences in DMI, ADG, and final BW were observed. However, early in the feeding periods (day 0 to 28) cattle that were provided shade had improved efficiency. There were also no differences in carcass characteristics. Boyd et al. (2016) fed steers in Southcentral Nebraska with shaded and unshaded pens. They observed no differences in DMI ($P = 0.55$) and G:F ($P = 0.53$) but did find a tendency for greater final body weight ($P = 0.08$) and ADG ($P = 0.10$) for shaded cattle compared to unshaded cattle. Panting scores were also not different between the two groups ($P = 0.99$).

Body temperature of cattle during summer months exhibits a nychthemeral variation which has a sinusoidal shape that peaks late in the afternoon after day time temperatures begin to fall and bottoms out late in the morning after temperatures begin to rise (Mader, 2003; Beatty et al., 2008). The sinusoidal shape was also observed in this study with the sense tag ear temperature data. The effectiveness of the sense tags to measure body temperature has not been established. However, when the data from the sense tag of this trial are compared to Davis et al. (2003) which used tympanic temperature, we see similar results in diurnal variation. Differences between the mean maximum and mean minimum tympanic membrane temperatures are between 1.4 and 2.1°C depending on severity of the heat stress, color of the cattle, whether cattle are fed in the morning or evening, and whether they are sprinkled with water or not. In the current study we saw differences of mean maximum and mean minimum ear temperature of 1.4 to 2.3°C which is comparable to Davis et al. (2003) and Guirdy and McDowell (1966). The range of temperatures observed were similar, but the temperatures recorded

by the sense tag were approximately 1.5°C lower than that of the tympanic membrane temperatures in the previous studies.

The movement of the cattle only differed by treatments during the two heat events. During Heat Event 1 and Heat Event 2 a treatment by hour interaction occurred. During Heat Event 1 the SHADE cattle moved significantly ($P < 0.05$) more than OPEN cattle during hours 1100 and 2000 to 2300. During Heat Event 2 the OPEN cattle had greater movement than the SHADE cattle during 1300 and 1400 hours, but the SHADE cattle had greater movement than the OPEN cattle during 1900, 2000, 2200, and 2300 hours. The movement of the animals was similar to the behavior that Mitlöhner et al. (2002) observed in finishing heifers on August 21, 2000 in New Deal, TX. The majority (79%) of the cattle in the Mitlöhner et al. (2002) study were black hided animals which is similar to the current study (70%) and the objective was to compare the effects of shade on cattle performance and behavior. In the Mitlöhner et al. (2002) study, human observation was used to categorize cattle behavior over a 24-h period using video recording. This method is very labor intensive and can only be done for short intervals. The current study measured movement using technology in place of human labor in order to have more measurements over time, although the measurement is less descriptive. The authors observed that cattle in shade behave similarly to cattle without shade from 0100 to 0700 hours and from 2200 to 2400 hours. For Heat Event 2 similar movement was observed from 2300 to 1200 and 1500 to 1700. In the current study, cattle movement was least from 2300 to 0600 the following day which is presumably lying behavior (Mitlöhner et al, 2002). The movement steadily increased at feeding time from 0600 until 1100 and dropped steadily afterwards. The difference in SHADE cattle and OPEN cattle

at 1300 to 1400 can be contributed to SHADE cattle lying under the shade structures while OPEN cattle were walking more and also making more trips to the water tank as observed by Mitlöhner et al. (2002). The difference in SHADE cattle and OPEN cattle from 1900 to 2300 can be explained by more agonistic behavior and bulling behavior in the SHADE cattle compared to the OPEN cattle which was also observed by Mitlöhner et al (2002). The behaviors described in the current study are speculation based on movement recorded by the sense tags and comparison of that data to previous research done by Mitlohner et al. (2002). More research is needed to verify these speculations.

Summer average high temperatures for Columbus, NE (nearest town with reported data) by month are 28, 31, and 29°C for June, July, and August, respectively (National Oceanic and Atmospheric Administration). The monthly average high temperatures for the weather station based at the feedlot in 2017 were 30.2, 30.2, and 26.2°C for June, July, and August, respectively.

The use of shades in feedyards can decrease heat stress and minimize performance losses of cattle on feed during extreme heat events. This is evident from our lower DMI, greater panting scores, and greater ear temperatures of OPEN cattle compared to SHADE during Heat Event 1 and Heat Event 2. Using shades for feedyard cattle did not impact performance but did improve some measures of heat stress and decrease body temperature. This would indicate that animals in shade pens were more comfortable and had improved welfare.

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Table 2.1. Ingredient and nutrient composition of finishing diets

	First diet (Fed from Start - July 2)	Second diet (Fed from July 3 – Finish)
Ingredient	Dry Matter Inclusion, % (Unless noted otherwise)	
DRC[1]	35	41
MDGS [2]	37	41
Wet Corn Gluten Feed	10	11
Corn Silage	12	0
Corn Stalks[3]	2	3
Liquid	4	5
Protein/Supplement[4]		
Supplement composition in the diet		
Protein	0.36	0.45
Fat	0.06	0.08
Calcium	0.58	0.73
Phosphorus	0.02	0.03
Vitamin A, IU	1233	1542
Vitamin D, IU	123	154
Vitamin E, IU	5.2	6.6
Salt	0.18	0.23
K	0.08	0.11
Na	0.07	0.09
S	0.03	0.04
monensin[5], mg/kg	32.4	40.5
tylosin[6], mg/kg	8.5	10.7

[1]Dry Rolled Corn
[2]Modified Distillers Grains plus Solubles
[3]Ground through a 5-inch screen
[4]Performance Plus Liquid (Palmer, NE)
[5]Rumensin (Elanco Animal Health; Greenfield, IN)
[6]Tylan (Elanco Animal Health)

Table 2.2. Effect of providing shade on performance of feedlot steers

	Treatment[1]			
Item,	Open	Shade	SEM	*P*-Value
Performance (Carcass Adjusted)[2]				
Initial BW, kg	372	372	1.0	0.75
Adjusted Final BW, kg[2]	668	670	2.3	0.42
Live Final BW, kg	688	690	2.3	0.47
Dressing Percent	61.2	61.2	0.16	0.93
DMI, kg/d	11.1	11.2	0.07	0.31
ADG, kg[2]	1.74	1.76	0.010	0.29
G:F[2]	0.157	0.157	0.0004	0.85
Carcass characteristics				
HCW[3], kg	420	422	1.5	0.46
12th rib fat, cm	1.52	1.55	0.017	0.49
Marbling	478	479	5.1	0.92
LM Area, cm^2	92.3	93.5	0.65	0.24
Calculated YG[4]	3.42	3.43	0.052	0.92

[1]Treatments consisted of 5 open pens and 5 shaded pens, with a total of 1677 cattle
[2]Carcass adjusted data include Adjusted Final BW, ADG, and G:F and were calculated from HCW and a common dressing percent of 63%
[3]HCW = Hot carcass weight
[4]USDA yield grade (YG) calculated as 2.5 + (6.35 × 12th rib fat, cm) + (0.2 × 2.5 KPH) + (0.0017 × HCW, kg) – (2.06 × LM area, cm^2) (formula derived from USDA, 1997).

Table 2.3. Cattle movement and panting scores across all days

	Treatment			*P*-Value		
Item,	Open	Shade	SEM	Trt	Hour	Trt*Hour
Movement[1]	29032	29827	636	0.38	<0.01	0.99
Panting Score[2]	0.74	0.55	0.02	<0.01	-	-

[1]Movement measured using a sense tag (Quantified Ag, Lincoln, NE) that measured total movement as well as velocity of the movement in a 3-dimensional space. Movement was measured continuously and recorded every hour.

[2]Panting Scores are based on a score of 0 to 4.5 in 0.5 increments

Table 2.4. Main effect of treatment on DMI, panting score, movement, and ear temperature during heat events and the cool event

	Treatments			*P*-Value		
Item,	Open	Shade	SEM	Trt	Hour	Trt*Hour
Heat event 1 (July 3 – July 7)						
DMI, kg/d	12.0	12.1	0.2	0.32	-	-
Panting Score[1]	0.88	0.61	0.06	<0.01	-	-
Ear Temperature, °C [3]	38.1	38.0	0.1	0.24	<0.01	0.50
Heat event 2 (July 18 – July 22)						
DMI, kg/d	9.5	10.1	0.2	<0.01	-	-
Panting Score[1]	1.75	1.42	0.03	<0.01	-	-
Ear Temperature, °C[3]	38.2	38.0	0.1	<0.01	<0.01	0.28
Cool Event (August 3 – August 7)						
DMI, kg/d	11.7	12.0	0.1	<0.01	-	-
Panting Score[1]	0.00	0.00	0.00	0.99	-	-
Movement[2]	30248	30593	1595	0.76	<0.01	0.96
Ear Temperature, °C[3]	36.7	36.5	0.1	0.11	<0.01	0.99

[1]Panting Scores are based on a score of 0 to 4.5 in 0.5 increments

[2] Movement measured using sense tag (Quantified Ag, Lincoln, NE) that measured total movement as well as velocity of the movement in a 3-dimensional space (n = 131 SHADE; n = 130 OPEN)

[3]Ear Temperature measured using sense tag (Quantified Ag, Lincoln, NE) (n = 131 SHADE; n = 130 OPEN)

*Movement from Heat Event 1 and Heat Event 2 are not shown in this table due to the treatment by hour interaction. These interactions are shown in Figure 2.3 and Figure 2.4

Figure 2.1. Maximum, minimum, and average adjusted temperature-humidity index (THI) across all days of the trial. The straight solid black line represents the threshold for cattle (THI = 74) set by Livestock Weather Safety Index (LWSI; LCI, 1970)

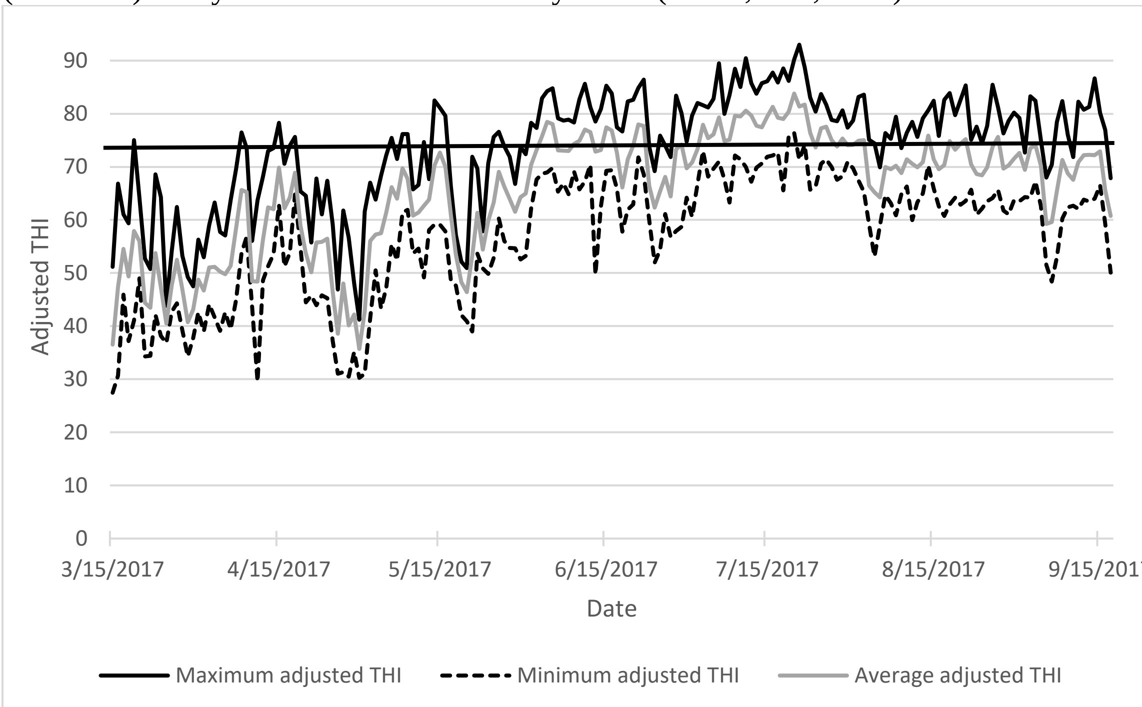


Figure 2.2. Effect of treatment (SHADE or OPEN) on ear temperature of cattle (n = 131 SHADE; n = 130 OPEN) across all days of the trial (April 28 to September 8). Ear temperature was measured 5 times per hour by a sense tag (Quantified Ag, Lincoln, NE). The interaction by treatment and hour was significant ($P < 0.01$). Treatment differences are significant ($P \leq 0.05$) at time points in the figure denoted with a *.

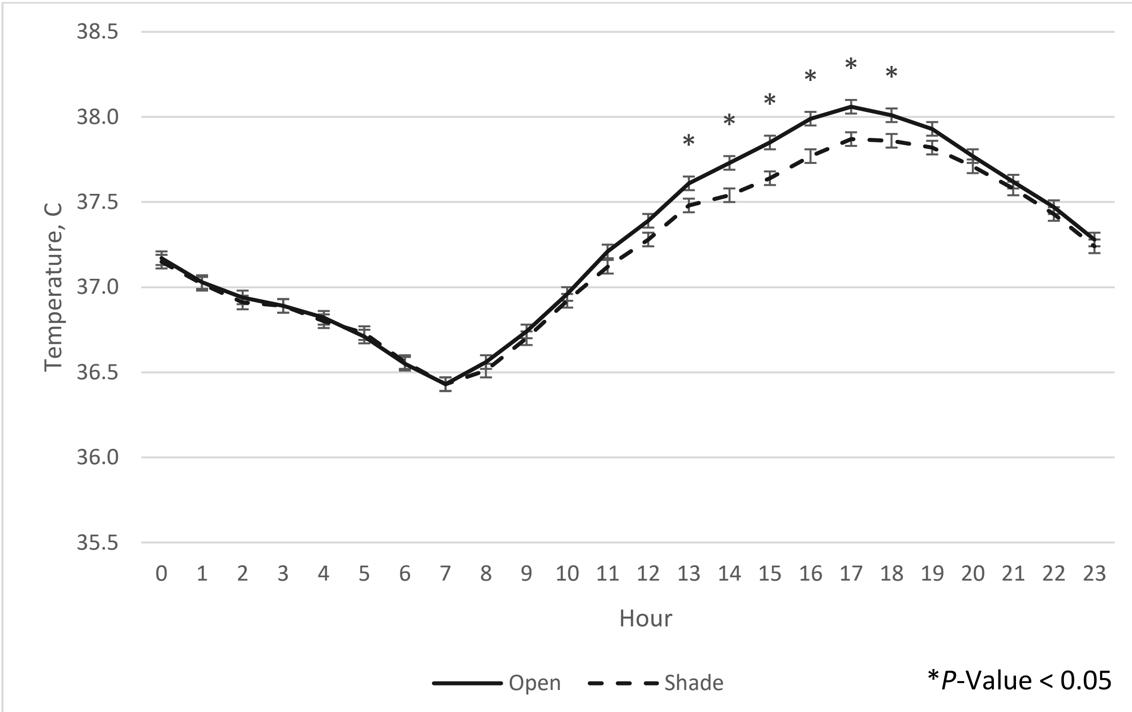


Figure 2.3. Effect of treatment (SHADE or OPEN) on movement of cattle (n = 131 SHADE; 130 OPEN) during Heat Event 1 (July 3 to July 7). Movement measured using sense tag (Quantified Ag, Lincoln, NE) that measured total movement as well as velocity of the movement in a 3-dimensional space. The interaction between treatment and hour was significant ($P < 0.01$). Treatment differences are significant ($P < 0.05$) at time points in the figure denoted with a *.

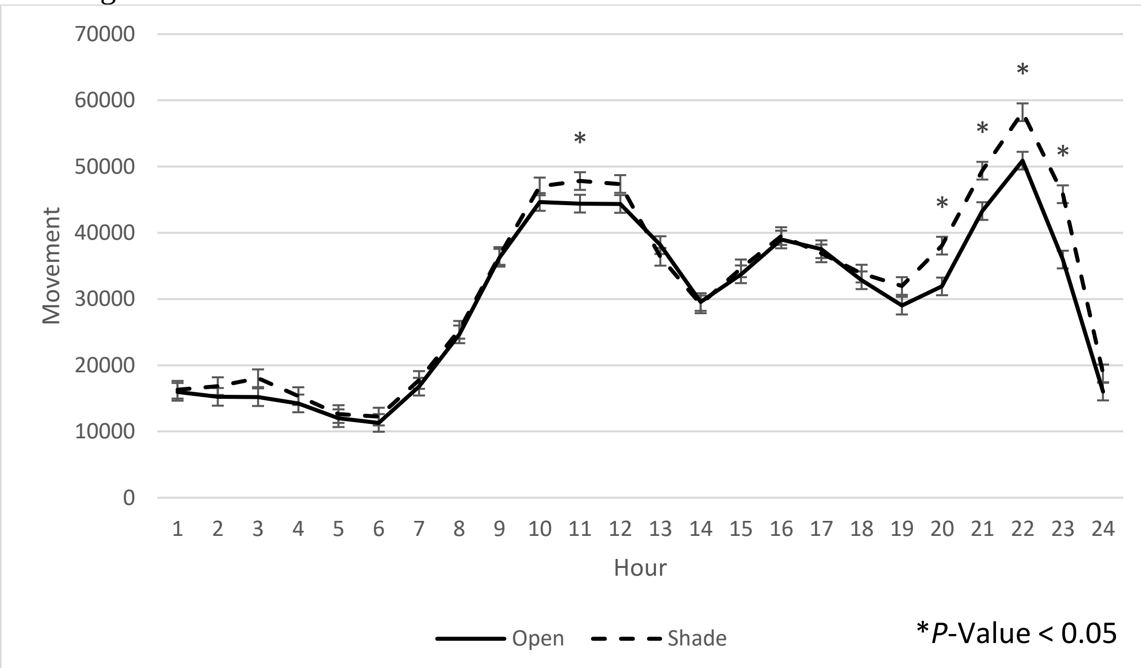
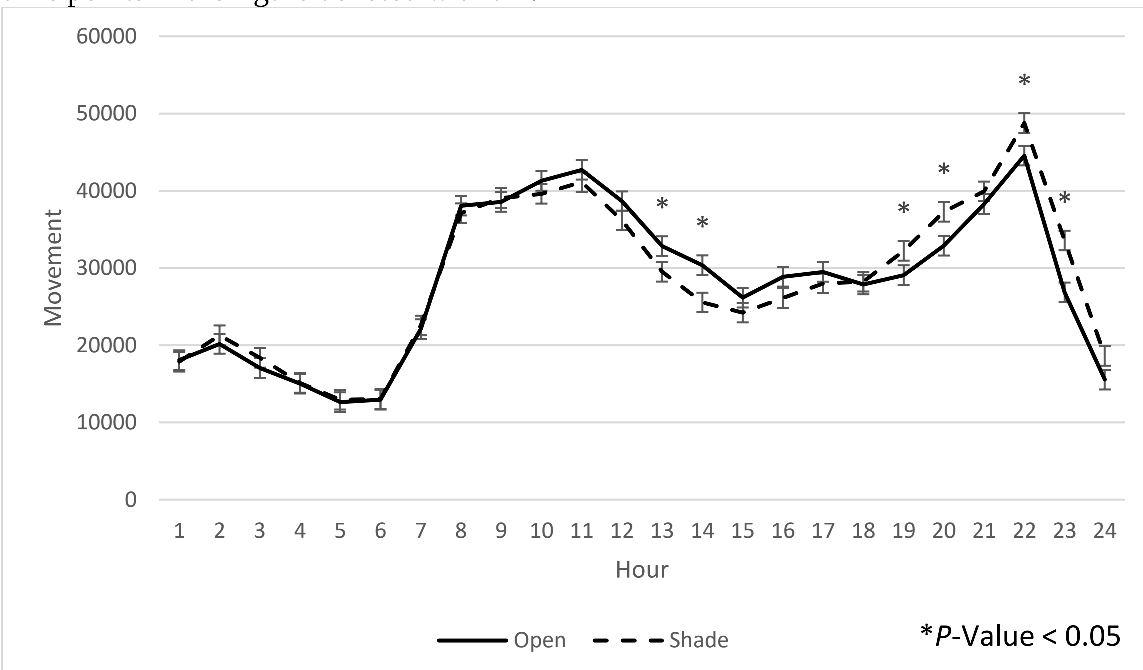


Figure 2.4. Effect of treatment (SHADE or OPEN) on movement of cattle (n = 131 SHADE; 130 OPEN) during Heat Event 2 (July 18 to July 22). Movement measured using sense tag (Quantified Ag, Lincoln, NE) that measured total movement as well as velocity of the movement in a 3-dimensional space. The interaction between treatment and hour was significant ($P < 0.01$). Treatment differences are significant ($P < 0.05$) at time points in the figure denoted with a *.



Appendix

Table A2.1. Maximum and minimum humidity, temperature, wind speed, and adjusted temperature-humidity index (THI) across all days of the trial

	Temperature, °C		Humidity, %		Wind Speed, KPH		Adjusted THI[1]		
Date,	Max	Min	Max	Min	Max	Min	Max	Min	Avg
March									
15	9.5	-4.1	84	48	21	0	51.2	27.5	36.5
16	20.0	-1.6	80	43	24	0	66.9	30.7	47.4
17	18.2	3.6	92	25	24	0	61.0	45.9	54.6
18	15.8	-1.9	85	20	14	0	59.4	37.2	49.4
19	28.3	6.4	76	37	27	0	75.0	41.0	57.9
20	18.1	7.1	84	29	21	0	64.1	49.0	56.0
21	9.0	0.3	86	54	21	0	52.7	34.3	44.4
22	12.2	0.1	80	28	23	8	50.8	34.4	43.5
23	21.6	7.2	82	45	27	5	68.6	42.1	53.8
24	18.6	4.7	96	75	34	2	64.3	38.2	47.3
25	5.1	2.8	96	95	14	3	43.8	36.8	40.5
26	8.8	3.7	97	88	8	0	54.2	42.7	47.8
27	13.6	5.8	96	62	10	0	62.4	44.3	52.5
28	9.7	0.2	97	80	16	0	53.3	39.2	47.0
29	7.3	4.5	96	93	24	5	49.2	34.3	40.7
30	6.4	3.6	96	90	14	3	47.5	37.8	43.1
31	11.2	4.4	95	68	18	0	56.3	42.6	48.8
April									
1	8.1	3.5	96	80	13	0	53.0	39.0	46.7
2	14.4	5.4	96	74	11	0	59.0	44.1	51.1
3	16.1	5.6	98	64	19	0	63.3	41.6	51.2
4	13.8	6.0	91	49	19	0	57.8	39.1	50.3
5	13.7	1.9	93	44	18	0	57.1	42.6	49.8
6	14.0	1.3	94	31	5	0	63.7	39.4	51.3
7	18.9	2.1	76	38	0	0	69.6	45.0	58.4
8	24.2	8.2	89	46	0	0	76.5	53.8	65.6
9	20.7	10.0	97	58	0	0	73.5	56.8	65.3
10	9.6	1.9	94	77	0	0	56.0	43.7	48.5
11	18.4	-4.1	94	33	13	0	63.7	29.5	48.4
12	20.3	9.8	86	59	24	0	68.1	48.6	56.3
13	24.1	7.1	96	55	10	0	73.0	51.3	62.4
14	22.4	14.8	96	79	21	0	73.5	53.6	62.0
15	24.2	13.6	95	63	0	0	78.3	62.8	69.9
16	19.7	7.0	96	36	0	0	70.6	51.3	62.2
17	21.6	8.1	88	52	0	0	74.0	53.8	64.2
18	23.8	14.8	94	41	0	0	75.6	64.8	68.9
19	15.2	9.0	97	70	0	0	65.4	54.9	59.0
20	17.3	8.2	93	52	19	0	64.5	44.5	53.7

	Temperature, °C		Humidity, %		Wind Speed, KPH		Adjusted THI[1]		
Date,	Max	Min	Max	Min	Max	Min	Max	Min	Avg
21	13.3	3.7	96	58	19	0	55.7	45.8	50.1
22	18.3	2.8	96	32	8	0	67.8	43.9	55.8
23	21.7	4.2	73	22	26	0	61.1	45.8	55.8
24	22.9	10.4	71	39	29	2	67.4	45.3	56.5
25	11.7	3.2	91	72	14	0	59.1	37.2	46.4
26	6.8	0.5	90	69	21	0	46.9	31.1	38.5
27	12.8	-3.6	94	49	6	0	61.8	31.3	48.0
28	9.4	2.6	96	71	24	0	56.7	30.5	40.2
29	7.8	4.2	93	66	24	0	48.1	35.1	42.2
30	4.5	1.8	96	90	27	5	41.2	30.3	35.7
May									
1	15.8	1.1	96	41	29	3	61.6	31.1	42.8
2	17.8	4.1	89	43	16	0	67.0	41.5	56.0
3	16.8	7.8	93	62	16	0	63.8	50.5	57.3
4	20.3	3.7	96	34	10	0	68.3	43.3	57.5
5	23.8	5.2	89	31	11	0	72.1	47.1	61.4
6	26.1	9.9	82	32	10	0	75.4	55.4	66.1
7	28.8	12.6	68	34	21	6	71.5	52.4	64.0
8	32.0	17.7	78	32	19	0	76.2	61.4	69.7
9	25.1	14.1	87	45	16	0	76.2	61.9	67.7
10	16.5	11.6	95	63	13	0	65.7	53.7	60.8
11	20.1	8.9	96	37	11	0	66.6	54.6	61.4
12	24.0	5.8	91	32	6	0	74.7	49.2	62.7
13	25.2	12.1	67	31	18	3	67.7	58.1	63.8
14	29.1	16.1	82	44	14	0	82.5	59.1	70.3
15	30.6	15.2	91	39	29	0	81.1	59.1	72.7
16	27.1	16.5	93	62	24	0	79.6	57.8	70.0
17	19.3	13.2	96	77	24	0	66.5	48.8	61.0
18	14.2	11.2	94	82	24	5	57.1	47.6	53.3
19	11.3	7.9	97	87	19	8	52.1	42.1	48.2
20	9.1	6.2	97	86	19	2	50.9	40.9	46.4
21	21.0	4.2	93	37	18	0	71.9	39.0	53.3
22	22.2	10.3	90	45	14	2	69.7	53.7	61.3
23	13.8	8.4	91	65	16	2	57.9	50.9	54.4
24	19.6	7.6	91	47	10	0	70.7	49.8	59.8
25	24.2	10.5	82	50	19	0	75.7	52.9	63.3
26	25.9	15.2	91	35	11	0	76.6	60.3	69.1
27	24.5	12.7	86	43	13	0	73.9	56.0	66.3
28	25.4	10.7	93	29	26	0	71.9	54.7	63.9
29	22.1	10.4	89	31	21	0	66.8	54.7	61.5
30	25.6	8.5	87	27	14	0	73.7	52.6	64.3
31	24.3	8.0	92	32	11	0	72.4	53.2	64.9

Date,	Temperature, °C Max	Temperature, °C Min	Humidity, % Max	Humidity, % Min	Wind Speed, KPH Max	Wind Speed, KPH Min	Adjusted THI[1] Max	Adjusted THI[1] Min	Adjusted THI[1] Avg
June									
1	28.7	13.4	83	48	11	0	78.3	62.1	70.4
2	30.8	18.9	91	37	14	3	77.3	67.6	73.2
3	31.0	18.4	86	38	8	0	82.9	68.7	75.7
4	32.9	17.2	92	34	5	0	84.2	68.9	78.4
5	34.3	17.8	89	23	10	0	84.8	69.8	78.1
6	29.2	19.4	70	39	14	0	79.1	65.3	73.1
7	29.1	17.5	68	34	11	0	78.7	66.9	73.0
8	30.7	17.3	70	27	10	0	78.9	64.8	73.0
9	31.6	19.2	80	42	16	2	78.3	69.1	74.3
10	32.7	21.2	83	55	21	6	82.7	65.8	74.9
11	33.8	22.9	83	48	19	3	85.7	67.3	77.0
12	31.6	22.6	84	56	16	3	81.3	70.4	76.5
13	35.1	18.3	90	41	43	5	78.5	49.7	72.9
14	29.5	17.6	93	36	13	0	80.9	62.6	73.2
15	32.8	18.8	78	38	10	0	85.3	69.3	77.4
16	33.6	19.1	92	52	14	0	83.9	69.3	76.8
17	26.5	17.1	97	55	11	0	77.5	65.9	72.7
18	26.7	12.8	92	34	21	0	76.6	57.8	66.1
19	30.0	14.3	85	27	11	0	82.3	62.0	71.4
20	33.8	14.2	90	28	11	0	82.6	62.9	74.0
21	35.8	20.2	83	44	18	0	84.8	71.8	78.0
22	32.5	22.1	78	46	18	2	86.4	68.6	77.7
23	23.0	13.9	83	46	16	0	73.8	60.0	66.4
24	25.8	8.2	89	26	21	0	69.2	52.0	62.3
25	25.0	8.6	90	29	10	0	75.9	54.4	65.4
26	25.2	13.8	79	42	13	0	74.0	61.1	68.1
27	27.6	12.0	96	60	26	0	71.8	56.8	64.4
28	30.9	17.8	95	47	26	0	83.4	57.9	73.3
29	29.7	19.8	89	57	26	0	80.1	58.7	74.2
30	25.8	15.2	89	51	13	0	74.7	64.2	69.7
July									
1	29.7	12.8	93	48	14	0	79.6	60.5	70.8
2	26.4	18.6	89	62	14	0	82.0	66.8	73.4
3*	29.9	19.5	95	56	13	0	81.6	73.0	77.9
4*	30.0	20.0	95	59	18	0	81.2	68.2	75.4
5*	30.1	18.1	94	48	10	0	82.8	69.7	76.1
6*	34.7	20.9	90	49	16	0	89.5	71.0	79.3
7*	27.3	17.7	91	48	16	0	80.0	67.6	74.9
8	30.2	14.9	94	56	10	0	83.5	63.3	75.1
9	33.0	19.2	90	52	13	0	88.5	72.1	79.6
10	32.6	20.9	85	49	18	0	85.0	71.4	79.5
11	32.2	20.8	91	68	13	0	90.5	70.0	80.6

Date,	Temperature, °C Max	Temperature, °C Min	Humidity, % Max	Humidity, % Min	Wind Speed, KPH Max	Wind Speed, KPH Min	Adjusted THI[1] Max	Adjusted THI[1] Min	Adjusted THI[1] Avg
12	29.0	22.1	93	57	26	0	85.8	67.2	79.7
13	28.2	20.7	96	68	10	0	83.8	69.8	77.7
14	29.1	18.6	97	65	8	0	85.8	70.7	77.4
15	31.4	21.0	93	60	11	0	86.1	71.9	79.5
16	32.3	19.1	95	52	8	0	87.7	72.1	81.3
17	31.8	21.8	90	53	11	0	85.9	72.7	79.2
18**	30.4	20.8	92	71	18	0	88.5	65.6	79.0
19**	32.9	22.8	93	68	18	0	86.2	75.8	80.4
20**	33.8	24.1	88	57	13	0	90.2	76.4	83.8
21**	34.5	24.9	91	63	19	0	93.0	71.4	81.3
22**	32.1	20.2	96	60	10	0	88.7	74.1	81.7
23	31.0	15.3	98	46	8	0	83.0	65.7	76.4
24	29.8	16.3	93	65	18	0	80.4	66.3	73.6
25	33.1	22.8	93	54	18	8	83.7	70.6	77.3
26	27.3	21.9	96	73	19	0	81.7	71.4	77.6
27	27.7	17.8	97	58	11	0	78.8	69.9	75.0
28	26.8	16.3	97	61	10	0	78.6	67.5	73.8
29	27.9	16.7	97	62	10	0	80.7	68.2	75.3
30	25.3	19.2	91	60	10	0	77.4	70.9	74.1
31	26.1	18.0	92	66	11	0	78.7	69.7	74.2
August									
1	29.3	16.3	97	58	11	0	83.2	67.4	74.9
2	28.8	15.1	97	56	5	0	83.6	65.3	75.0
3***	23.3	12.2	96	56	18	0	75.1	59.2	66.5
4***	23.9	8.8	97	46	8	0	74.4	53.1	65.2
5***	20.3	14.4	95	71	16	2	69.9	58.9	64.2
6***	22.3	16.3	97	75	8	0	76.4	64.6	69.9
7***	24.3	13.8	98	62	8	0	75.3	63.1	69.5
8	26.2	12.6	98	55	8	0	79.4	60.9	70.2
9	24.3	17.6	92	72	14	2	73.5	64.9	68.8
10	24.8	16.2	96	64	8	0	76.4	66.3	71.4
11	26.2	12.1	97	53	5	0	78.4	60.0	70.6
12	26.2	14.9	92	55	13	0	75.6	63.3	69.9
13	25.6	17.3	95	73	14	0	79.2	65.0	70.9
14	27.9	17.9	96	61	8	0	80.7	70.3	75.9
15	28.3	18.1	95	73	18	2	82.5	65.9	71.4
16	24.4	17.7	97	76	18	2	75.8	62.5	69.6
17	28.3	14.5	96	56	11	0	82.6	60.7	70.3
18	28.8	16.9	93	61	19	0	83.9	62.9	74.9
19	28.7	15.2	97	69	21	0	79.7	64.2	73.2
20	27.8	17.6	94	73	14	0	82.6	62.9	74.4
21	29.4	19.6	96	71	19	0	85.4	63.6	75.2
22	23.9	15.3	96	48	6	0	75.1	65.7	70.5

	Temperature, °C		Humidity, %		Wind Speed, KPH		Adjusted THI[1]		
Date,	Max	Min	Max	Min	Max	Min	Max	Min	Avg
23	25.4	14.1	89	58	11	0	77.6	61.0	68.6
24	25.8	15.3	88	61	16	0	74.4	62.1	68.4
25	27.7	18.5	89	67	19	3	77.7	63.5	69.9
26	28.5	17.8	94	71	14	0	85.4	64.1	73.7
27	27.1	18.1	96	61	14	0	81.2	65.6	75.6
28	25.2	13.1	97	50	6	0	76.3	61.8	69.7
29	25.4	12.7	97	58	5	0	78.7	61.1	70.3
30	26.3	14.2	94	60	6	0	80.2	63.7	71.6
31	26.2	14.1	96	65	6	0	79.2	63.5	72.6
September									
1	23.7	17.1	92	74	14	2	72.7	64.3	69.4
2	28.3	16.7	93	62	10	0	83.3	64.2	73.5
3	30.4	16.4	96	65	14	0	82.4	67.3	74.1
4	24.6	15.7	90	54	11	2	75.1	62.6	70.2
5	19.4	8.6	92	44	18	0	68.0	51.5	59.2
6	20.2	6.1	96	43	10	0	70.4	48.4	59.6
7	26.2	9.1	86	43	8	0	78.4	53.0	65.5
8	28.6	12.1	92	51	10	0	82.4	60.3	71.3
9	25.2	15.8	88	58	13	0	76.1	62.4	68.8
10	25.1	18.1	83	56	21	5	71.9	62.7	67.6
11	27.9	15.3	88	53	13	0	82.3	62.1	70.9
12	28.2	15.3	90	51	8	0	80.8	63.8	72.2
13	29.6	14.2	92	47	10	0	81.3	63.5	72.3
14	32.1	18.6	72	41	14	0	86.7	64.0	72.2
15	32.3	17.6	84	39	24	0	80.1	66.6	72.9
16	23.7	12.1	94	77	10	0	76.9	59.3	65.6
17	19.9	6.4	96	54	10	0	67.9	50.1	60.8

[1]Ajusted THI = 4.51 + [(0.8*Temperature, °C + ((humidity, %/100) * (temperature, °C - 14.4)) + 46.4] – (1.992 * wind speed, m/s) + (0.0068 * solar radiation, W/m^2). Calculated with maximum values of each measure (temperature, humidity, and wind speed) every half-hour during the day. Solar radiation was assumed at 250 W/m^2.

*Day included in the first heat event

**Day included in the second heat event

***Day included in the cool event

CHAPTER III. POOLED ANALYSIS OF INDIVIDUALLY FED FIINISHING TRIALS AT THE UNIVERSITY OF NEBRASKA-LINCOLN

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Abstract

A pooled analysis of 21 finishing trials (2002-2016) from the University of Nebraska-Lincoln with individually fed (Calan gate) finishing cattle was conducted for: 1) the effect of metabolizable energy (ME) concentration on cattle performance, 2) effect of DMI and ADG on feed efficiency (G:F), 3) effect of G:F on fat thickness and marbling, and 4) how closely predicted DMI from the NASEM (2016) is to actual DMI. Mixed model regression analysis following random coefficient methodology was used to evaluate the relationships. As ME concentration increased, there was a cubic effect on DMI ($P < 0.01$), a cubic effect on ADG ($P = 0.02$), a cubic effect on ME intake ($P < 0.01$), and a linear increase in G:F ($P < 0.01$). The cubic effect of ADG increased with increasing ME concentration and began to decrease at 3.14 Mcal/kg of DM. The cubic effect for DMI was a general decrease with increasing ME concentration that was relatively flat in the middle. Although ME intake was a significant cubic response, the values seem to be relatively consistent across all ME concentrations. As DMI increased, ADG increased at a decreasing rate ($P < 0.01$). The variable with greatest influence on G:F was ADG ($R^2 = 0.72$) compared to DMI ($R^2 = 0.02$). The effect of ADG on G:F was a cubic response ($P < 0.01$) while DMI was a quadratic response ($P < 0.01$). The cubic relationship between ADG and G:F was continually increasing with relatively slight curves in the line that were influenced by the points that lay on the ends of the data. Feed efficiency had significant cubic relationship with fat thickness and marbling of carcasses ($P < 0.01$), but the relationships were poor ($R^2 = 0.01$). There was a significant relationship between G:F and fat thickness and marbling, but the variation around the

trend line was relatively high. Feed efficiency alone is a poor predictor of fat thickness and marbling.

Keywords: metabolizable energy, individually-fed cattle, performance, carcass traits

Introduction

Predicting feedlot intake, performance, and carcass characteristics of cattle is important in order for producers to predict profitability and make marketing decisions. Predicting DMI is critical for estimating the amount of feed needed and subsequent profitability. If a prediction equation for DMI underestimates actual DMI it can lead to overestimating profitability and a shortage of feed supply forcing producers to switch diet ingredients at inopportune times. When prediction equations overestimate actual DMI, feed may spoil due to longer than expected storage time.

Lofgreen and Garrett (1968) observed when ME concentration of a diet is increased, the amount of feed required to maintain equilibrium is reduced. Metabolizable energy (ME) concentration of cattle diets can be increased many ways. Typical feedlot diets range from 2.70 to 3.45 Mcal/kg of DM (Krehbiel et al., 2006).

Also of interest is how DMI, ADG, and efficiency all affect carcass composition. Reinhardt et al. (2009) found a significant but small correlation coefficient between marbling score and ADG ($r = 0.077$) of 15,631 steers and 5,897 heifers fed at 18 different feedlots in southwest Iowa from 2002 to 2006. This led to the later conclusion by Reinhardt et al. (2012) that quality grade and performance are not genetically linked based on ADG.

The purpose of this analysis was to examine: 1) the effect of ME concentration on cattle performance, 2) the effect of DMI and ADG on feed efficiency (G:F), 3) the effect

of G:F of cattle on fat thickness and marbling, and 4) how closely predicted DMI from the NASEM (2016) is to actual DMI. This analysis was done with individually fed animals which allowed for each animal to be accounted for individually and gives a better understanding of how individual animals perform.

Materials and Methods

Cattle Data

A pooled analysis of 21 previous cattle feeding studies (1,530 animals) performed at the University of Nebraska-Lincoln Eastern Nebraska Research and Extension Center, near Mead, NE, was conducted. All research activities followed the guidelines stated in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010). All data reported are from published literature and no live animals were used to conduct this pooled analysis. Results for each trial are published in Nebraska Beef Cattle reports from various years with the exception of trial 6, 10, 11, and 21. Titles and authors are listed in Table A3.1. The data were collected at the individually fed barns that are equipped with the Calan gate system. There are 4 barns with 30 bunks in each barn. Barns are approximately 15 by 35 meters and allow for 17.5 m^2/animal and 46 linear cm of bunk space when there are 30 animals in the barn. Cattle are trained to use the bunks for approximately 3 weeks prior to start of the trial. The cattle 'choose' their bunk based on which one they eat out of for the training period, which are then assigned to them. Treatments are then assigned to the bunks with all treatments represented in each barn.

Trials selected were all finishing trials from 2002 to 2015. There were 5 trials with intact heifers, one trial with spayed heifers, and 15 trials with steers. Initial BW

ranged from 225 to 542 kg with the mean starting weight of 373 kg. Initial BW was taken after a five-day limit feeding period and cattle were weighed on three consecutive days. Trial 10 started as a growing trial and cattle were stepped up directly to a finishing diet. One day weights were taken between the growing and finishing period and these weights were shrunk 4%. Fifteen of the trials utilized 60 animals, 5 trials utilized 120 animals, and 1 trial utilized 30 animals. Dietary treatments for each trial were replicated 5 to 40 times with 18 of the trials having 10 to 20 replications per treatments. Animals were fed from 93 to 189 days in each trial. A complete description of each trial is listed in Table A3.2.

All cattle were shipped to the same abattoir (Greater Omaha Packing Co., Omaha, NE) for harvest and carcass data collection. The HCW and liver scores were collected at the time of harvest. Marbling, 12^{th} rib fat thickness (FT), and LM area were collected following a 48-hour chill. Final BW was calculated from HCW with a common 63% dressing percentage. Cattle ADG and G:F were calculated from this adjusted final BW. The DMI for trial 14 was not available so it was removed from all analyses using DMI. In trial 6, a unique byproduct was included in two of the three diets. Because a metabolizable energy (ME) value is not available for that feed, diets that included it were omitted from the ME analysis.

The ME of the diets was calculated using NASEM (2016) values if available. If values were not available, then values were assigned based on published literature. All values used to calculate ME concentrations of each diet are described in Table 3.1. The ME concentration ranged from 2.99 to 3.35 Mcal/kg of DM. Mean BW was calculated by the difference of initial BW and final BW divided by 2 and added to initial BW.

Predicted DMI was calculated only for yearling steers (n = 1120) using the NASEM (2016) equation predicting NE_m intake for yearling steers. Predicted NE_m intake was then divided by NE_m concentration (Mcal/kg) of the diet to get predicted DMI of each animal. Only yearling steers were used due to the inherent differences in intake between yearling and calf-feds as well as steers and heifers.

Statistical Analysis

Mixed model regression analysis following random coefficient methodology (St. Pierre, 2001) was used to evaluate relationships between variables. Animal was used as the experimental unit. Trial was included in the CLASS statement because it does not contain quantitative information. Also in the CLASS statement were sex and age classification which served as fixed, discrete independent variables. The MODEL and RANDOM statement specify the model to be executed. This expresses that the outcome is modeled by a fixed intercept, a fixed slope, a random intercept clustered by study, and a random slope also clustered by study. Unstructured variance-covariance matrix was used for the intercepts and slopes. If the unstructured variance-covariance matrix was not significant then it was removed and a reduced model without a covariance component was fitted. Also, in instances in which the random interaction of trial by independent variable was not significant then a reduced model without a random slope was used. In this case the study effect was solely a shift in intercept.

For each analysis there was a dependent and independent variable with the linear, quadratic, and cubic terms in the model. If the Type III fixed effect for the cubic term was not significant ($P > 0.10$) the model was reduced to just the quadratic and linear term. If the model was reduced to the linear term and there was no significance, then it

was assumed that no predictive relationship existed between the dependent and independent variables.

When statistics indicated a model was significant ($P < 0.10$) based on regression coefficients defining variation in the response variable, the estimates from the fixed effects were used as coefficients to create regression lines. The significance of term was used to determine if the coefficient of each term was different from zero. Residuals from random effect of trial were then added to the regression line prediction from each independent variable to calculate trial adjusted dependent variables.

Clear fits of the regression lines to the scatter plot of data points are not always visually apparent. Some data with large variability can still have significant trends. This demonstrates the importance of the standard error for each term in order to understand how well each regression line describes the data.

Results and Discussion

Effect of Concentration of Metabolizable Energy on Performance

There was a cubic relationship between ME concentration and DMI as percent of mean BW ($P < 0.01$; $R^2 = 0.09$; Figure 3.1). At the lowest level of ME concentration (2.99 Mcal/kg) DMI as a percent of BW was the greatest, and at the highest level of ME concentration (3.35 Mcal/kg) DMI as a percent of BW was lowest. The fit of the line was fairly flat in the middle ranges of ME concentrations. Previous research has shown that as ME concentration of the diet increases, DMI decreases (Plegge et al., 1984; Krehbiel et al., 2006).

There was a quadratic relationship between ME concentration and ME intake ($P = 0.04$; $R^2 = 0.03$; Figure 3.2). Although the fit was significantly quadratic, there were very

small differences in ME intake across all ME concentrations. The ME intake averaged 0.30 Mcal/kg of mean $BW^{0.75}$ and ranged from 0.29 to 0.31 Mcal/kg of mean $BW^{0.75}$. Plegge et al. (1984) reported that ME intake increased at a decreasing rate from 2.0 to 3.0 Mcal/kg of DM at which point it leveled off. Krehbiel et al. (2006) observed no differences in ME intake (Mcal/ kg mean BW) across different ME concentrations using NRC (1996) values. When ME values were calculated from literature (Zinn, 1989, 1994; Owens et al., 1997) the same increase in ME intake until approximately 3.0 Mcal/kg of DM was observed. However, ME intake increased again from approximately 3.4 to 3.7 Mcal/kg of DM, reaching the highest ME intake of approximately 0.345 Mcal/kg of $BW^{0.75}$ at 3.7 Mcal/kg of DM. The range in ME concentration for the Krehbiel et al. (2006) analysis was 2.66 to 3.70 Mcal/kg of DM which was a wider range than the 2.99 to 3.35 Mcal/kg of DM in the current study. Data from the current analysis would support the finding that cattle consuming more than 3.0 Mcal/kg of DM consume a consistent amount of ME on a Mcal/kg of $BW^{0.75}$ basis. However, there are no data points below 2.99 Mcal/kg of DM.

The relationship between ME concentration and ADG was also a cubic ($P = 0.02$; $R^2 = 0.12$; Figure 3.3). The zenith of the curve was at 3.14 Mcal/kg of DM. In a similar analysis, Krehbiel et al. (2006) reported a quadratic response between 187 different treatments and a zenith at 3.16 Mcal/kg of DM. This indicates that cattle on finishing diets consuming 3.14 to 3.16 Mcal/kg of DM have the greatest ADG.

The final relationship observed with ME concentration was with G:F, and was a positive linear relationship ($P < 0.01$; $R^2 = 0.03$; Figure 3.4). As energy concentration increased in the diets, feed efficiency was linearly improved. A linear improvement in

G:F was also observed by Krehbiel et al. (2006) with a similar slope from 2.90 to 3.35 Mcal/kg of DM. However, the overall regression line reported by Krehbiel et al. (2006) was cubic, but covers a wider range of ME concentrations and their values for G:F were greater by approximately 0.016.

Overall, as concentration of ME increased in the finishing diet, animals had lower DMI and greater ADG. This resulted in a positive effect on G:F, as observed in Figure 3.4 with the linear improvement. The ME intake (Mcal/kg of $BW^{0.75}$) should remain consistent once the ME concentration of the diets exceeds approximately 3.0 Mcal/kg of DM (Plegge et al., 1984; Krehbiel et al. 2006).

Effect of DMI and ADG on Feed Efficiency

Feed efficiency (G:F) is described as the amount of body weight gained per unit of feed consumed (G:F = ADG/DMI). As DMI increases in finishing animals, ADG increases at a decreasing rate (Ferrell and Jenkins, 1995). This same relationship was observed in the current analysis ($P < 0.01$; $R^2 = 0.46$; Figure 3.5). However, the relationship between DMI and G:F or ADG and G:F is not as well understood. Because DMI and G:F were measured in individually fed animals in the current analysis, these relationships can be evaluated.

The relationship observed for G:F and DMI was a quadratic response ($P < 0.01$; $R^2 = 0.02$; Figure 3.6). However, the relationship between G:F and ADG was a cubic response ($P < 0.01$; $R^2 = 0.71$; Figure 3.7). One observation is that more variation is accounted for by the ADG to G:F relationship ($R^2 = 0.71$) compared to the DMI to G:F relationship ($R^2 = 0.02$). This indicates that ADG is more influential at determining G:F in finishing beef cattle than DMI. In the current analysis, G:F continually improved as

ADG increased. When the first derivative of the quadratic response of G:F and DMI was calculated, the x-intercept of the line is at 9.03. This intercept indicates the most efficient animals were those consuming 9.03 kg of DM daily, although the relationship between DMI and G:F was very weak. This is likely heavily impacted by ME concentration of the diet. We must also consider the fact that the variables for this analysis are not independent of one another.

Tatum et al. (2012) reviewed closeout records of 67,570 commercially fed steers and heifers across feedyards in the United States. Data included carcass records of each animal. In the analysis, when feed costs were held constant, the greatest influence on cost per unit of gain was largely dependent on G:F. Also, G:F was the single most important contributor to differences in net return per animal. The authors also noted that carcass based ADG and days on feed were the two most important determinants of value of carcass gain. Based on the current analysis of individually fed animals, the most efficient cattle are those that have the greatest ADG. Also, the most efficient cattle are the most profitable (Tatum et al., 2012). This would indicate that the most profitable cattle are also those that have the greatest ADG.

Effect of Performance on Fat Thickness and Marbling

Many producers and researchers define animal performance as ADG, DMI, and G:F. The relationships between G:F and carcass characteristics are not well documented. It is not clear if more efficient animals also have greater FT or marbling. Relationships between G:F and FT or marbling were examined. The relationship between G:F and FT was quadratic ($P < 0.01$; $R^2 = 0.01$; Figure 3.8) and the relationship between G:F and marbling score was a cubic response ($P < 0.01$; $R^2 = 0.01$; Figure 3.9). Although statistics

indicated a significant trend, using G:F alone is still a poor predictor of how an animal will deposit subcutaneous ($R^2 = 0.01$) and intra-muscular fat ($R^2 = 0.01$).

The relationship between FT and marbling was quadratic ($P < 0.01$; $R^2 = 0.14$; Figure 3.10). As FT increased, marbling score increased at a decreasing rate. This quadratic response is heavily influenced by only a few animals that had greater than 2.1 cm of FT. Wertz et al. (2001 and 2002) observed a linear increase in marbling score as FT increased for Angus and Wagyu heifers that finished as either calves or yearlings.

Reinhardt et al. (2009) found a significant but small correlation coefficient between marbling score and ADG (r = 0.077) for 15,631 steers and 5,897 heifers fed at 18 different feedlots in southwest Iowa from 2002 to 2006. The author noted that calculated YG (r = 0.324), percent Angus genetics (r = 0.315), frame score upon arrival (r = 0.145), and initial BW upon arrival (r = -0.094) all had greater correlation to marbling score than ADG. Brethour et al. (2000) used ultrasound and prediction equations to forecast FT and marbling of two groups of finishing cattle. In the first group of cattle ultrasounds were taken 43 days before harvest and in the second group it was 58 days before harvest. For FT, ultrasound predictions for the first and second group accounted for 70 and 68% of the variation, respectively. Marbling score ultrasound predictions accounted for 51 and 34% of the variation in the first and second group, respectively. This demonstrates that with ultrasound imaging FT can be estimated with reasonable accuracy but marbling score is much more difficult to predict.

Accuracy of Predicting DMI for Individually Fed Cattle

The relationship between predicted DMI and actual DMI was quadratic ($P < 0.01$; $R^2 = 0.33$; Figure 3.11). With lower levels of intake (9 kg/d), predicted DMI was

approximately 0.5 kg/d greater than actual intake. This relationship improved as intake increased up to approximately 10.5 kg/d where predicted DMI was approximately 0.25 kg/d greater than actual intake. As DMI further increased, the over prediction also increased. At the upper end of measured DMI (12.5 kg/d), predicted DMI was approximately 1 kg/d greater than actual DMI. If an equation were to predict an outcome perfectly then the response would be linear with a slope of 1 and an intercept of 0 and the R^2 value would be 0.99. That was not the case with this prediction equation. However, this equation was developed for animals fed in pen settings and should be considered when a comparison is made.

Implications

This analysis provides evidence that cattle being fed high ME diets are more efficient compared to low ME diets. The correlation between ADG and G:F was better than the correlation between DMI and G:F. Feed efficiency of animals had little effect on carcass traits. However, marbling score increased with increased back fat thickness. The NASEM (2016) overestimated the amount of feed required for individually fed cattle in this dataset.

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Table 3.1. Metabolizable energy values assigned to diet ingredients

Ingredient,	Metabolizable energy, Mcal/kg
Dry rolled corn	3.17[1]
High moisture corn	3.27[1]
Steam flaked corn	3.43[1]
Coarse grits	3.17[2]
Wet distillers grains plus solubles	3.54[1]
Modified distillers grains plus solubles	3.36[1]
Dry distillers grains plus solubles	3.22[1]
Wet distillers grains	3.54[3]
Solubles	3.54[1]
Wet corn gluten feed	3.11[1]
Sweet Bran	3.22[1]
Corn bran	2.78[4]
Steep	3.54[1]
Corn Silage	2.45[1]
Sorghum Silage	2.08[1]
Alfalfa	1.99[1]
Brome	1.88[1]
Corn Stalks	1.90[1]
Wheat Straw	1.81[1]
Corn oil	6.39[1]
Animal Fat	7.67[1]
Tallow	7.67[1]
Molasses	2.71[1]
Supplement	3.17[5]

[1]NASEM values

[2]Used same value as dry rolled corn

[3]Used same value as wet distillers grains plus solubles

[4] Milton et al., 2000

[5] Used same value for dry rolled corn because fine ground corn was used as a carrier

Figure 3.1. Relationship between ME calculated from NASEM (2016) and DMI as a percent of BW from individually fed finishing cattle (n = 1370) at the University of Nebraska feedlot near Mead, NE. DMI, % mean BW = -32.1 ± 9.4 × ME^3 + 306.1 ± 89.3 × ME^2 – 974.5 ± 284.0 × ME +1036.3 ± 300.7 (R^2 = 0.09)

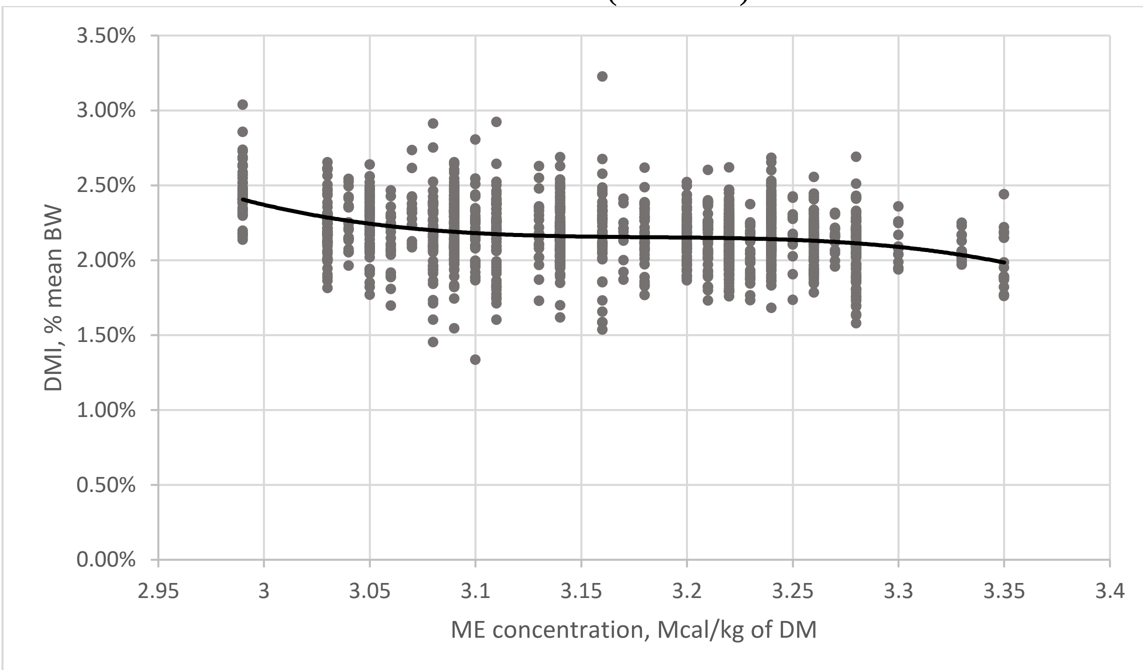


Figure 3.2. Relationship between ME calculated from NASEM (2016) and ME intake from individually fed finishing cattle (n = 1370) at the University of Nebraska feedlot near Mead, NE. ME intake, Mcal/kg of mean $BW^{0.75} = -0.505 \pm 0.248 \times ME^2 + 3.160 \pm 1.566 \times ME - 4.630 \pm 2.472$ ($R^2 = 0.03$)

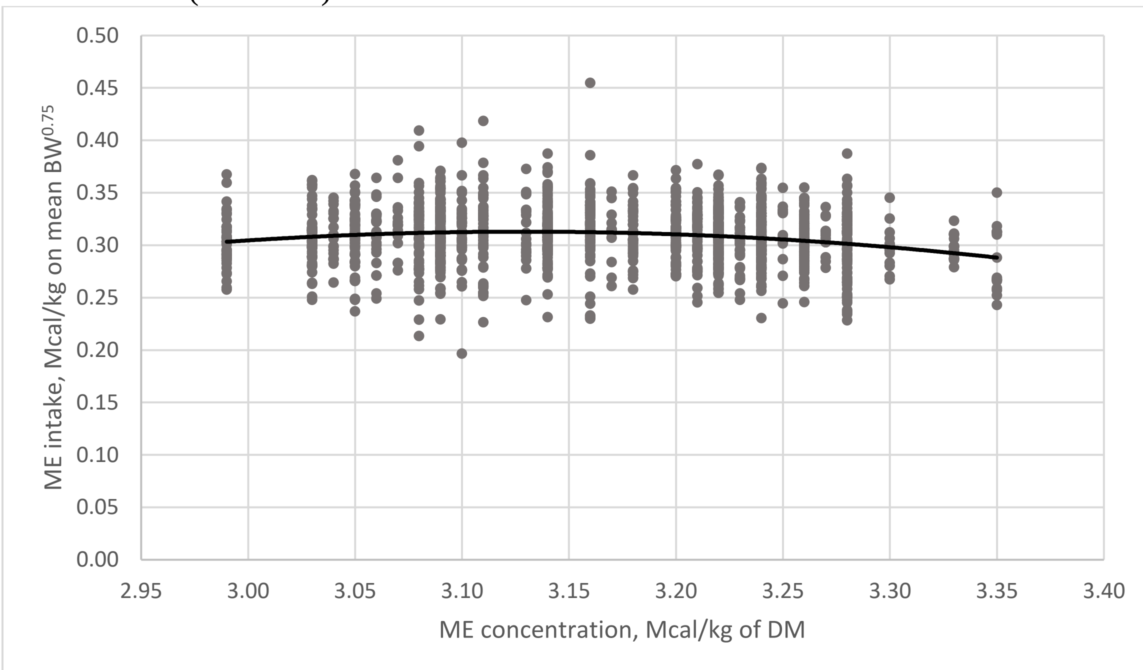


Figure 3.3. Relationship between ME calculated from NASEM (2016) and ADG from individually fed finishing cattle (n = 1490) at the University of Nebraska feedlot near Mead, NE. ADG, kg/day = 45.568 ± 19.625 ME^3 – 443.810 ± 187.660 ME^2 + 1439.150 ± 597.960 ME – 1552.300 ± 634.89 (R^2 = 0.12)

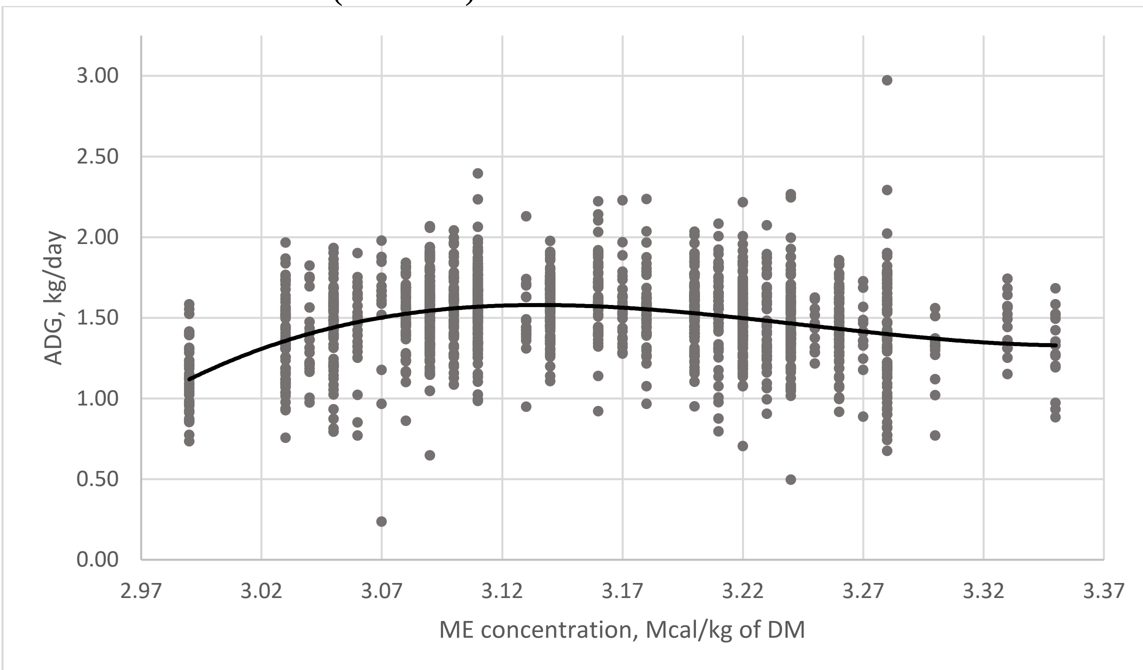


Figure 3.4. Relationship between ME calculated from NASEM (2016) and G:F from individually fed finishing cattle (n = 1370) at the University of Nebraska feedlot near Mead, NE. G:F = 0.0437 ± 0.0089 ME + 0.0099 ± 0.0281 (R^2 = 0.03)

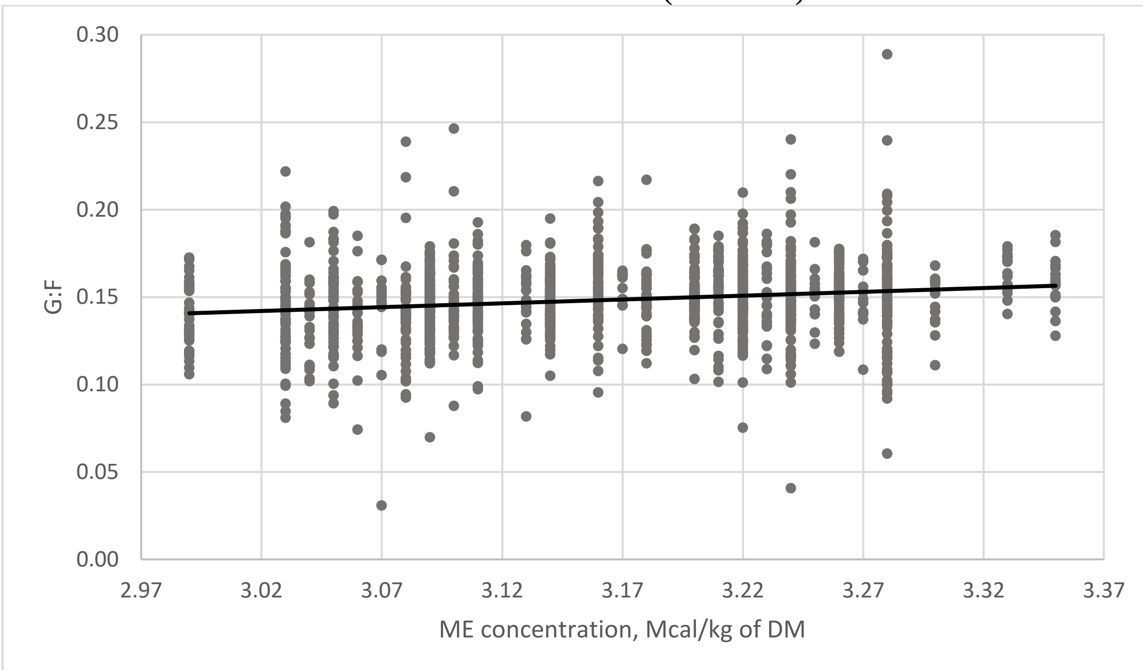


Figure 3.5. Relationship between DMI and ADG from individually fed finishing cattle (n = 1400) at the University of Nebraska feedlot near Mead, NE. ADG, kg = -0.01215 ± 0.0031 DMI^2 + 0.3685 ± 0.0617 DMI – 0.9821 ± 0.3194 (R^2 = 0.46)

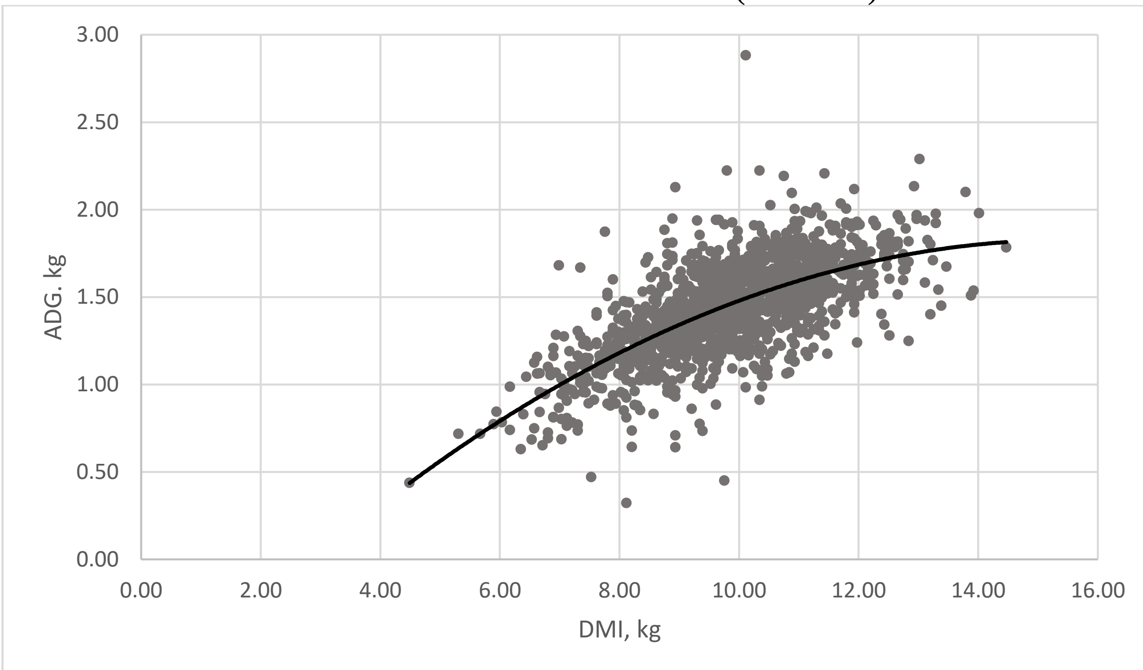


Figure 3.6. Relationship between G:F and DMI from individually fed finishing cattle (n = 1400) at the University of Nebraska feedlot near Mead, NE. G:F = -0.00098 ± 0.00032 DMI^2 + 0.0177 ± 0.0065 DMI + 0.0700 ± 0.0340 (R^2 = 0.02)

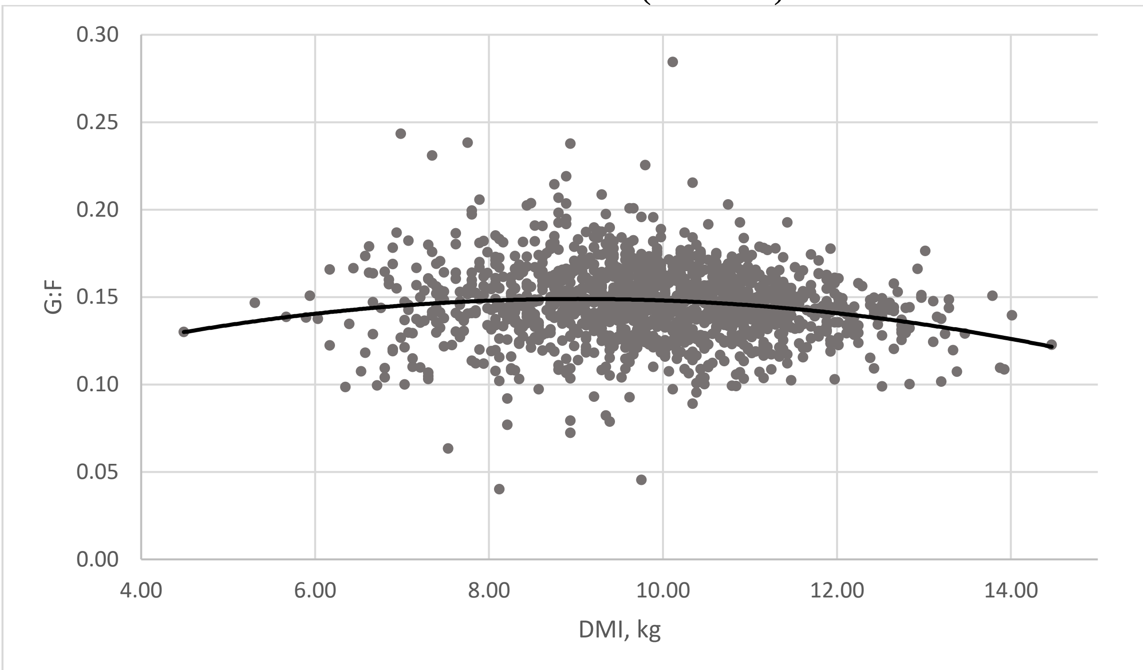


Figure 3.7. Relationship between G:F and ADG from individually fed finishing cattle (n = 1400) at the University of Nebraska feedlot near Mead, NE. G:F = 0.0163 ± 0.0041 ADG^3 – 0.0781 ± 0.0181 ADG^2 + 0.1818 ± 0.0265 ADG – 0.0012 ± 0.0141 (R^2 = 0.71)

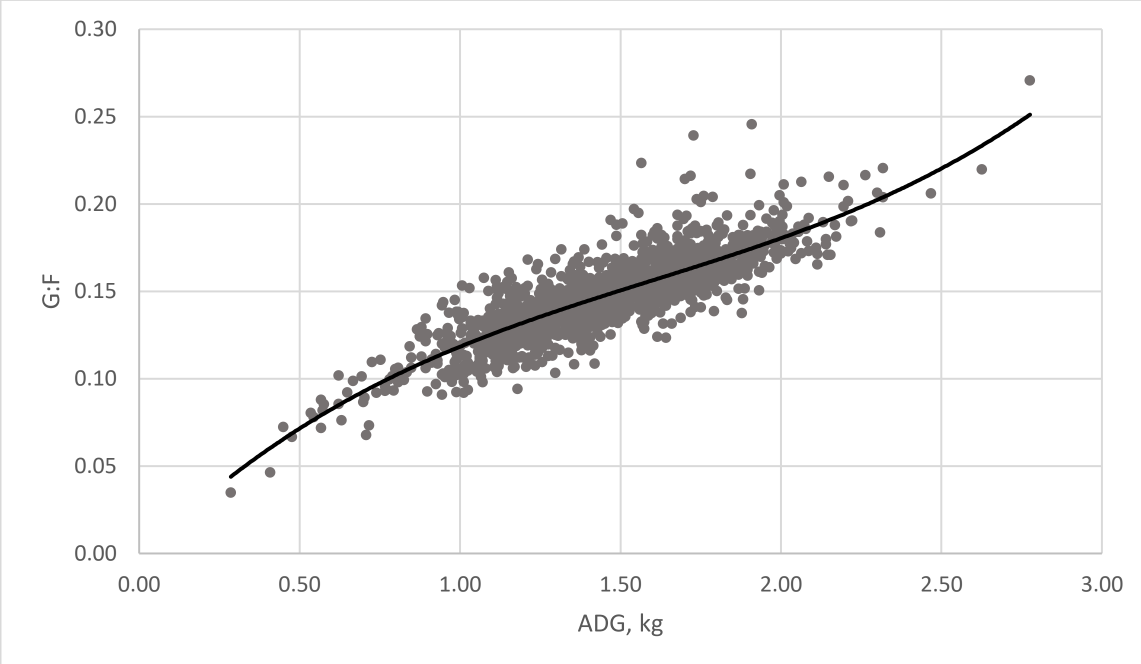


Figure 3.8. Relationship between G:F and 12th rib fat thickness (FT) from individually fed finishing cattle (n = 1400) at the University of Nebraska feedlot near Mead, NE. FT, cm = 269 ± 160 G:F^3 – 155 ± 75 G:F^2 + 27 ± 11 G:F - 0.4 ± 0.6 (R^2 = 0.01)

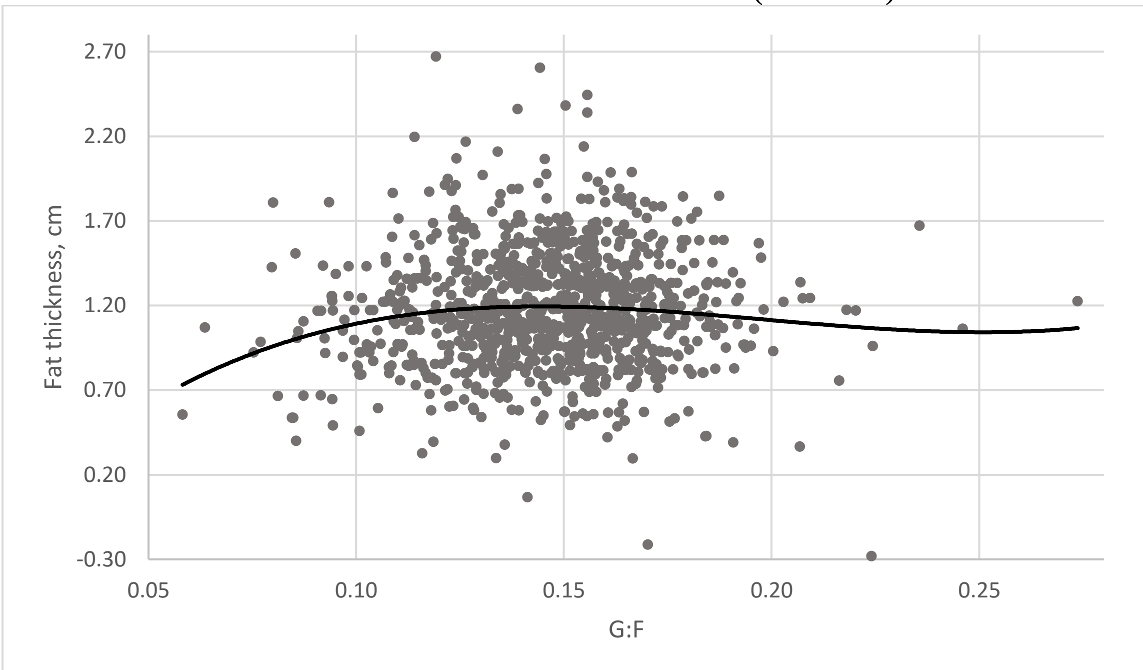


Figure 3.9. Relationship between G:F and marbling from individually fed finishing cattle (n = 1400) at the University of Nebraska feedlot near Mead, NE. Marbling = 104587 ± 32612 G:F^3 – 50931 ± 15268 G:F^2 + 7841 ± 2341 G:F + 108 ± 118 (R^2 = 0.01)

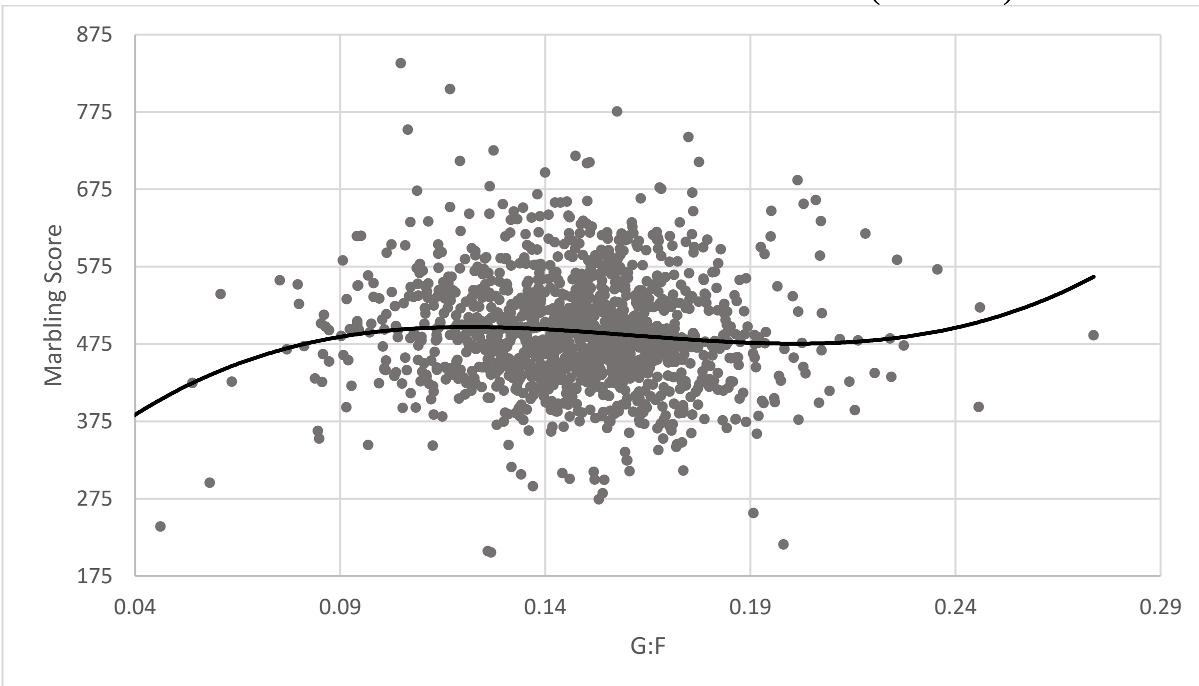


Figure 3.10. Relationship between 12th rib fat thickness (FT) and marbling from individually fed finishing cattle (n = 1520) at the University of Nebraska feedlot near Mead, NE. Marbling = -44.32 ± 9.51 FT^2 + 174.22 ± 25.45 FT + 349.11 ± 20.00 (R^2 = 0.14)

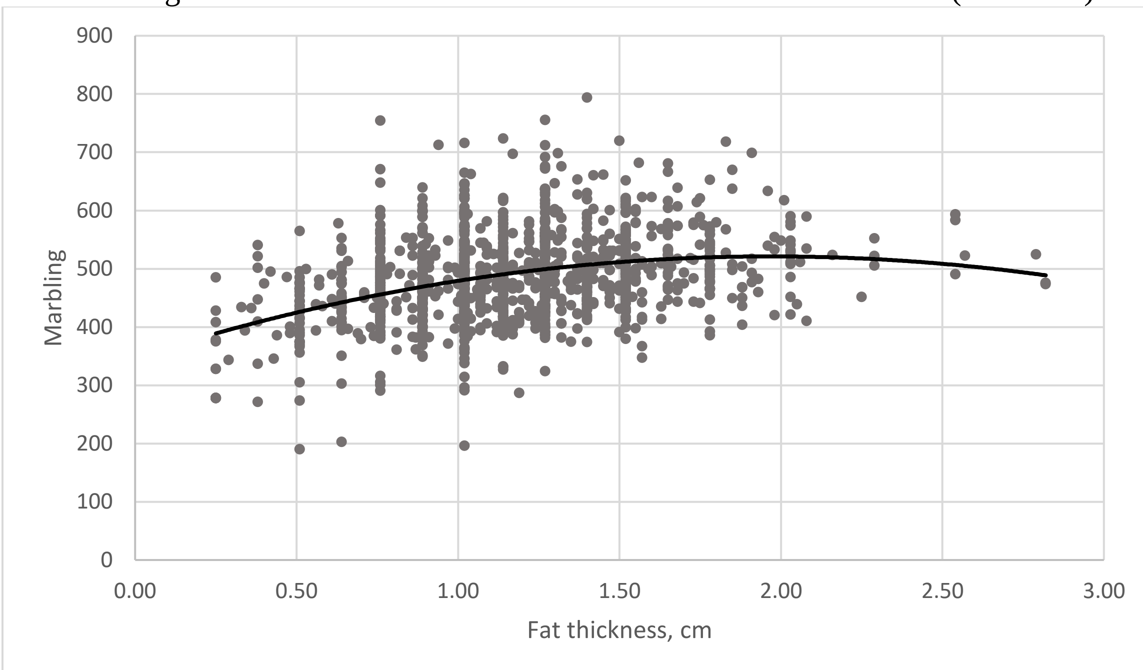
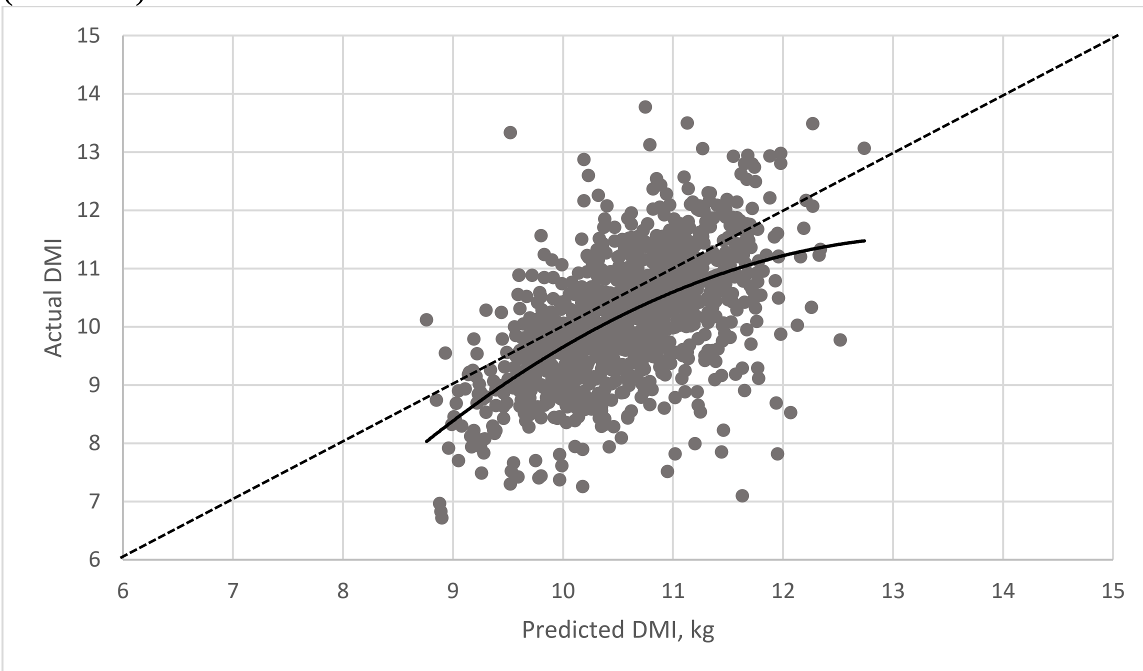


Figure 3.11. Relationship between predicted DMI and actual DMI from individually fed yearling finishing cattle (n =1120) at the University of Nebraska feedlot near Mead, NE. DMI, kg = -0.16 ± 0.05 × Predicted DMI^2 + 4.32 ± 1.17 × Predicted DMI – 17.48 ± 6.22 (R^2 = 0.33).



Appendix

Table A3.1. Titles and Authors of trials found in literature

Trial	Authors	Title	Found In
1	K. J. Vander Pol, G. E. Erickson, T. J. Klopfenstein, C. N. Macken	Effects of Wet and Dry Distillers Grains Plus Solubles and Supplement Fat Level on Performance of Yearling Finishing Cattle	Nebraska Beef Report 2004
2	C. B. Wilson, G. E. Erickson, C. N. Macken, T J. Klopfenstein	Sodium Chloride Levels for Finishing Feedlot Heifers	Nebraska Beef Report 2004
3	B. G. Geisert, G. E. Erickson, T. J. Klopfenstein, C. N. Macken	Phosphorus Requirement for Finishing Heifers	Nebraska Beef Report 2004
4	P. L. Loza, K. J. Vander Pol, G. E. Erickson, T. J. Klopfenstein, R. A. Stock	Effect of Different Corn Processing Methods and Roughage Levels in Feedlot Diets Containing Wet Corn Gluten Feed	Nebraska Beef Report 2005
5	K. J. Vander Pol, G. E. Erickson, T. J. Klopfenstein	Degradable Intake Protein In Finishing Diets Containing Dried distillers Grains	Nebraska Beef Report 2005
6	S. Morris, K. J. Vander Pol, T. J. Klopfenstein, R. A. Stock, G. E. Erickson	Burnt Sugar Finishing Trial	N/A
7	G. I. Crawford, K. J. Vander Pol, J. C. MacDonald, G. E. Erickson, T. J. Klopfenstein	Diurnal and Dietary Impacts on Purine Derivative Excretion from Spot Samples of Urine	Nebraska Beef Report 2007
8	G. I Crawford, S. A. Quinn, T. J. Klopfenstein, G. E. Erickson	Relationship Between Metabolizable Protein Balance and Feed Efficiency of Steers and Heifers	Nebraska Beef Report 2008
9	T. J. Huls, G. E. Erickson, T. J. Klopfenstein, M. K. Luebbe, K. J. Vander Pol	Effect of Feeding DAS-59122-7 Corn Grain and Non-transgetic Corn Grains to Finishing Feedlot Steers	Nebraska Beef Report 2007
10	N. Meyer, M. K. Luebbe. G. E. Erickson, T. J. Klopfenstein	Effect of Rumensin Level on Ruminal VFA in Finishing Diets with WDGS/MDGS	N/A
11	M. K. Leubbe, M A. Greenquist, G. E. Erickson, R. A. Stock, T. K. Klopfenstein	Cargill Bran Treatment and Level	N/A
12	C. M. Godsey, W. Griffin, M. K. Luebbe, J. R. Benton, G. E. Erickson	Cattle Performance and Economics Analysis of Diets Containing Wet Distillers Grains and Dry Rolled or Steam-Flaked Corn	Nebraska Beef Report 2009

13	C. M. Godsey, M. K. Luebbe, J. R. Benton, G. E. Erickson, T. J. Klopfenstein	Evaluation of Feedlot and Carcass Performance of Steers Fed Different Levels of E-Corn, a Potential New Feed Product form Ethanol Plants	Nebraska Beef Report 2010
14	J. O. Sarturi, G. E. Erickson, T. J. Klopfenstein, J. Vasconcelos, J. R. Benton	Effects of Sulfur Concentration in Distillers Grains With Solubles in Finishing Cattle Diets	Nebraska Beef Report 2011
15	S. K. Pruitt, K. M. Rolfe, B. L. Nuttelman, W. A. Griffin, J. R. Benton	Association of Myostatin on Performance and Carcass Traits in Crossbred Cattle	Nebraska Beef Report 2012
16	J. L. Harding, K. M. Rolfe, C. J. Schneider, B. L. Nuttelman, G. E. Erickson	Spoilage of Wet Distillers Grains Plus Solubles and Feed Value	Nebraska Beef Report 2012
17	C. J. Schneider, B. L. Nuttelman, D. B. Burken, T. J. Klopfenstein, G. E. Erickson	Transitioning Cattle from RAMP to a Finishing Diet on Feedlot Performance and Feed Intake Variance	Nebraska Beef Report 2014
18	A. C. Pesta, A. K. Watson, R. G. Bondurant, S. C. Fernando, G. E. Erickson	Effects of Dietary Fat Source and Monensin on Methane Emissions, VFA Profile, and Performance of Finishing Steers	Nebraska Beef Report 2015
19	L. F. Prados, N. D. Aluthge, R. G. Bondurant, S. C. Fernando, G. E. Erickson	Impact of a Newly Developed Direct-Fed Microbial on Performance in Finishing Beef Steers	Nebraska Beef Report 2016
20	A. C. Pesta, R. G. Bondurant, S. C. Fernando, G. E. Erickson	Use of Dietary Nitrate or Sulfate for Mitigation of Methane Production by Finishing Steers	Nebraska Beef Report 2016
21	T. Wes, R. G. Bondurant, G. E. Erickson	DFM Finishing Diets	N/A

Table A3.2. Trial descriptions

							Corn		Byproduct		
Trial	Sex[1]	N[2]	Average Initial BW[3], kg	Start Date	Days on feed	Implants	Type	% DM in diet	Type	% DM in diet	[ME], Mcal/kg DM
1	H	60	348	5/30/2002	113	1	DRC/HMC in equal amounts	47.5, 67.5, 82.5, 85, 87.5	MDGS/ CDS	0, 13/7, 26/14	3.13, 3.17, 3.20[5], 3.21, 3.28[5]
2	SH	59	365	7/18/2002	113	1	DRC/HMC in equal amounts	84.5	none	-	3.26[5]
3	H	60	279	11/15/2002	180	2	HMC/coarse grits	65	corn bran	15	3.24[5]
4	S	60	398	6/25/2003	121	1	DRC or HMC	65, 72	WCGF	25	3.07, 3.14, 3.16, 3.23
5	S	58	383	7/24/2003	99	1	DRC	66, 76	DDGS	10, 20	3.09
6	H	30	416	12/23/2003	93	1	DRC	58.5, 68.5	Sweet Bran	20	3.09, **
7	H	119	423	7/23/2004	95	1	SFC	25, 85	WCGF/ corn bran	0, 30/30	2.99, 3.28
8	S	117	337	4/1/2005	158	?	DRC or SFC	79.8	none	-	3.03, 3.24
9	S	59	396	1/27/2006	109	1	DRC	82	none	-	3.05
10	S	60	371*	6/7/2006	147	?	DRC/HMC in equal amounts	52.5, 82.5	MDGS	0, 30	3.10, 3.14

Trial	Sex[1]	N[2]	Average Initial BW[3], kg	Start Date	Days on feed	Implants	Corn		Byproduct		[ME], Mcal/kg DM
							Type	% DM in diet	Type	% DM in diet	
11	S	60	425	7/25/2006	133	1	SFC	37.5, 43.5, 49.5, 55.5, 61.5, 67.5	Corn bran/ steep	10, 16, 22, 28, 34, 40 of bran/10 of steep in all diets	3.06, 3.10, 3.14, 3.18, 3.22, 3.26
12	S	120	356	7/27/2007	145	1	DRC or SFC	40, 43.8, 47.5, 67.5, 82.5	WDG	0, 20, 40	3.06, 3.16, 3.25, 3.27, 3.23, 3.30, 3.33, 3.35
13	S	120	372	5/29/2008	153	1	DRC	60	WCGF or WDGS	30	3.09, 3.22
14	S	120	345	6/12/2009	152	2	DRC/HMC[4]	47.5, 57.5, 67.5, 87.5	WDGS or DDGS	0, 20, 30, 40	3.10, 3.11, 3.17, 3.20, 3.23
15	S	59	276	12/16/2009	189	0	DRC/HMC in equal amounts	52	WDGS	35	3.22
16	S	59	398	7/9/2010	130	?	DRC	45, 80	WDGS	0, 40	3.04, 3.21
17	S	60	382	5/11/2012	138	1	HMC	42.5	Sweet Bran/ MDGS	25/22.5	3.20
18	S	60	415	5/23/2013	125	1	DRC	37, 84, 87	MDGS	0, 50	3.08, 3.18[5], 3.22[5]
19	S	60	385	5/23/2013	132	2	DRC	47, 87	MDGS	0, 40	3.08, 3.16

Trial	Sex[1]	N[2]	Average Initial BW[3], kg	Start Date	Days on feed	Implants	Corn: Type	Corn: % DM in diet	Byproduct: Type	Byproduct: % DM in diet	[ME], Mcal/kg DM
20	S	60	417	6/20/2014	109	1	DRC/HMC in equal amounts	71.5	MDGS	10	3.11
21	S	60	407	6/3/2015	133	1	DRC/HMC	44.5/24	MDGS	20	3.14

[1]H = heifers; SH = spayed heifers; S = steers

[2]N = number of animals

[3]Limit fed for 5 days and weighed on 3 consecutive days prior to feeding for an average individual BW unless noted otherwise.

[4]15% corn silage included in all diets and assumed to be 50% HMC

[5]Fat/oil included in the diet

*Weighed once and shrunk 4%

** Diet was not included in ME analysis because burnt sugar was included in the diet at 10% and no ME value was established

Table A3.3. Regressions that were not included in the discussion of results

Dependent variable	Independent Variable	Intercept	Independent Variable Coefficients: Linear	Quad	Cubic	R^2
ADG	Initial BW	0.25	0.0064	-8.4×10^{-6}	-	0.01
		P = 0.45	*P* < 0.01	P < 0.01		
DMI	Initial BW	6.34	0.010	-	-	0.20
		P < 0.01	*P* < 0.01			
G:F	Initial BW	0.19	-0.0001	-	-	0.08
		P < 0.01	*P* < 0.01			
HCW	Initial BW	129.84	0.61	-	-	0.69
		P < 0.01	*P* < 0.01			
	G:F	272.17	579.79	-	-	0.28
		P < 0.01	*P* < 0.01			
	DMI	152.48	27.47	-0.67	-	-
		P < 0.01	*P* < 0.01	*P* = 0.04		
	ADG	234.71	84.18	-	-	0.69
		P < 0.01	*P* < 0.01			
Marbling	Initial BW	121	1.66	-0.0018	-	-
		P = 0.41	*P* = 0.04	*P* = 0.06		
	ADG	426.14	40.99	-	-	0.03
		P < 0.01	*P* < 0.01			
	DMI	94.25	66.43	-2.62	-	0.09
		P = 0.41	*P* = 0.01	*P* = 0.01		
	HCW	24.24	2.12	-0.0023	-	-
		P = 0.90	*P* = 0.05	*P* = 0.10		
Fat thickness	ADG	0.30	0.86	-0.18	-	0.10
		P = 0.12	*P* < 0.01	*P* = 0.02		
	DMI	-0.37	0.22	-0.0061	-	0.17
		P = 0.31	*P* < 0.01	*P* = 0.10		
	HCW	-2.26	0.016	-0.0001	-	-
		P = 0.01	*P* < 0.01	*P* = 0.01		