EFFECTS OF FORAGE ALLOWANCE AND

SUPPLEMENTATION ON PERFORAMNCE

OF STEERS GRAZING WINTER

WHEAT PASTURE

By

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Abstract: A study was conducted over two fall/winter wheat grazing seasons (2018 – 2020) to estimate the combined effect of forage allowance and a fiber-based energy supplement in stocker cattle grazing wheat. Eight pastures (2.7 to 5.1 ha) were stocked with seven test steers (initial BW = 210 ± 36 kg). Weekly, additional steers were added or removed in each pasture, a put and take method, to achieve forage allowance of either 1.5 or 3.0 kg forage DM / kg steer BW (4 pastures each). Two pastures in each forage allowance were fed daily with a supplement containing 50% wheat middlings and 50% soybean hulls at the rate of 1.5 kg (as fed) per steer. Forage mass was measured twice weekly using a calibrated rising plate meter. Cattle were weighed weekly on calibrated scales. Data were analyzed using linear regression with pasture as the experimental unit. Mean ADG was 1.49 ± 0.36 kg/d. One pasture in the high forage allowance, non-supplemented treatment was removed from analysis in year one because desired forage allowance could not be maintained. There was an interaction of forage allowance and supplementation on ADG (P = 0.053) such that cattle receiving greater forage allowance with supplementation produced greater daily gains. To further investigate forage DMI, a 14-d trial began on day 36 in each year. Three of the seven test steers in each pasture were randomly selected to receive 7 ± 0.1 g of TiO_2 daily at 0700 as an external marker to estimate fecal output. Forage DMI averaged 2.03% of midpoint BW, below our expectation. There was no interaction of forage allowance and supplementation (P = 0.14) on forage DMI. Forage allowance affected forage DMI (P = 0.04), but supplementation had no effect (P = 0.37).

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CHAPTER I

INTRODUCTION

The stocker cattle industry is important to producers in the Southern Great Plains, with over three million hectares of wheat planted in this region grazed by stocker cattle (Carver et al., 2001). Stocker cattle allow producers in the beef industry to capitalize on the seasonality of cattle markets. In addition to higher market prices in the spring, cattle grazing winter wheat have a lower cost of gain than cattle on a concentrate-based feedlot diet. The cost of gain for grazing winter wheat typically averages \$0.50 to \$0.60/hd/d, while the cost of gain for a concentrate-based, preconditioning diet averages close to \$0.90/hd/d (Bradley, 2019). The additional gain achieved at a lower price creates opportunity for cattle producers to attain greater profits.

Stocker cattle production is often deemed a high-risk business endeavor, due to the multitude of factors that contribute to the profitability. Not only are there uncontrollable animal performance and genetics factors but also environmental variability from year to year can have a significant impact on the industry's success rate. Supplementation of additional nutrients is an area of interest in efforts to offset some of the risk by creating greater gain in cattle throughout the duration of the stocker period. Complementary feed sources can help improve utilization of forage and maintain greater forage mass (Horn et al., 1995). Wheat pasture usually contains excess levels of protein, above that required by stocker cattle to ensure optimum growth and performance. Crude protein generally averages between 25% - 30% of winter wheat dry matter (DM). Excess crude protein in wheat can be utilized at a greater rate by implementing an energy supplementation strategy. Additional carbohydrate sources from supplementation can optimize microbial growth and efficiency, creating greater utilization of the abundant nitrogen provided from wheat pasture. Energy supplements can starch-based (corn) or fiber-based (soybean hulls and/or wheat middlings). Research has shown both high-fiber and high-starch supplements to create a positive effect in wheat forage utilization by increasing gain per hectare by 64 kg/ha and 50 kg/ha, respectively (Horn et al., 1995). The benefits of utilizing a high-fiber feed source have included a slightly greater average daily gain, a lower supplement conversion rate, and less incidence of bloat (Horn et al., 1995, 2006).

In addition to energy supplementation for wheat stocker cattle, monensin supplementation has proven to be effective in increasing profitability. An ionophore can be fed in a loose mineral or in a pelleted feed source. Concentrations of monensin are typically higher in a mineral source due to the lower amount of consumption (2-3 oz/hd/d). Monensin supplementation has improved average daily gain in stocker cattle by 0.15 kg/d (Horn et al., 2005). In addition to the increased gains, ionophores have also proven to reduce bloat incidences (Branine and Galyean, 1990).

Supplement conversion ratio (kg of supplement per kg of additional ADG) is vital to ensuring supplement profitability. In past research, energy supplement conversion rates have averaged between 6 to 10 kg/d of supplement per kg/d of added body weight (Fieser et al, 2003, 2007; Horn et al., 1995, 2006). As the conversion rate increases, profitability from supplementation is no longer achievable. Research conducted by Horn et al. (1995)

has shown more promising supplement conversion ratios averaging between 4.8 to 6.4 kg/d of feed per kg/d of gain. At a rate of 5 kg/d of feed per 1 kg/day of gain, individual animal profits can be increased from $15 to $31 over the stocking period depending on the price of feed and cattle markets (Horn et al., 2005).

In addition to conversion ratios, substitution ratios of energy supplementation added to the diet of stocker cattle grazing wheat pasture has been an area of interest in past research. With goals of decreasing the volatility associated with stocker cattle on wheat, high substitution ratios could help to reduce the risk of inadequate forage mass in years of drought and harsh weather. In a trial providing high-starch and high-fiber energy supplementation to cattle grazing wheat forage, a -0.86 substitution ratio was observed (Cravey et al., 1992). These results indicate that for each kg of supplement fed, dry matter intake of wheat pasture was decreased by 0.86 kg. More data are needed to find substitution ratios for varying amounts of forage mass of wheat pasture.

Little research has been conducted to determine the effects of forage mass on energy supplement conversion rates and substitution ratios for wheat forage. To allow producers to optimize use of a wheat crop, data are needed to evaluate the interaction of forage allowance and supplementation for cattle grazing winter wheat pasture. The objective of this study was to analyze the effect of forage allowance and energy supplementation on the performance of stocker cattle grazing winter wheat.

CHAPTER II

REVIEW OF LITERATURE

Winter Wheat Dynamics

Winter wheat (*Triticum aestivum* L.). is an important crop in the Southern Great Plains. Millions of hectares of winter wheat are planted throughout this region each year. Depending on the producer, three different management practices can be utilized for a wheat crop; Grain-only (no grazing), forage-only (full-grazing), or a combination of the two (dual-purpose).

Grain-Only Production Practices

Operations outside of the Southern Great Plains, a region of relatively warmer winters and greater rainfall, may choose to utilize a grain-only production practice to avoid issues from snow-cover, drought, and harsh winter temperatures. A system that utilizes a grain-only practice will follow generic wheat crop protocols. The seed will be sown in early to late October and harvested during early summer months (Hunger et al., 2017). A lower seeding rate and less fertilizer nitrogen is needed for winter wheat utilizing this type of management practice (Carver et al., 2001). Higher grain yields than dual-purpose practices, ranging from 7% to 30%, have been reported from wheat crops utilized in a grain-only system (Carver et al., 2001; Edwards et al., 2011). The quality of grain is also higher than wheat that undergoes grazing pressure (Virgona et al., 2006).

Forage-Only Production Practices

Many wheat producers located in the southern region of the United States choose to implement a forage-only wheat crop. Winter wheat planted using this system will be sown one month earlier and seeded at 1.5 to 2 times greater seeding rate than wheat in grain-only systems (Butchee and Edwards, 2013). Planting wheat at an earlier time period will ensure adequate forage mass for cattle grazing through the winter. An earlier planting date implemented with this management system allows cattle to graze the wheat during late fall/early winter, but creates a greater incidence of root diseases, caused by viruses transmitted by the wheat curl mite (Hunger et al., 2017). To avoid greater occurrences of root diseases, seed treatment can be utilized. Also, a dual-purpose cultivar is likely chosen to withstand some of the issues associated with early planting. A nitrogenous fertilizer will be applied to the chosen cultivator prior to seeding. Oklahoma State University Extension recommends providing adequate nitrogen to ensure 213 kg/ha of nitrogen is available to allow forage to reach yields around 3360 kg/ha (Zhang et al., 2009). Stocker cattle will be placed on wheat 45 to 60 days after sowing to allow time for wheat to establish root integrity and mass. Typically, when producers choose to implement this production practice, cattle prices are more profitable than wheat prices. One must study the futures market of both cattle and wheat, while considering all associated input costs for the two different scenarios (Sahs and DeVuyst, 2018).

Dual-Purpose Production Practices

The most popular wheat program in the Southern Great Plains is a dual-purpose system, encompassing over three million acres of wheat yearly (Carver et al., 2001). Utilizing a dual-purpose production system will provide producers with a grain crop and quality forage for cattle, potentially increasing overall profitability. Reports have shown increases in profits for dual-purpose systems to double that of grain-only systems (Kelman and Dove, 2009). The dynamics are similar to that of a forage-only system, however, cattle must be removed by the ‘first hollow stem’ to ensure a grain-yield is obtained. The first hollow stem of a wheat crop is indicated by a 1.5 cm (dime-sized) long hollow-stem below the developing wheat head (Edwards, 2017). Typically, first hollow stem occurs between the end of February to the middle of March. Holman et al., (2009) discovered that when cattle were removed before the first hollow stem, there were no negative effects associated with grain-yield from grazing cattle during the winter months. Grazing wheat forage over the winter has proven to benefit grain-yield during years of droughts by removing leaf area and reducing the plants evaporation abilities (Kelman and Dove, 2009). However, in years of normal rainfall and temperatures, many publications have shown decreased grain-yields derived from a dual-purpose system in relation to a grain-only system, averaging around 20% (Carver, 2001; Virgona et al., 2006; Thapa et al., 2010). The yield reduction potential created by grazing pressure and early planting of dual-purpose wheat operations creates the need for a proper management system to be in place (Carver, 2001). Research has shown that cattle grazing wheat forage 14 days past the first hollow stem will reduce grain yields up to 40% (Taylor et al., 2010). Allocating a specific plot inside the wheat field where cattle have no access to graze is vital to monitoring for the first hollow stem (Taylor et al., 2010). Alternatively, when wheat prices are lower than cattle prices, extending the grazing period for additional gain could be feasible. Observing the yearly trends of cattle and grain markets is vital to ensuring profitability in a dual-purpose wheat operation.

Wheat Pasture Nutrient Analysis

Wheat pasture is commonly utilized by producers throughout the winter months as a complimentary forage type. Wheat is complimentary to native range, in southern states, due to the capability of producing high nutritional values during the months that native range is dormant. Native range nutrient composition during winter months will average 5% to 7% crude protein (CP), while wheat pasture will average 25% to 35% CP. A large proportion of this protein is considered to be degradable intake protein (DIP). Degradable intake protein consists of amino acids that are utilized by microbial populations in the rumen for growth and efficiency. The average percentages of DIP found in previous studies ranges from 75% to 79% of CP (Reuter and Horn, 2000; NASEM, 2016). In a report by Reuter and Horn (2000), crude protein averaged 26% throughout the fall, winter, and early spring. A study completed by Beck et al. (2015), reported protein levels beginning at 30% in November, plateauing around 25% throughout the winter months of December, January, and February, and peaking at 30% again in March before reaching maturity. The reduction in CP over the winter months can be attributed to the senescence of the forage due to colder temperatures and less sunlight (Morgan et al., 2012). The high protein composition of wheat pasture is greatly above the requirements of an average 250 kg stocker steer gaining 1.2 kg/d (Morgan et a., 2012; NASEM, 2016). Typically, protein is the most expensive feed source in the diet of cattle. Supplemental protein is usually needed for cattle grazing winter dormant range, creating costly feed inputs. Wheat pasture allows an alternative to supplementation practices by offering cattle a high-quality forage in seasons when native range is dormant.

Dry matter percentages of winter wheat pasture are lower than dormant native range due to the forage having a cool-season growth phase. Wheat forage contains 20% to 45% DM in relation to 90% DM of native range during senescence. Phillips and Horn (2008) reported DM percentages of wheat pasture averaging 24 ± 5.5% at the beginning of the trial and averaging 21.4 ± 2.3% throughout the entire study. Although the DM percentages are lower, the digestibility of wheat is high, averaging around 75% DM (Cravey, 1993). Vogel (1988) reported in vitro organic matter digestibilities (IVOMD) observed in late fall and early spring at 82% and 77% respectively. The findings in the Reuter and Horn (2000) research report presented higher IVOMD for fall and spring around 88% and 81% respectively.

A diversity of carbohydrates, structural and non-structural, are present in wheat forage. Structural carbohydrates consist of cellulose, hemicellulose, lignin, and pectin and are broken down by microbial enzymes inside the rumen and cecum (Holechek et al., 2011). For cattle grazing ryegrass during different growth stages of the forage, average cellulose intake was 5.4 g/kg BW per day (Beever et. al, 1986). Lignin cannot be utilized by the animal's enzymes or the microbial enzymes present in the digestive tract. As the maturity of a plant increases, the lignin percentages of the cell wall will increase (Holechek et al, 2011). Winter wheat forage consists of 2.5 to 5% lignin on a DM basis for most of the grazing season (Cravey, 1993). Cellular carbohydrates consist of more soluble carbohydrates, such as glucose, sucrose, and starch. Native warm-season grasses will lack cellular carbohydrates during the winter months while structural carbohydrates dominate the nutrient composition. The cellular carbohydrates of wheat forage are of greater proportion due to wheat being a C3 (cool-season) plant. Forages that result in a grain product are typically higher in soluble carbohydrates (Cravey, 1993). Beever et al. (1986), reported higher levels of soluble carbohydrates during the early growth of ryegrass, with values decreasing as forage reached maturity.

Changes in nutrient compositions of wheat forage will occur as the maturity of the plant increases through the season. As wheat pasture matures throughout the spring, protein levels will decrease. Beck et al, (2015) observed crude protein levels greater than 25% DM during December and levels lower than 20% DM during April. Protein levels of wheat pasture can approach lows of 13% at peak maturity during the month of May (Lippke et. al., 2000; Reuter and Horn, 2000). As the forage maturity increases, digestibility of the wheat will decrease. In vitro organic matter digestibility can average 90% in early-winter and reach lows of 80% in late-spring (Reuter and Horn , 2000). Correspondingly, TDN percentages of wheat pasture will decrease as the forage maturity increases over time at a range of five to eight percent (Fieser et al., 2007; Beck et al., 2015). The decrease in forage digestibility can be attributed to the greater amount of structural carbohydrates present as forages mature and prepare to reproduce.

As with any cattle grazing a forage diet, mineral composition of the diet and adequate supplementation protocols need to be established for cattle grazing winter wheat. Wheat pasture poisoning is a metabolic disorder that can occur in cows grazing wheat forage. Cows grazing wheat pasture for greater than 60 days during late gestation and early lactation are at greater risk than stocker cattle (Horn et al, 2006). The disorder derives from a calcium and magnesium deficiency. The mineral composition of wheat pasture is variable. In a study conducted by Beck et al., (2014), calcium percentages ranged from 0.30% DM to 0.56% DM during a two-year time period. The same study observed ranges of magnesium concentration from 0.12 % DM to 0.20% DM (Beck et al., 2014). The magnesium requirements for growing cattle have been reported at levels of 0.10% of DM (NASEM, 2016). The calcium requirements for a 250-kg steer to gain 1.2 kg/day is 0.44% DM (NASEM, 2016). Calcium deficiencies have been shown to compromise rumen motility (Huber et. al, 1981). Rumen motility is necessary for the eructation of gases created from fermentation of feed sources. The probability of bloat incidences will increase if rumen motility of cattle is compromised. To ensure adequate calcium supply for cattle, Horn et al., (2005) suggests supplementing 10 g/hd/d to stocker cattle grazing winter wheat pasture. Although less likely, phosphorus in wheat can be inadequate at times for stocker cattle growth when the levels are less than 0.26% DM (Horn et al., 2005). To ensure optimum performance of stocker cattle grazing winter wheat pasture, mineral supplementation of magnesium, phosphorus, and calcium is a necessity.

Factors Contributing to Forage Intake

Cattle grazing a forage based diet have a variety of factors that regulate the amounts of forage consumption within a grazing period. The nutrient composition of the forage, the nutrient requirements of the cattle, the availability of forage, the maturity of forage and additional supplementation of nutrients are all factors that will influence the forage intake of cattle. Forage diets are generally less energetically dense than a concentrate based diet. Cattle grazing native winter range will consume around 2.0% - 2.5% of their body weight of forage DM in a day. Cattle grazing winter wheat pasture will typically consume 2.7% - 3.0% of their body weight in a daily period (Horn, 2006). Dormant native range is mature in its growth cycle and will be less palatable and digestible, due to its physical and chemical composition. Winter wheat pasture is a C3 forage, allowing the growing season to occur during the winter months, producing high nutrient composition in the forage.

Physical and Chemical Composition of Forage

The physical and chemical composition of forages influence intake of grazing cattle. Neutral detergent fiber (NDF) is one of the most important chemical influencers on forage intake. The NDF fraction of feeds include the structural carbohydrates (lignin, hemicellulose, cellulose) responsible for the rigidity of the cell wall. Mature and dormant plants have a greater amount of NDF present, creating lower palatability and digestibility of the forage. NDF has the greatest chemical effect on the “fill factor” generated from reticulorumen distension in cattle grazing forages (Allen, 1996). The NDF fraction of forages ferments and passes from the rumen more slowly than other nutrients, creating a greater fill effect than other forage constituents (Allen, 1996). Allen (1996) attributes particle size, chewing frequency, particle fragility, INDF, rate of fermentation of the NDF, and characteristics of reticular contractions to the distention of the reticulorumen. The distention, or “fill effect”, is responsible for the inhibition of additional forage intake.

Essential nutrients, such as proteins and minerals, can also influence intake in cattle grazing a forage-based diet. For cattle grazing dormant native range, protein levels of the grass are inadequate for optimum microbial population growth and will reduce intake. Protein composition of the tallgrass prairie during the winter months can range from 4% to 6% (Preedy et al., 2018). The protein intake of cattle during the growing season of forages will average 10% to 12% (Holocheck et al., 2011). Protein levels of winter wheat pasture is usually in excess of 20% and will not cause a detrimental effect on forage intake.

Mineral deficiencies of forages can negatively affect intake of cattle. Phosphorus is the most limiting mineral to grazing animal productivity (Holocheck et al., 2011). The National Academies of Sciences, Engineering, and Medicine (NASEM, 2016) suggests that cattle gaining two pounds per day have a phosphorus requirement of nine grams per day. Generally, winter wheat pasture contains adequate levels of phosphorus required for growth. However, Horn et al, (2005) observed phosphorus levels that were marginal and could indicate a potential need for supplementation. Phosphorus is required by the microorganisms inside the rumen for growth and function (NASEM, 2016). In the case of a deficiency, fermentation inside the rumen would be hindered and intake could be depressed. Calcium is an additional macromineral important to cattle grazing wheat pasture. Calcium levels of wheat forage have shown variable ranges above and below the requirements of stocker cattle (Horn et al., 2005; Beck et al., 2014). Deficiencies can cause forage intake to decrease by depressing rumen motility. Subsequently, passage rate could then be hindered, causing distension of the rumen to occur. Supplemental calcium is needed for cattle grazing a wheat-based diet (Horn et al., 2005). Cattle with a potassium deficiency have been observed to have depressed feed intake, loss of body weight, rough hair coat, and muscular weakness. Wheat potassium levels reported in a trial conducted by Horn et. al. (2005) were 0.1% to 0.2% below a growing steer's requirement, indicating a need for supplementation. Devlin et. al., 1969 found that a finishing steer's diet needs to contain between 0.51% and 0.72% potassium to ensure adequate growth and feed intake.

Passage of Digesta

Passage rate is a significant contributor to the intake of forages in grazing cattle. Ruminants will have a greater capacity for feed intake as the extent of digesta flow from the reticulorumen to the GI tract increases (Freer and Campling, 1963; Pearce and Moir, 1964; Poppi et al., 1980). Nutrient composition of feed, rumen contractions, saliva flow, microbial concentrations, particle size, extent of rumination, and maturity of forages, all contribute to the rate digesta, and will be hydrolyzed and flow from the reticulorumen.

Particle size is instrumental in passage rate. Forage particles that measure three to four millimeters can cause the flow of digesta from the reticulorumen to cease and inhibit intake within the animal (Dixon and Milligan, 1985). Martz et al. (1986) stated particle size must be smaller than 1200 μm before passage though the reticulo-omasal orifice can be achieved. The primary action responsible for the breakdown of forage particles is the mastication process during rumination (Balch, 1971). Roughage sources which have been pelleted or ground have been proven to increase passage rate as cattle spend less time ruminating to break down forage particulate (Laredo and Minson, 1974). Fermentation has less effect on particle size reduction than rumination, but increases the fragility of the digesta. The increase in digesta fragility aids in increasing the effectiveness of mastication (Murphey and Nicoletti, 1984). With decreased particulate size, distension of the rumen will be reduced due to smaller particle sizes and greater passage rate, creating greater opportunity for increased forage intake.

Reticulorumen contractions are vital to ensure that passage rates of ruminant animals maintain at the proper level to ensure adequate DMI is achieved. Rumen motility has a key role in passage rate by controlling eructation of gasses, rumination of feeds, and mixing of digesta and microbes inside the rumen. The relationship of reticular contractions on the passage of digesta to the lower gastrointestinal tract is fundamental in controlling voluntary intake and digestion of roughages within ruminants (Okine and Mathison, 1991). There are two types of reticulorumen contractions that create motility inside the rumen: primary and secondary contractions. Primary contractions move in a backwards cycle and involve a two-stage contraction of the reticulum, immediately followed by a contraction of the left dorsal and right ventral sacs (Weiss, 1953). Primary contractions are responsible for mixing the digesta with the microbial population of the rumen to begin the fermentation process. The second contraction of the primary contraction mechanism is responsible for moving ingesta from the rumen into the omasum, making this process vital for the passage rate of forages. The other set of contractions, known as secondary contractions, are forward-moving ruminal contractions starting at the posterior dorsal blind sac and followed by a pause of varying length (Weiss, 1953). Secondary contractions are responsible for the eructation of gases, and is vital to ensure frothy bloat does not occur for cattle grazing wheat pasture.

Duration and amplitude of reticular contractions are the two main contributors to rumen motility, and have the greatest effect on passage rate (Okine and Mathison, 1991). Greater DMI in ruminants does not initiate additional contractions of the rumen to compensate for the greater fill. However, the duration and amplitude of these contractions become longer allowing ample time for the feed to thoroughly mix and flow to the duodenum for additional absorption. Okine and Mathison (1991) observed an increase in duodenal outflow of 79% to be positively correlated to a 37% increase in the duration of reticular contractions with increased feed intake. During the same study, Okine and

Mathison (1991) also observed an increase in amplitude of reticular contractions by 28% to 44% when quantity of feed intake was increased.

Quantity of Forage

One of the biggest factors contributing to the limitation of a grazing animal's performance and profitability is the amount of forage available for consumption. Wheat pasture provides a nutrient dense forage source for cattle during a season of senescence of native range (Beck et al., 2005; Morgan et al., 2012). As with any grazing system, the productivity of stocker cattle is highly dependent upon environmental factors, such as rain, temperature, soil fertility, and cattle genetics. Cool-season grasses typically follow a biphasic growth curve, in which the forage mass during the fall and winter is much less than during the spring (Beck et al., 2007, 2015; Bowman et al., 2008; Morgan et al., 2012). Herbage mass in the fall can range from 600 kgDM/ha to 2800 kgDM/ha (Redmon et al., 1995; Bowman et al., 2008; Morgan et al., 2012; Beck et al., 2015). Forage masses observed in trials completed by Bowman et al. (2008) showed a linear increase from fall to spring by a range of 2500 kgDM/ha to 4400 kgDM/ha.

To ensure that cattle are allotted adequate forage allowance to achieve desired weight gain, proper stocking rates must be calculated. Hodgson (1990) stated that forage and cattle performance would increase linearly with greater herbage allowance, but will plateau at 10% to 12% of cattle's BW. Forage IVOMD has also been observed to decrease 10% as wheat forage allowance was decreased to low levels of 700 kg/ha (Redmon et al., 1995). Ellis et al. (1984) reported that DM digestibility by steers grazing annual ryegrass was decreased when forage allowance was reduced to less than 30 kg/100 kg BW. Lower levels of critical herbage allowance were observed by Redmon et al. (1995) and Pinchak et al. (1996) with DM digestibility of the wheat declining when forage mass fell below 24.3 kg/100 kg BW and 27.3 kg/100 kg BW, respectively. In a trial conducted by Redmon et al. (1995), cattle consumed 1.5 kgOM/100 kg BW and had an ADG of 0.1 kg with access to 672 kg/ha of wheat pasture. During the same trial, cattle that had access to 2645 kg/ha of wheat pasture consumed 2.9 kgOM/100 kg BW and gained 1.4 kg/day.

Unlike OM and DM digestibility of wheat pasture when mass is limited, fecal output has been shown to remain relatively static. Fecal output ranged from 0.54% to 0.73% of BW and was not influenced by herbage allowance in previous research (Redmon et al., 1995). The observation that fecal output was not significantly different for high and low herbage masses indicate that the cattle are maintaining forage intake through additional methods. Allden and Whitaker (1970) speculated that, as herbage mass decreases, cattle compensate by increasing grazing time. As the extent of forage depletion is increased, steers have been observed to increase feeding station rate (eating steps,min), distance walked while eating, area covered while grazing, and took fewer bites per feeding station (Gregorini et al., 2011).

Results derived from research conducted in the past validate the issue of herbage mass being a strong limiting factor to cattle performance on wheat pasture. Due to the biphasic growth phase of winter wheat, the greater amount of forage growth during the spring months allows producers to stock heavier than during the fall and winter months at 4.9 to 7.4 calves/ha and 1.9 to 3.7 calves/ha, respectively (Bowman et al., 2008; Morgan et al., 2012). Beck et al. (2013) compiled data from eight years of experiments on wheat and found a forage allowance of 3.5 kgDM/kg BW maximized ADG at 1.2 kg/d.

Stocking rates of 1.24 and 1.51 steers/ha have been proven to perform at an equal rate, while steers stocked at a rate of 1.79 showed depressed daily gains (Horn et al., 1995). Beck et al. (2015) observed a decrease in ADG when setting stocking rates based on forage allowance. The report indicated that setting stocking rates using forage allowance based on BW alone may lead to overstocking and suggested metabolic BW be used instead. As stocking rates increase, particularly during the fall, reductions in BW have been seen for stocker cattle (Horn et al., 1995; Morgan et al., 2012). However, BW gain per hectare is linearly increased as stocking rates increase (Horn et al., 1995; Morgan et al., 2012). Economics become an attributor in the decision, when there is adequate forage mass, to increase stocking rates and create more gain/ha but less ADG for cattle.

Effects of Energy Supplementation on Forage Intake and Utilization

Supplementation protocols are often implemented for cattle grazing native forages during the dormant season. Protein is the most popular supplement fed to grazing cattle during the winter season when C4 grasses are senesced. The additional supplementation of protein during winter offsets the protein deficiency of the grass and increases forage intake and utilization (McCollum and Galyean, 1985). Energy supplements are often reported to reduce forage intake in cattle grazing all types of forages. With the high percentages of crude protein found in wheat pasture, energy supplementation could help to “stretch” available forage without hindering the nutrient requirements of the cattle (Horn, 2005). Conversely, if too much energy is supplemented for cattle grazing protein-deficient native range during winter, the reduced intake could potentially lead to inadequate protein levels in cattle. Moore et al. (1999) discovered energy supplements reduced forage intake if the ratio of TDN:CP was less than seven. Energy supplementation can also be utilized to provide a more balanced nutrient supply with expectations of better protein utilization for cattle grazing winter wheat pasture (Horn, 2005).

Numerous mechanisms and hypotheses have been contributed to the reduction of forage intake observed when cattle are supplemented with an energy source. Ruminal pH, VFA concentrations, and bacterial composition are factors attributed to decreased forage intake with the addition of energy to a ruminant's diet.

Ruminal pH.

The pH of the rumen is highly dependent on the diet consumed. A diet largely composed of concentrate feed sources will generally range from 5.8 to 6.6, while a diet largely composed of forage/fiber feed sources will range from 6.2 to 6.8 (Church, 1979). The drop in pH levels for concentrate diets can be attributed to the readily fermentable carbohydrates present in the feed. When the carbohydrates are degraded, volatile fatty acids are created and are responsible for the decrease in pH levels. The pH level of the rumen has a significant effect on the digestion and utilization of fiber in a diet (Mould et al., 1984a; Horn and McCollum, 1987; Caton and Dhuyvetter, 1997). When the pH of the rumen is depressed to levels below 6.0, the cellulolytic bacteria activity, responsible for the degradation of cellulose, begins to decrease due to a reduction in the rate of cell division and growth efficiency of the microbes (Mourino et al., 2001; Dijkstra et al., 2012). At lower pH levels accompanying concentrate diets, a ruminal bacteria shift can occur to favor greater populations of amylolytic bacteria and less cellulolytic bacteria (Russell and Dombrowski, 1980; Caton and Dhuyyetter, 1997).

The consumption of energy supplements with readily fermentable carbohydrates can impact forage digestion by lowering the pH levels inside the rumen, or by a "carbohydrate effect" (Mould et al., 1984a). In a study completed by Mould et al. (1984a), the rumen pH of steers being supplemented with barley on a forage diet was linearly decreased as the percentage of barley in the diet increased. The ruminal pH of the steers ranged from 6.8 to 5.3 as the levels of barley in the diet went from 0% to 100%. Dry matter digestibilities were also reduced from 51% to 24% for an all-hay diet and a 75% barley diet, respectively (Mould et al., 1984a). Loy et al., (2007) found that steers consuming ad libitum grass hay, while being supplemented energy at 0.4% and 0.8% of BW, had repressed ruminal pH levels and hay DMI compared to the control group. Within the "carbohydrate effect", carbohydrates are rapidly broken down into volatile fatty acids (VFAs) suppressing the pH level along with hindering the buffering effect of saliva inside the rumen (Dijkstra et al., 2012). Energy supplementation is rapidly masticated, relative to forage particles, and can reduce the amount of saliva traveling to the rumen. When saliva production is hindered, phosphate and bicarbonate buffers traveling to the rumen become suppressed and pH levels can become harder to maintain. Mould et al., (1984b) conducted a trial observing the effects of supplementing bicarbonate salts to diets with various energy and forage as a buffer for pH level. Results from the trial indicated that fiber degradation may be maintained, as energy levels of the diets increase, if an additional buffer is added to counteract the lower level of saliva buffers available in the rumen.

When energy supplementation causes the pH of the rumen to be depressed to levels below 5.7, the degradation of VFAs creates a buildup of lactic acid from lactate-utilizing microbes. Optimal pH for lactic acid forming microbes occurs when levels fall below 5.5 (Counotte and Prins, 1979). As the pH levels of the rumen begin to decline towards levels seen in concentrate-fed diets, lactate-utilizing microbes become more abundant and active creating a buildup of lactic acid that can lead to acidosis in the cattle (Dijkstra et al., 2012). Lactate-utilizing microbes are typically observed at a greater rate when the VFA production inside the rumen shifts from acetate and/or butyrate to a greater proportion of propionate. This shift can be observed in cattle consuming diets that are more energy dense. VFA absorption is also hindered by lower ruminal pH values and can contribute to the buildup of lactic acid within the reticulo-rumen (Dijkstra et al., 1993; Dijkstra et al., 2012). Harmon et al. (1985) explained that as bouts of low pH are repeated in an animal, the absorptive capacity of VFAs through the ruminal epithelium will decrease. The depression in absorptive capability of the epithelium can create a buildup of acid inside the rumen, causing lower pH values and subsequent acidotic issues in the animal. Cattle exposed to repeated bouts of lower pH can become "chronics", due to the decreased absorptive capabilities of the rumen epithelial lining, and may have reoccurring bloat issues.

VFA Concentrations

Cattle consuming a roughage-based diet will maintain a fairly stable VFA concentration in the rumen. The concentration of VFAs consist of the ratio between moles of acetate:propionate:butyrate and can be observed at 65:25:10 and 50:40:10 for roughages and concentrates, respectively (Owens and Goetsch, 1988). Energy supplementation can have a direct, or indirect, effect upon the concentration of volatile fatty acids in the rumen. High energy supplementation can create greater amounts of propionate inside the rumen

(Hess et al., 1996). The depressed pH effect, often observed with energy supplementation, can have an indirect effect on VFAs by increasing fermentation of the rapidly degradable carbohydrates and shifting production from acetic and butyric acid to propionic acid (Dijkstra et al., 2012). Volatile fatty acids are a major end product of ruminal fermentation and while a portion are downregulated through the GI tract alongside digesta, the majority of VFAs are absorbed through the rumen epithelium (Foote, 2019, personal communication). VFA concentration in the rumen is highly variable, between 60 to 150 mM, depending on the diet and time from feeding (Bergman, 1990). Maximum VFA levels are generally observed between 2 - 4 hours after feeding (Barcroft et al., 1944).

There are three major VFAs that contribute to the animal's energy demands through different physiological pathways. Butyrate is used as a fuel source by the epithelium to remove VFAs from the rumen (Kristensen, 2005). Conditions that stimulate the formation of butyric acid can results in lower acid formation inside the rumen, helping to prevent low pH levels and subsequent digestion issues (Dijkstra et al., 2012). Acetate is used as a precursor for acetyl-CoA, which is vital to all oxidative processes of the body (Bergman, 1990). Propionate has the greatest effect on forage intake, as this fatty acid is the only VFA contributor to glucose synthesis in cattle (Bergman, 1966). With the creation of glucose, propionate has a higher caloric density potentially allowing the animal to consume less feed to meet energetic needs.

Loy et al. (2007) observed a greater concentration of VFAs produced in the rumen of cattle consuming an energy supplement while consuming ad libitum access to grass hay. The production of propionate in the cattle was also increased for the supplemented groups when compared to the control groups of the trial. Monensin supplementation has also been proven to increase the level of propionate produced in ruminant animals, creating DMI decreases in cattle consuming roughage and concentrate-based diets. Branine and Galyean (1990) did not observe any changes of VFA concentrations from energy supplementation, but higher levels of propionate were produced with the addition of monensin to the diet. The VFA shift to propionate with the use of energy or monensin supplementation can improve the energy efficiency of ruminants, while grazing or consuming a less energy-dense diet (Cravey, 1993).

Bacterial Composition

The microbial population of the rumen is highly dependent upon diet and pH level. Two major bacterial groups predominate in the rumen, cellulolytic and amylolytic bacteria. The major cellulolytic species responsible for the degradation of cellulose are *R. albus, R. flavefaciens* and *B. Succinogens,* with *B. Succinogens* being the most active species (Lin et al., 1985). These enzymes are responsible for the hydrolysis of cellulose found in forage based diets and produce a greater amount of acetate. A few major amylolytic enzymes responsible for the hydrolysis of starch are *R. amylophilus, S. bovis,* and *S. Ruminatium* (Cotta, 1987). The end-products of starch degradation consist of a larger ratio of propionate to butyrate and acetate.

In a study completed by Wanapat and Khampa (2007), data indicated the rate of carbohydrate digestion can be a major factor in controlling the energy available for growth of rumen bacteria. The study also concluded high soluble fractions of starch and sugar can be added to diets to increase the utilization of ruminal ammonia nitrogen for microbial protein synthesis. As the level of concentrate supplementation was increased from zero to three percent of body weight, the bacteria population was decreased from

1.1 X 10^{11} to 0.8 X 10^{11}. Both the proteolytic and amylolytic bacterial increased as higher levels of concentrate were added to the diet, while the cellulolytic species were decreased.

Ammonia nitrogen can be attributed to being the main source of nitrogen for bacterial protein growth and synthesis (Hoover, 1986; Wanapat, 2000). Previous research has shown when adequate levels of ammonia nitrogen are present, incorporating a concentrate supplement can increase the nitrogen concentration, resulting in bacteria growth and synthesis (Wanapat and Khampa, 2007). Increased bacterial efficiency can lead to optimum fermentation and utilization of high quality forages.

Associative Effects

An associative effect can take place in ruminant nutrition when two or more feedstuffs are fed at varying proportions. The effect can be either positive or negative, but very rarely results in a linear response for the digestibility and energy values of the diet. The differences between feedstuffs in digestibility and net energy when fed together creates the associative effect (Rust, 1983). Nutrient deficiencies or imbalances in diets, particularly in certain seasons of the year, generate the need for supplementation that would create a positive associative effect. Other research has discovered various nutrient proportions, when fed at certain rates, can create a negative associative effect in cattle.

Vast research has been conducted with cattle grazing low-quality roughages during the dormant season and the effects of supplemental protein. Positive associative effects have been found when supplementing protein for cattle grazing roughages that contain 6% to 8% crude protein (Campling, 1970; DelCurto et al., 2000). The positive effects include; increased body weights of cattle, increased weaning weights of calves, increased milk production, increased conception rates, increased body condition scores, increased calf birthweight, and decreased calving intervals (Cochran et al., 1986; Judkins et al., 1987; DelCurto et al., 1991). However, to achieve an increase in performance from protein supplementation with low-quality forages, forage availability cannot be limited (Rittenhouse et al., 1970).

In most research, supplemental energy in diets of low-quality roughage has produced a negative associative effect. Energy supplementation has proven to decrease intake and digestibility of senesced forage by replacement or substitution (DelCurto et al., 2000). However, when forage is limited during the dormant season, energy supplementation can be a viable option to ensure that cattle are receiving adequate energy levels in the diet. Clanton and Zimmerman (1970) reported depressed heifer gain when supplemental energy was added to a low-quality forage with inadequate protein levels.

Positive associative effects have been observed for energy supplementation of diets that contain high-quality forage with an abundance of protein. Clanton and Zimmerman (1970) discovered a protein and energy interaction in which heifer gains were increased with energy addition when protein levels of the forage was high. Energy supplementation for stocker cattle grazing winter wheat pasture has proven to achieve a positive associative effect under particular conditions. Dietary carbohydrate addition to wheat pasture diets have reduced the concentration of ruminal ammonia nitrogen, thereby increasing ammonia nitrogen incorporation into microbial protein (Branine and Galyean, 1990). ADG has also been shown to increase with the utilization of a concentrate supplement to stocker steers grazing ryegrass (Grigsby et al., 1991). Greater increases in body weight in relation to energy supplementation have been observed in trials that have less herbage mass (Lippke et al., 2000). Negative associative effects can be observed for energy supplementation on wheat pasture if the supplementation levels are too high and reductions in rumen pH level were to occur. Wanapat and Khampa (2007) observed a ruminal pH decrease to 5.7 when 3.0% of BW was supplemented in the form of a readily fermentable carbohydrate. A pH level under 6.0 will hinder the activity of cellulolytic bacteria and decrease the digestibility of the wheat pasture.

Substitution of Energy Supplements for Forages

The relative decrease in forage intake often observed in cattle receiving energy supplementation can be deemed a "substitution effect". Factors responsible for the rate at which a substitution ratio will occur include; quality of forage, quantity of forage, amount of energy supplement, and the breed of cattle (Cravey, 1993).

Jarrige et al. (1986) completed a data review to create a method to predict voluntary intake of forage-based diets in ruminants. The data observed an increase in the substitution ratios for energy supplements in the diet as the digestibility of the forage decreased. Concentrates were added to the diet at rates of 10% to 50%. At all levels, the substitution rate decreased as the "forage fill value" or maturity increased. In a review conducted by Horn and McCollum (1987), results indicated that as forage digestibilities increased, the substitution ratio associated with energy supplementation decreased. During a trial of cattle grazing native tallgrass prairie throughout the month of August, a decrease in forage intake was observed when corn supplementation exceeded 0.55 g/100g BW (Mieres and McCollum, 1992). Ulmer et al. (1990) observed a decrease in consumption of medium-quality hay when barley supplementation was greater than 1.0 kg a day. Substitution ratios are higher for forages of lesser quality than those of higher quality. Branine and Galyean (1990) assisted in proving prior observations of substitution ratios being greater for lower quality forages. Forage DM intake observed during the trial was not influenced during any sampling period until the month of May. During the month of May, wheat nutrient values were lower than all other sampling periods, creating a greater substitution effect between the grain supplement and the wheat pasture.

Limited high-quality forage mass has proven to increase substitution ratios associated with energy supplementation. Cravey et al. (1992) reported substitution ratios of -0.86 for high-starch and high-fiber energy supplements. These results indicate that for each kg of supplement fed, DMI of wheat pasture was decreased by 0.86 kg. Other substitution values have been observed at a level of 0.66 in studies supplementing silage to stocker cattle grazing winter wheat pasture (Vogel et al., 1989). The greater substitution ratios observed for energy supplementation when wheat forage is limited indicates a potential for utilizing supplementation to conserve forage mass.

The substitution effect, and the mechanisms associated with it, can be partially explained by the energy content in the diet and supplement. As concentrate supplementation is added to the diet, cattle can receive adequate amounts of energy while decreasing intake of forage. The NASEM (2016) indicates that as concentrates increase in the diet, efficiency of energy use for maintenance and gain increases. Reductions in forage intake can be compensated partially by the changing efficiencies of ME use (Caton and Dhuyvetter, 1997).

Another mechanism that can contribute to the substitution ratio is the amount of time cattle spend grazing based upon forage quantity. Adams (1985) observed that as energy supplementation increased, the amount of time spent grazing decreased. Cattle that spend less time grazing will have reduced energy expenditures and can have decreased maintenance energy requirements. Sheep that obtained forage by grazing had 30% greater energy requirements than sheep that were fed in confinement (Osuji, 1974). The difference in energy usage can be attributed to muscular work of the animal, specifically the work of eating, standing, and walking (Caton and Dhuyvetter, 1997). The amount of forage available can also influence the energy expenditure in animals. Energy supplementation has proven to have a greater substitution effect when adequate levels of forage are available to the animal. As forage availability decreases, the amount of time that cattle spend grazing can increase dramatically, creating greater energy requirements. Therefore, any management or environmental factor that affects grazing time or forage availability can potentially alter energy expenditure for maintenance (Caton and Dhuyvetter, 1997).

Breed can have an effect on the substitution ratio of energy supplementation for a forage-based diet. Larger, more productive cattle are typically observed to have greater energy requirements for maintenance and work. Laurenz et al. (1991) observed that breed differences in energy requirements varied and dependent upon the season of year. Angus cattle had greater energy requirements than Simmental cattle during the summer months, but lower in the winter months. However, for the entire year, Simmental cattle had the greatest amount of energy for maintenance requirements. NASEM (2016) explains when cattle gain weight more efficiently and/or have higher lactation abilities, greater maintenance energy requirements occur. Cattle of the *B. indicus* breed have a 10% lower energy requirement for maintenance than those of the *B. taurus* breed makeup.

High-Fiber Energy Supplements vs. High-Starch Energy Supplements

Prior research compared high-fiber energy supplementation with high-starch energy supplementation, observing benefits and detriments of each. Considerable interest has shifted to utilizing a higher fiber-based energy supplement for cattle to avoid the complications occasionally observed from starch-based supplementation. Fiber-based energy supplements, wheat middlings, corn gluten feed, soybean hulls, and rice bran, have proven to provide an excellent source of energy, while not providing the complications that can accompany feeds high in starch content.

High-Fiber Energy Supplementation

Many research trials have utilized fiber-based energy feed sources for supplementation of cattle. The fiber composition of the feed can help to minimize fermentation issues that can be observed from the use of energy supplements. High-fiber energy sources have proven to contain comparable energy values to those of high-starch sources. In a study conducted by Horn et al. (1994), an energy supplement consisting of soybean hulls and wheat middlings produced NEm and NEg values of -0.37 Mcal/kg and +0.18 Mcal/kg, respectively, when compared to the high-starch supplement. The starch content of the soybean hull/wheat middling feed was 18% of the DM in relation to 67% of DM for the high-starch supplement.

Cattle performance has proven to be similar for fiber-based and starch-based energy supplements. In one study, the high-fiber supplement produced 13 additional pounds of gain over the high-starch supplement during a 115-day trial for steers grazing winter wheat (Horn et al., 1995). Previous research also indicated a difference in forage intake for higher fiber-based energy supplementation. During a trial supplementing corn and corn gluten feed to cattle grazing fescue grass, intakes were reduced by 19% for the corn supplementation but no decrease in DMI was observed for the corn gluten feed treatment groups (Patterson et al., 1988).

High-Starch Energy Supplementation

Energy supplementation of cattle with feed sources higher in starch content, such as corn, typically must be carefully formulated to ensure that no fermentation issues occur. With higher amounts of readily fermentable carbohydrates in the diet, rumen pH will be depressed, lowering the digestibility of forages. However, high-starch energy supplementation is not usually fed at high enough rates for significant digestibility issues to occur. In a study conducted by Branine and Galyean (1990), stocker cattle grazing winter wheat were supplemented 0.5 kg/hd/d of a grain-based energy supplement. The largest difference in pH level of the rumen, in comparison to the control, for the entirety of the trial was 0.1 higher for grain supplementation.

A decrease in DMI of forages is common when supplementing a high-starch energy supplement. The decrease in forage intake could derive from the greater level of NE_m in the feed-source. A 0.37 increase in NE_m was recorded in relation to a high-fiber energy supplement in a trial conducted by Horn et al. (1994). The corresponding result on DMI portrayed a decrease for steers receiving the high-starch supplement. After a 54-day trial period, the forage mass in the high-starch supplement treatment had increased by 210 kg/steer from the initial starting mass. The forage mass in the same study had decreased by 190 kg/steer, from the initial forage mass, in high-fiber supplement treatment group.

Energy Supplement Conversion Ratio

Energy Supplementation protocols must take into account the feasibility of price versus the additional performance produced in cattle. A supplement conversion ratio may be calculated to ensure the additional profitability produced from the utilization of an energy supplement exceeds to input costs of the feed. The added gain achieved from the use of a supplemental feed can be considered a supplement conversion ratio. The ratio will be calculated as kilograms of supplement, as-fed, per kilogram of increased gain per hectare (Horn et al., 1995).

Previous research reported supplement conversion ratios between a broad range of 3.0 to 10.3 kg of supplement fed per kg of additional gain produced (Utley and McCormick, 1975, 1976; Gulbransen, 1976; Grigsby et al., 1991; Horn et al., 1995, 2005; Fieser et al., 2007). Older data from research conducted before the use of ionophores achieved supplement conversions ratios of 5.6 to 10.3 kg of supplement per kg of additional gain (Utley and McCormick, 1975, 1976; Gulbransen, 1976). In recent studies, the utilization of monensin in energy supplements have produced conversion ratios of 2.4 to 6.4 (Horn et al., 1995, 2006; Fieser et al., 2003, 2007). The larger supplement conversion ratios observed in older literature have been hypothesized to result from the absence of monensin technology in feed (Horn et al., 1995). This assumption was derived from results indicating that heifers fed monensin had 0.08 kg greater gain than those fed only an energy supplement (Horn et al., 1981, 1995). Fieser et al. (2005) found that by increasing monensin intake concentration from 100 to 188 mg supplement conversion ratios were decreased by 1.3 kg of supplement needed to produce an additional kg of gain. Another study reported depressions in conversion rates, from 9.8 to

4.3, when 110 mg of monensin was added to an energy supplement fed at a rate of 0.91 kg/hd/d (Horn et al., 1981). In a two-year study conducted by Fieser et al. (2007), year one produced excellent supplement conversion ratios of 2.7 and 3.5 for an Oklahoma Green Gold supplement and a soybean hull plus monensin mineral supplement, respectively. However, in the second year of the trial, conversion ratios were 20.5 and 14.7, over four to five times the typical conversion rates. The study found that in years of excellent daily gains of wheat cattle, energy supplementation may not induce much additional gain.

Studies reporting supplement conversion ratios have various results for the performance of high-starch and high-fiber energy supplementation efficiencies. Horn et al. (1995) observed that steers gained an additional kg of weight with the addition of 5.9 and 4.8 kg of a high-starch and high-fiber energy supplement, respectively, during year one of the trial. Throughout the same three-year study, cattle gained an additional kg of weight with the addition of 2.4 and 3.3 kg of a high-starch and high-fiber energy supplement, respectively. Fieser et al. (2007) reported higher supplement conversion ratios for a soybean hull and medicated-mineral energy supplement than the Oklahoma Green Gold energy feed. The soybean hull/medicated-mineral supplement utilized 2.5 kg less feed to produce 1 kg of gain than the Oklahoma Green Gold feed during the two-year study.

The volatility of supplement conversion ratios in past literature can be indicative of the importance of creating a supplement having a low conversion rate to ensure increased cattle gain exceeds feed and labor costs of the supplement. When observing the economics of feeding Oklahoma Green Gold at a rate of one pound per day, results indicated additional steer gains of 0.25 pounds per day at a cost of $0.214 per pound of improved gain (Fieser et al., 2003). The improvement in gain was achieved at a supplement conversion ratio of 3.6 pounds of supplement fed per pound of additional gain. Within an average 125-day stocking period for cattle grazing winter wheat pasture, an additional 31 pounds of gain would be achieved through the supplementation protocol at a price of $6.69. Taylor et al (2007) discovered a $6.00 per head increase from the utilization of Oklahoma Green Gold supplementation for cattle grazing winter wheat pasture. An increase of $15 to $31, depending on the price structure and profit potential of the cattle, was observed when an energy supplement produced a 5.0 supplement conversion ratio (Horn et al., 2005).

Effects of Energy Supplementation on Performance of Cattle Grazing High-Quality Pastures

Energy supplementation for cattle grazing winter wheat pasture has become an area of interest to help dissipate the volatility of seasonal cattle prices and fluctuating forage masses observed throughout the years. Previous research has proven supplementation of carbohydrates to increase average daily gains, decrease DMI of forage/increase stocking rates, increase the utilization of excess protein in the wheat pasture, and decrease bloat incidences (Lake et al., 1974; Branine and Galyean, 1990; Horn et al., 1995, 2005; Fieser et al, 2003).

Increased Nitrogen Utilization

The composition of high-quality nutrients found in winter wheat pasture can be attributed to the large ADGs achieved by stocker cattle. The volatility of herbage mass in winter wheat pasture has created an interest in utilizing energy supplementation protocols to maximize the usage of excess nutrients in the forage. Previous publications have proven that through the utilization of energy supplementation, wheat forage can be conserved in years of little rain and low forage mass (Horn et al., 1995, 2005; Fieser et al., 2007). The assumption for utilizing energy supplementation in the diet of cattle grazing wheat pasture involves a greater usage of the excess nitrogen available in the forage for the microbial population in the rumen to utilize.

High-quality forages, such as wheat, have a high nitrogen to digestible organic matter ratio (Cravey, 1993). Vogel et al. (1987) reported that 50% to 75% of nitrogen in wheat pasture disappeared from the rumen at a rapid rate of 13% to 28% per hour. The rapid rate of nitrogen disappearance from the rumen indicated that the utilization of small amounts of energy supplementation may increase microbial protein synthesis by reducing the nitrogen/digestible organic matter ratio (Cravey, 1993). Lake et al. (1974) observed decreases in ruminal ammonia nitrogen with the addition of supplemental carbohydrates. The decrease of ammonia nitrogen inside the rumen created an assumption of increased nitrogen utilization from the addition of the energy supplement. Branine and Galyean (1990) reported similar finding when supplementing wheat pasture steers a daily grain supplement or a daily grain supplement with the addition of 170 mg of monensin. Rumen samples were obtained -4, -1, 2, 5, 8 after supplementation of grain to measure ammonia nitrogen concentrations. Results from the study indicated a decrease in ruminal ammonia nitrogen concentrations with the addition of the grain-only supplement. Thus, suggesting that through the addition of a carbohydrate, nitrogen in the rumen was reduced by a reciprocal increase in ammonia nitrogen incorporation into microbial protein.

Increased Average Daily Gains

Literature from pasture research observed a positive response in daily gains with the addition of an energy supplement, with or without the addition of an ionophore, to cattle grazing winter wheat pasture. Many trials reported a positive increase in gains, while additional studies reported no effect on cattle gains. Elder (1967) observed a 0.05 to 0.21 kg/d increase in weight gains when steers were supplemented 2.27 to 2.72 kg/d of corn or grain sorghum. During a three- month sampling period, Branine and Galyean (1990) reported a 0.9 kg/d increase in weight gains with the utilization of 0.5 kg/hd/d of a grain supplement. A four-year study conducted in Oklahoma reported averages of 0.14 kg of increased daily gains for steers supplemented with 2.5 kg/d of grain (Wagner et al., 1984). Utley and McCormick (1976) observed a 0.19 kg/hd/d increase in weight gains of steers grazing rye pasture with the addition of 5.91 and 5.85 kg of grain sorghum and corn, respectively. The level of supplementation in the trial was much larger than most studies, however, stocking densities were doubled for the supplemented groups. Steers grazing wheat and receiving 0.4 kg/hd/d of Oklahoma Green Gold supplementation produced an additional 0.11 kg/hd/d at a stocking rate of 1.7 acres/steer (Fieser et al., 2003). The supplemental groups had a total increased weight gain of 13.2 kg for the 120 day study. Many producers will supplement a non-medicated, free-choice mineral to stocker cattle on wheat pasture. To observe the differences in production of non-medicated mineral and an energy supplement with monensin, Fieser et al. (2007) completed a two-year trial at the Oklahoma State University Wheat Pasture Research Unit. Results indicated through the utilization of monensin and energy supplementation, an additional 0.18 kg/hd/d could be achieved in cattle grazing wheat pasture in relation to a non-medicated, free-choice mineral. Previous research produced data suggesting smaller amount of energy supplementation could potentially be more beneficial for daily gains. Rouquette et al. (1990) found that when feeding a corn-based supplement to cattle grazing ryegrass at 0.3% and 0.6% of body weight, ADGs were 0.04 kg greater for the 0.3% supplemented group than the 0.6% group. With these results, cattle could potentially gain more on less feed, creating an economic benefit for both the additional pounds of gain produced and the decrease in feed costs.

Increased Stocking Rates

Through the utilization of energy supplementation in past research, increased stocking rates have been proven achievable due to the decreases in forage intake accompanying the supplementation. When adequate forage is available for cattle grazing wheat pasture, a depression in DMI has been observed through carbohydrate supplementation. Lippke et al. (2000) reported a decrease in forage intake of steers grazing winter wheat pasture at a rate of 9 g of wheat per kg of BW when supplemented 8.5 g of steam-rolled corn grain. These results indicated that forage intake was likely reduced by an amount equivalent to corn intake. Results indicating a substitution ratio for energy supplementation and forage allow producers to consider stocking wheat pasture at heavier rates on the basis of decreased forage intake. Horn et al. (2005) states that 0.75% BW of energy supplementation could be utilized to increase stocking rates by one-third as long as adequate forage mass is available. The study deemed sufficient herbage mass to occur at a level of 20 to 30 kg DM per 100 kg BW. In Horn (2006) wheat cattle herd health and management review, increased stocking rates of 1.25- to 2.0-fold were reported through the use of energy supplementation at levels of 1% to 1.5% of BW. Utley and McCormick (1976) increased stocking rates from 1.3 ha/steer to .67 ha/steer and still observed increased ADG with the utilization of 5.88 kg of energy supplementation.

Depression in Bloat Incidences

Bloat prevention is a vital management tactic for producers grazing cattle on winter wheat pasture. Estimates of 2% to 3% death loss from bloat have been recorded for the millions of cattle grazed on wheat pastures throughout the Southern Great Plains (Clay, 1973). The abundance of soluble-protein in wheat pasture, and its rapid release inside the rumen, have been identified as precursors of frothy bloat (Bartley et al., 1975). Prior studies conducted to find methods to mitigate bloat issues associated with wheat forage have discovered positive effects of utilizing energy supplementation and monensin. In the study conducted by Branine and Galyean (1990), cattle were supplemented energy with a grain-only feed or a grain plus 170 mg of monensin feed. The cattle allotted to grain-only treatment groups had a 5% decrease in bloat incidence than those within the control group, as well as lower bloat scores. Cattle that received grain and monensin had a 24% decrease in bloat occurrences and lower bloat scores throughout the duration of the trial. The authors assumed that monensin's bloat depression effect was largely driven by the fact that the ionophore maintained a higher ruminal pH above that required for foam stability and growth. A pH range of 5.2 to 6.0 has been reported as an optimal range for maximum foam strength for most forage proteins (McArthur and Miltmore, 1969).

High-Fiber energy supplementation has resulted in higher ruminal pH levels than that of a concentrate-based energy source. Anderson et al. (1988) recorded the lowest pH level, for a diet consisting of 75% corn stalks and 25% soybean hulls, to be 6.15 at eight hours post-supplementation of soybean hulls. When the cattle were fed 25% corn supplement while grazing the corn stalk forage, a pH low of 5.90 was observed at eight hours post-feeding of the corn. Although the trial was conducted on a low-quality to medium-quality forage diet, the results indicate that utilizing a fiber-based energy diet will be more advantageous to decrease bloat incidences in wheat cattle.

Monensin has become a very popular product in mitigating frothy bloat occurrences in cattle grazing winter wheat. Observations from previous trials have indicated that ionophores, in particular monensin, have proven to reduce ruminal frothing and subsequently ruminal bloating by minimizing the entrapment of gases (Branine and Galyean, 1990). Paisley and Horn (1998) administered boluses to cattle grazing wheat forage at a level of 300 mg of monensin per day and recorded subsequent bloat scores. There was a 50% decrease in the number of steers bloated of the cattle that received a monensin bolus, in relation to the control group. The mean bloat score for cattle in the control group was 0.88, while the mean for the monensin-treated group was 0.05. There was a trending effect for the utilization of monesin and the mean bloat score per steer ($P = 0.097$). A rise in pH levels associated with monensin supplementation has also been attributed to helping decrease the incidence of bloat in wheat cattle. Horn et al. (1981) measured the rumen characteristics associated with supplementing monensin to cattle grazing wheat forage. In trial one, treatment cattle receiving 200 mg of monensin per head per day had a significant increase in pH levels at 4 hours post-feeding. The pH levels in the rumen four hours after supplementation were 0.53 higher than the control, reaching highs of 6.75.

Effects of Forage Allowance on Energy Supplementation Response in High-Quality Forages

Little research has been conducted in past literature to indicate the effect of forage mass on the utilization of energy supplementation for cattle grazing winter wheat pasture. The volatility associated with forage mass of wheat pasture from year to year presents the need for a better understanding of supplementation protocols to help hedge this risk. Previous research has found critical points of initiating supplementation protocols at certain levels of forage mass, but the question of forage mass influence on supplementation response still remains. The dairy industry, however, has researched the effects of herbage allowance and energy supplementation on the lactation, DMI, grazing behavior and body condition scores of cattle. This data can give insight on a few effects observed from the interaction of forage mass and energy supplementation on cattle performance.

McEvoy et al. (2008) conducted a trial observing the interaction of various levels of energy supplementation and herbage allowances for cattle grazing high-quality native range during the spring and early-summer months. Supplement levels were implemented at 0 kg DM, 3 kg DM, or 6 kg DM of a concentrate fed daily to dairy cattle. The herbage allowances in the study were either 13 kg DM/d or 17 kg DM/d. A significant difference was observed in the herbage mass removed between the high and low forage allowance groups according to level of supplementation ($P < 0.001$). Cattle receiving 6 kg DM/d of concentrate supplementation in both forage allowance treatments decreased DMI by more than 1.0 kg/hd/d. The body condition scores (BCS) of the cattle were greatest for the treatment groups receiving 3 kg DM/d of concentrate supplement. Cattle in the highest energy supplementation group had lower average BCS than the control groups for both forage allowance treatments, indicating that a smaller quantity of supplement may be more beneficial to weight gain.

Pulido et al. (2010) conducted a study with dairy cattle grazing a high-quality ryegrass pasture at two daily herbage allowances of 25.5 kg DM or 38.5 kg DM. The groups were supplemented with a beet pulp-based concentrate supplement or a corn-based concentrate supplement at a level of 4.3 kg/d. No significant differences were observed in BCS from pasture allowance or supplementation. Cattle consumed 0.5 kg/d less pasture for the beet pulp supplement than the corn-based supplement. However, there was no significance observed for concentrate supplementation effect on pasture intake or grazing behavior. The lack of significance for supplementation during the study indicates that grazing management may be more beneficial than supplementation protocols.

The interaction of forage allowance and energy supplementation within dairy cattle will differ greatly from that in stocker cattle. Dairy cattle have significantly greater energy requirements due to size, lactation, and gestation needs of the animal. Further research is needed to observe the effect of herbage allowances and energy supplementation on the performance of stocker cattle grazing winter wheat pasture. With new data, energy supplementation strategies based upon levels of forage mass present within an operation can create new feed strategies for producers. Improved supplementation protocols would potentially allow producers to achieve optimum cattle performance and profit.

Use of Titanium Dioxide as an External Marker for Estimating Forage Intake in Grazing Ruminants

Forage intake data has been collected in past research utilizing external and internal markers that are completely indigestible to ruminants. Previous literature used chromic oxide (Cr_2O_3) as an external marker to measure forage digestibility in cattle. However, in recent years Cr_2O_3 has been outlawed because the FDA has not approved it as a dietary additive due to the presence of carcinogenic properties (Titgemeyer et al., 2001; Mioto da Costa et al., 2019). Research indicated recoveries of Cr_2O_3 utilized as an external marker was not 100% (Western Regional Coordinating Committee, 1980). Due to the variation in fecal recovery from Cr_2O_3, titanium dioxide (TiO_2) started to be used as an external marker for digestibility studies in ruminant animals. Forage intake can be estimated by subtracting out any additional feedstuffs from the total fecal excretion and dividing by the forage indigestibility percentage (De Souza et al., 2015).

To obtain a stable dosage of TiO_2 inside the rumen of cattle, a 14-day dosing period is recommended to create a stable flow of the external marker (De Souza et al., 2015). During this dosing period, the first ten days is an adaptation period, followed by a four-day fecal sample collection period. When TiO_2 was compared to the utilization of Cr_2O_3 in a digestibility trial completed by De Souza et al. (2015), the mean bias for chromic oxide was greater than that of TiO_2. The mean bias of forage intake estimated with the TiO_2 marker was -0.012 and -0.12 was reported for the Cr_2O_3 marker. Both markers used within the trial underestimated dry matter and organic matter digestibilities within the cattle. The DM and OM digestibilities calculated utilizing Cr_20_3 were underestimated by 3.5% and 3.8%, respectively. Glindemann et al. (2009) found that using TiO_2 as an external marker in sheep resulted in a mean fecal recovery of 95.9% to 108.8% between all diets. These recoveries were much higher than Titgemeyer et al. (2001) found for cattle on a forage diets where mean recovery rates were 90% to 95%. TiO_2 fecal recovery obtained from day one of administering an external marker to the sheep increased from 31.9% to 98.5% on day five of dosing (Glindemann et al., 2009). This data suggests the smaller size of sheep can cause the adaptation period to be cut in half in relation to cattle.

Various methods for analyzing external markers concentration in fecal samples have been conducted in past literature. Once obtained, fecal samples are generally dried at 50 to 60 ℃ for 36 to 72 hours in an air forced open, and ground through a 1 mm screen (Titgemeyer et al., 2001; Glindemann et al., 2009; De Souza et al., 2015). One of the earliest published methods of qualifying TiO_2 concentrations in samples was completed by Njaa (1961) and involved digesting 0.5 g of a sample in concentrated H_2SO_4, in the presence of a copper catalyst, at 420℃. An addition of 30% H_2O_2 was then added to the mixture and results were measured at 408 nm. Leone (1973) utilized the AOAC method which involved ashing 10g of a TiO_2 concentrated sample, adding 1.5 g of anhydrous Na_2SO_4, cooling sample, adding 10 ml of H_2SO_4, diluting with 100 ml of distilled water and making aliquots that were measures at an absorbency of 408 nm. In more recent studies, Meyers et al. (2004) combined the wet-ash digestion of samples by Njaa (1961) with the addition of H_2O_2 as completed by Titgemeyer et al. (2001) to create a reaction which produced an orange/yellow color and can be read at an absorbency of 410 nm. Recent work utilizing portable X-ray fluorescence spectroscopy as a rapid test for quantifying TiO_2 levels in sunscreen products have given insight to a new technology to find external marker concentrations in fecal samples (Bairi et al., 2016). The method produced good linearity ($r^2 > 0.995$) for the analysis of titanium, indicating a strong potential for usage in ruminant digestibility trials utilizing metal external markers.

Summary of Review of Literature

The stocker cattle industry is one that is very volatile from year-to-year and dependent upon an assortment of factors. Due to this volatility, vast research has been conducted with interest in decreasing the risk associated with running stocker cattle on wheat pasture. Energy supplementation has proven to assist in hedging these risks associated with the industry by increasing ADG, stocking rates, and decreasing bloat incidences. Energy supplementation has also proven to assist is stretching inadequate forage masses during years of drought and harsh weather. Little research, however, has been completed to look into the interaction of forage allowance and supplementation on the subsequent performance of stocker cattle grazing winter wheat pasture.

Ruminal mechanisms involved with energy supplementation have proven to be effective on intake in cattle grazing wheat forage. By adding energy to the diets, cattle consumed less forage while maintaining the same level of performance. Previous research established ratios for energy supplement substitution for wheat forage, but more investigation is needed to examine the effects of forage masses on these ratios. Results from previous literature found that substitution effects are greater when there is adequate forage available for consumption. More research is needed to find details on substitution ratios associated with limited forage mass scenarios.

Supplement conversion ratios for energy supplementation are also of interest to ensure that the feasibility of such protocols can be obtained for producers to make a profit. Past research indicated lower conversion ratios for scenarios with less forage mass due to the greater additional gain achieved from supplementation rather than forage intake. More data is needed to observe the differences in supplement conversion ratios of energy supplementation when forage masses are abundant and limiting. This type of data could allow producers to implement supplementation strategies at the most opportune time to ensure maximum profit

CHAPTER III

EFFECTS OF FORAGE ALLOWANCE AND SUPPLEMENTATION ON PERFORMANCE OF STEERS GRAZING WINTER WHEAT PASTURE

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ABSTRACT: A study was conducted over two fall/winter wheat grazing seasons (2018 – 2020) to estimate the combined effect of forage allowance and a fiber-based energy supplement in stocker cattle grazing wheat. Eight pastures (2.7 to 5.1 ha) were stocked with seven test steers (initial BW = 210 ± 36 kg). Weekly, additional steers were added or removed in each pasture, a put and take method, to achieve forage allowance of either 1.5 or 3.0 kg forage DM / kg steer BW (4 pastures each). Two pastures in each forage allowance were fed daily with a supplement containing 50% wheat middlings and 50% soybean hulls at the rate of 1.5 kg (as fed) per steer. Forage mass was measured twice weekly using a calibrated rising plate meter. Cattle were weighed weekly on calibrated scales. Data were analyzed using linear regression with pasture as the experimental unit. Mean ADG was 1.49 $\pm$ 0.36 kg/d. One pasture in the high forage allowance, non-supplemented treatment was removed from analysis in year one because desired forage allowance could not be maintained. There was an interaction of forage allowance and supplementation on ADG (P = 0.053) such that cattle receiving greater forage allowance

with supplementation produced greater daily gains. To further investigate forage DMI, a 14-d trial began on day 36 in each year. Three of the seven test steers in each pasture were randomly selected to receive 7 ± 0.1 g of TiO_2 daily at 0700 as an external marker to estimate fecal output. Forage DMI averaged 2.03% of midpoint BW, below our expectation. There was no interaction of forage allowance and supplementation (P = 0.14) on forage DMI. Forage allowance affected forage DMI (P = 0.04), but supplementation had no effect (P = 0.37).

Introduction

Winter wheat pasture is a major economic contributor to the Southern Great Plains. Over ten million ha of wheat are sown each year throughout this region of the United States (Christiansen et al., 1989). A large portion of the wheat forage is grazed by stocker cattle during the winter months. As many as six to seven million cattle are grazed on wheat pasture every winter (Fieser et al., 2007). A recurring problem facing producers in this industry is the variability of forage mass production (Peel, 2003). External influences, such as weather, affect forage production which creates volatility in profitability of wheat pasture stocker cattle.

Energy concentrate supplementation has been used to assist producers in hedging risks associated with unknown forage mass production in wheat pasture (Horn et al., 2005). Horn et al. (1995) reported an increase of 0.15 kg in ADG and a 33% increase in stocking rates when cattle received 0.75% BW of a supplement composed of carbohyrdrates and monensin. Increased gain per ha achieved from energy supplementation in past studies assists in risk mitigation associated with unknown yearly forage masses (Coulibaly et al., 1996). However, little research has been conducted to observe the effect of forage allowance on the response of energy supplementation in the performance of cattle grazing wheat pasture.

The objective of our study was to determine if an interaction will occur between forage allowance and supplementation and the subsequent response on stocker cattle ADG, DMI and grazing behavior. We also wanted to observe the effect of forage allowance on supplement conversion ratio. In year two of the study, traits of grazing behavior were measured to analyze the effect of supplementation and forage allowance on cattle's grazing patterns.

Materials and Methods

Study Site

Thirty-one hectares of winter wheat pasture located at the Oklahoma State University Animal Science Stillwater Wheat Pasture Stocker Unit, nine km west of Stillwater, OK (long 36°07'N, lat 97°08'W; Payne County), was divided into eight pastures. The pasture sizes ranged from 2.41 to 5.14 ha, and were used during the winter wheat grazing seasons for both years of the experiment. The average temperature throughout the trial in year one was 9.5 ℃, with the lowest being -3 ℃ in the month of January (Oklahoma Mesonet Data; **Table 1.**). Monthly precipitation values for both years averaged 72 mm in year one and 76 mm in year two. The average temperature throughout the second year was 10.3 ℃ with a low of -2 ℃ during the month of February. At the initiation of the study in year one, there was 2702 ± 768 kg/ha of available wheat forage. Less forage mass was available at the initiation of the study in year two averaging 1253 ± 377 kg/ha.

Year One. A 72-d (26 Nov 2018 – 4 Feb 2019) trial was completed utilizing a hard-red, dual-purpose winter wheat (*Triticum aestivum;* Smith's Gold) sown at 125 kg/ha between September 20 and 22. On October 17th, 28 kg/ha was added to the wheat field. The pasture was then fertilized with composted manure at a rate of 1,839 kg/ha between September 15th - 22nd.

Year Two. A 73-d (26 Nov 2019 – 4 Feb 2020) trial was completed utilizing a hard-red winter wheat (*Triticum aestivum*; Big Country) sown at 134 kg/ha between September 16 and 18. Diammonium phosphate fertilizer was applied in the drill row at a rate of 45 kg/ha.

Treatments

Treatments were placed into a high forage allowance group or a low forage allowance group. The high forage allowance treatment was allocated 3.5 kg DM/kg BW and the low forage allowance treatment was allocated 1.5 kg DM/kg BW. Forage mass was measured by taking forage measurements twice weekly. The plate meter was calibrated weekly using wheat clippings from the pastures by placing dry weights and plate meter heights into a linear equation model that predicted forage mass. The study was set up into four randomly-assigned treatment groups as follows:

1) High forage allowance control (HFAC); 2) Low forage allowance control (LFAC); 3) High forage allowance supplementation (HFAS); 4) Low forage allowance supplementation (LFAS).

The breakdown of treatment groups for both years of the trial are displayed in **Table 2.** All treatment groups received ad libitum access to a monensin-containing, loose mineral product produced by Stillwater Milling Company (A & M Wheat Balancer R)

(**Table 3.)**. The mineral contained 0.56 g/kg of monensin. Consumption was measured to ensure that cattle were consuming adequate amounts of the product as suggested on the label at 28 to 113 g/hd/d. Treatment groups receiving energy supplementation received 1.5 kg/hd/d of a 50% soybean hull and 50% wheat middling pelleted feed made by the Oklahoma State University Feed Mill (**Table 4.**) Treatment groups (HFAS and LFAS) were hand-fed the supplement at 1200 daily in three-meter long bunk feeders, allocating 0.3 to 0.4 m of bunk space per head. The supplement was completely consumed in 30 minutes of placement into the bunks.

Cattle

Year One. 56 steers (initial BW = 210 ± 36 kg), sourced from Oklahoma State University Field and Research Service Unit and Deseret Ranches, of similar breed type were utilized as test steers. Upon arrival, steers were turned out on wheat for a two-week acclimation period. On day 0 of the study (November 25, 2018), all test steers were tagged with lab identification tags, pastures tags, and electronic identification tags, administered a Component TE-G implant (Elanco, Intervet Inc., Summit, NJ), and weighed full. Steers were stratified by body weight and randomly assigned to the eight pasture treatments with seven steers per pasture. Steers had previously been adapted to bunk feeding and no adaptation period was needed. Put-and-take grazers were utilized in pastures with an abundance of forage mass to ensure that forage allowance remained at designed levels. Timely rainfall after seeding (**Table 1.)** created an abundance of wheat at turnout. At the initiation of the trial, up to 13 grazers were added to pastures to ensure desired forage allowances were maintained. As the trial progressed, grazers were removed as forage mass decreased, indicated by the weekly measurements taken with the rising plate meter.

The average stocking density for treatment groups over the course of the 72-trial was 4.2 steers/ha and 2.2 steers/ha for the low forage allowance group and high forage allowance group, respectively. Steers were weighed full weekly and weights were captured electronically (Datamars Livestock, Bedano, Switzerland). Stocking densities were altered weekly from test steer weights and forage mass of pastures to maintain forage allowances of approximately 1.5 kg DM/kg BW and 3.5 kg DM/kg BW.

Year Two. 56 steers sourced from Oklahoma State University Field and Research Service Unit (initial BW = 264 ± 60 kg) were used as test steers. Upon arrival, all steers were administered a Safeguard oral drench wormer (Merck Animal Health, Kenilworth, NJ), a Longrange injectable wormer, a Component TE-G implant (Elanco, Intervet Inc, Summit, NJ), a lab identification ear tag, an electronic identification tag, and initial weights for randomization into treatment groups were recorded. After processing, steers were turned out on wheat for a one-week adaptation period. The adaptation period was shorter for year two than year one due to forage mass inadequacies that pushed grazing date initiation back. On day 0 of the trial (November 26, 2019), all test steers were weighed, administered a pasture tag, and placed into treatment groups of seven steers per pasture. Put and take grazers were utilized to maintain designed forage allowances, however, fewer grazers were needed in year two due to a shortage of wheat forage. A group of six grazers was the largest number of grazers utilized at one time during the trial. By week 6 (January 13, 2020 – January 21, 2020), all put and take grazers had been removed from the trial, as no additional forage mass depletion was needed. Due to shortages in forage, a few test steers in treatment groups were removed to maintain the designed forage allowances between treatments. Two groups, one in a high forage allowance treatment and one in a low forage allowance treatment, had three randomly-chosen test steers removed to maintain adequate forage mass. The remaining treatment groups had one to two test steers removed to maintain forage allowance. Average stocking density for the treatment groups for the duration of the 73-d study was 2.1 steers/ha and 1.6 steers/ha for the low forage allowance group and high forage allowance group, respectively. Steers were weighed weekly and weights were recorded with the utilization of an EID reader and an electronic weigh scale-head. (Datamars Livestock, Bedano, Switzerland). Stocking rates were altered weekly from weights of test steers recorded and forage mass of pastures measured to maintain desired herbage allowance.

Forage Intake Data Collection

A 14-d intake study (31 Dec 2018 – 14 Jan 2019 and 30 Dec 2019 – 13 Jan 2020) was conducted between days 36 and 50 during year one and year two of the research trial to obtain DMI data. Three steers from each treatment group were randomly chosen for use in the study. Gelatin capsules (No. 10 Torpac, Fairfield, New Jersey) were filled with 7 ± 0.01 g of Titanium Dioxide (TiO_2) powder prior to the initiation of the digestibility study. Cattle were administered the TiO_2 boluses at 0700 h, each morning, for the 14-d period to allow a steady state of the external marker to accumulate inside the rumen. On days 10 - 14, fecal samples were collected from the cattle twice daily at 0700 hours and 1530 hours.

Grazing Behavior Observations

In year two, cattle were also outfitted with a IceQube pedometer (Ice Robotics, South Queensferry, Edinburgh, Scotland, UK) during the 14-d intake study to observe grazing behavior of cattle. Two to Three steers from each of the eight pastures were randomly chosen to outfit with a pedometer. The pedometers were placed on the hind leg of each steer under observation. Lying bouts, standing time, and steps were collected for the 21 remaining days of the trial. While the traits under study do not give an exact representation of grazing time, the traits can impact the cattle's grazing patterns and give an estimate of grazing duration.

Sample Collection and Preparation

Forage and Supplement Samples. Wheat forage mass measurements, 60 per pasture, were obtained twice weekly (see **Figure 1**.) utilizing a rising plate meter. The plate meter was calibrated with wheat forage clippings obtained each week. Hand-clipped samples were obtained by placing a 0.096 ft^2 ring in ten randomized locations throughout the wheat pasture. The height of forage inside the ring was measured, clipped to ground level, and placed into sample bags for drying. All wheat clippings were dried at 50℃ in an air forced drying oven for seven days to determine dry matter (DM) of the samples. Clippings were composited by date of acquisition and ground through a one mm screen using a Fritch Cutting Mill (Fritsch-International, Pittsboro, NC). Forage samples were then run through a near-infrared spectrometer (FOSS NIRS DS2500F SR, Hilleroed, Denmark) for nutritional analysis. Individual feed samples were obtained from each batch of supplement received during year one and two. Samples were composited within year, ground through a 1 mm screen, and analyzed to observe the nutritional composition of the supplement utilizing a near-infrared spectrometer at Oklahoma State University.

Fecal Samples. Ten fecal samples were collected for each of the 24 test steers utilized during the 14-d intake portion of the trial. Samples were obtained through fecal palpation, placed into an aluminum baking pan, and dried in an air forced drying oven at 50℃ for

36 to 72 hours based on the density of the samples. Once dry, samples were ground through a 1 mm screen with a Fritch Cutting Mill (Fritsch-International, Pittsboro, NC). A fecal sample composite containing 10 g of each sample was made for the 24 steers used in the intake and digestibility trial. The composites were analyzed with a handheld x-ray fluorescent analyzer (Delta Professional, Olympus Cooperation, Waltham, MA) at the United States Department of Agriculture Southern Plains Research Center (Woodward, OK) to measure the concentrations of titanium remaining in the samples. Dry matter intake calculations were then computed with the concentrations of titanium found in the analysis.

Statistical Analysis

The experiment was set up into a completely randomized design with R (RStudio Team, 2015) being used to analyze data using both a linear regression mixed model and a linear regression model. The data were analyzed using four models. A linear regression mixed model was used to analyze the effect of forage allowance, supplementation, and the interaction between supplementation and forage allowance on ADG and forage DMI of the cattle. The dependent variables were ADG and forage DMI. The independent variables were supplementation, forage allowance, and the interaction between supplementation and forage allowance. All independent variables were sued as fixed effects. Year was used as a random effect for the experiment. A linear regression model was used to analyze the effect of forage allowance, supplementation, and the interaction between supplementation and forage allowance on grazing behavior of the cattle. The dependent variables were steps, standing minutes, and lying bouts. The independent variables were supplementation, forage allowance, and the interaction between supplementation and forage allowance, all of which were fixed effects. A linear regression mixed model was also used to analyze the effect of forage allowance on supplement conversion ratio. Forage allowance was a fixed effect and used as the independent variable. The dependent variable was supplement conversion ratio. All data were considered significant at $P \leq 0.05$. Average daily gains and forage allowance data were calculated by regression of weekly measurements (Appendix A.).

Results

Forage Availability, Forage Quality and Stocking Density

Monthly temperatures throughout the study averaged 9.9 ℃ for the months of November through February. The greatest variance in monthly temperature from both years of the study was 2 ℃. A 0.26 ℃ difference was observed from average temperatures of our study and average temperatures from past climate data in Stillwater, OK for the months of November through February. Total average rainfall for the 72-d trial was 74 mm (**Table 1.**) Year two of the trial produced 3.6 mm greater rainfall than year one. Overall, the two-year study had above average precipitation levels, producing 13 mm greater rainfall than observed from past climate data for the months of November through February.

Average forage mass in year one of the study was greater than year two measuring 2215 kg/ha and 1302 kg/ha, respectively (**Figure 2.**). The average forage mass observed for the entirety of the study was 1759 kg/ha (**Table 5.**). Pastures allocated to low forage allowance had averaged herbage mass of 1607 $\pm$ 21 kg/ha. Treatments in the HFA pastures had average forage mass of 1911 $\pm$ 95 kg/ha. Theoretical forage allowance levels were set at 1.5 kg DM/kg BW and 3.5 kg DM/kg BW for the low and high treatments, respectively. The actual forage allowance maintained for the duration of the trial was 3.51 kg DM/kg BW for the HFA pastures and 1.75 kg DM/kg BW for the LFA pastures (**Table 5.**).

Wheat forage nutrient composition for the study can be observed in **Table 6.** Crude protein levels averaged 23.5% DM with a range in value from 27% DM in November to 18% DM in January. Lignin concentrations increased from 1.7 % DM to 3.9% DM from November through January. Total digestible nutrient of the forage was calculated using the Weiss Equation (Weiss, 1992) and averaged 71.3 $\pm$ 4.4 % throughout both years of the study. The main minerals of concern in wheat pasture, calcium, phosphorus, and magnesium, maintained concentrations in the forage of 0.37% DM, 0.31% DM, and 0.17% DM, respectively. Mineral composition of the pastures was adequate in all three minerals according to the requirements for a 300-kg steer gaining 1.6 kg/d (NASEM, 2016).

Stocking density, with the utilization of put-and-take grazers, averaged 2.55 steers/ha for all treatment groups (**Table 5.**). Stocking densities for the low and high forage allowance treatment groups, including put and take grazers, were 3.18 and 1.93 steers/ha, respectively. Pastures allocated to low forage allowance treatments were stocked 60% heavier than pastures in high forage allowance treatments. Stocking densities were greater in year one of the trial due to the greater forage mass available.

Cattle Performance

Average initial BW for cattle during the two-year trial was 248 ± 69 kg with the average final weights being 348 ± 99 kg (**Figure 3.)** Average daily gains of the cattle were 1.49 kg for all treatment groups. Forage allowance and supplementation interacted to affect ADG (*P* = 0.053; **Figure 4.**) such that cattle in HFAS gained more per day than cattle in LFAC, LFAS, or HFAC (**Table 5.**). The interaction of forage allowance and supplementation produced a greater impact in treatment groups allocated to LFA (1.75 kg DM/ kg BW). Cattle in LFAS had increased gains of 0.34 kg/hd/d compared with LFAC, where HFAS only increased ADG by 0.13 kg/hd/d compared with HFAC (**Table 5.**). Additional ADG achieved from the interaction of forage allowance and supplementation in high forage allowance treatment groups were slightly lower, averaging increases of 0.13 kg/hd/d.

Supplement Conversion

Supplement conversion ratios, kg of supplement divided by kg of additional ADG, for treatment groups are shown in **Table 5.** Forage allowance affected the supplement conversion ratio (*P* = 0.015; **Figure 5.**) such that HFA (3.51 kg DM/kg BW) had a 2.5X greater conversion ratio than LFA (1.75 kg DM/kg BW). Average supplement conversion ratio for LFA was 4.51 kg of feed needed to produce an additional kg of gain. Average supplement conversion ratio of 11.45 kg of feed needed for an additional kg of gain was produced in HFA pastures. The lower supplement conversion ratio observed for cattle allocated to LFA indicates replacement of forage intake resulting in better utilization and efficiency of the energy supplement.

Forage Intake

Average forage-only DMI for cattle in all treatment groups throughout the duration of the two-year trial was 2.03% of midpoint BW (**Table 5.**). Forage allowance and supplementation did not interact to affect DMI (*P* = 0.14; **Figure 6.**). High forage allowance increased DMI of cattle by 0.20% BW (*P* = 0.035). Supplementation had minimal effect on DMI in cattle receiving 1.5 kg DM/kg BW of forage allowance, as both the supplemented group and control group averaged 1.94% BW of forage intake (*P* = 0.372). However, a large decrease in forage intake observed for cattle receiving supplementation in high forage allowance pastures was observed. A 0.41% BW decrease in DMI was produced from cattle receiving 3.5 kg DM/kg BW and 1.5 kg of supplementation daily.

Grazing Behavior

Pedometer data from year two of the trial produced evidence of a desired difference in forage allowance between treatments (**Figure 7.**; **Figure 8.**; **Figure 9.**)

Daily Standing Time

Forage allowance and supplementation did not interact to affect the amount of time cattle spent standing in a 24-hr time period (*P* = 0.433; **Table 5.**; **Figure 10.**). Cattle spent an average of 698 $\pm$ 74 minutes standing across all treatment groups. Supplementation had a minimal effect on the time cattle spent standing (*P* = 0.187). Forage allowance produced a tendency for daily standing time in cattle (*P* = 0.078) such that cattle allocated to high forage allowance treatments spent less time standing on a daily basis.

Daily Lying Bouts

The average number of daily lying bouts in cattle across all treatments was 11.7 $\pm$ 3.4 bouts/d (**Table 5.**). Forage allowance and supplementation interacted to affect the quantity of lying bouts in cattle (*P* = 0.015; **Figure 11.**) such that cattle receiving LFA increased lying bouts by 3.2 bouts/d. Cattle grazing pastures with HFA had greater lying bouts for HFAC than HFAS.

Daily Steps

The average number of daily steps taken by the cattle during year two of the study was 2765± 290 steps/d (**Table 5.**). Forage allowance and supplementation did not interact to affect the number of daily steps in cattle (*P* = 0.682; **Figure 12.**). Supplementation did not induce an effect on daily steps of cattle (*P* = 0.815). Daily steps were also not affected by forage allowance (*P* = 0.581).

Mineral and Supplement Intake

Cattle consumed larger amounts of mineral (135 g/hd/d) in the first two weeks of the study during both years. Around week three, consumption leveled out around 85 g/hd/d. Average consumption throughout both years of the trial was 96 g/hd/d. At such a consumption rate, steers were receiving a daily dose of 151 mg of monensin. Due to the variability of mineral composition in wheat pasture, phosphorus and calcium were supplemented above requirement levels to ensure cattle's full requirements were met. With an average consumption of 96 g/hd/d, cattle received a calculated dose of 26.8 g of supplemented calcium from mineral. Phosphorus was supplemented at 2.5% DM (**Table 3.**) providing an additional calculated dose of 2.4 g per daily mineral consumption.

The average supplement consumption throughout the trial ranged from 0.5% - 0.55% of midpoint BW for both years of the study. The supplement provided an additional 1.25 Mcal/kg of energy for gain to the diet (**Table 4.**). The fiber carbohydrate composition, NDF, in the energy supplement was 29.6% DM. The fiber level of the supplement used during our study averaged over 10% higher than a non-fiber, corn-based energy supplement (NASEM, 2016).

Discussion

Forage Availability, Forage Quality, and Stocking Density

Forage mass was measured throughout the duration of the study to ensure that treatment groups were allocated desired forage allowance. The average forage mass observed in our trial is similar to values observed in previous literature for dry-land wheat pasture (Horn et al., 1995; Morgan et al., 2012; Beck et al., 2015).

Forage clippings were presumed to provide a realistic expectation of diet quality due to the monoculture nature of the crop (Fieser et al., 2007). The CP decline from November to January observed in our trial agrees with previous literature (Reuter and Horn, 2000; Beck et al., 2015). However, the CP observed for the forage during the month of January was lower than CP observed in previous studies (Horn, 1995; Reuter and Horn, 2000; Beck et al., 2015). Lower CP values observed in January could be attributed to senescence of leaves from the reduced forage growth in colder weather (Morgan et al., 2012). Decreased CP could have also derived from the limited forage mass in pastures allocated to 1.5 kg DM/kg BW. At this time, greater stem to leaf ratio was observed in LFA treatment groups, indicating a potential for decreased nutrient quality of the wheat.

The increase in lignin percentages of the forage from November through February could have derived from the observed increase in stem-to-leaf ratio. Less rainfall, colder weather, and forage senescence were potential contributors to the decrease in leaf-cover of the wheat forage towards the end of our trial. The TDN values calculated for the forage in our study was 9.6% greater than the average percentage depicted for fresh wheat forage in NASEM (2016). The larger TDN value calculated in the current trial is presumed to arise from wheat being in earlier growth phases than wheat grazed through the month of March. Fieser et al. (2007) reported TDN values of 67.2% DM for wheat forage in earlier stages of growth during November.

Cattle Performance

Cattle in our experiment averaged greater ADG, 1.49 kg/hd/d, than previous research has reported (Horn, 1995; Reuter and Horn, 2000; Horn et al., 2005; Fieser et al., 2007; Morgan et al., 2012; Beck et al., 2014, 2015). Beck et al. (2013) found that in an eight-year average, cattle with 3.5 kg DM/kg BW of forage allowance gained an average of 1.2 kg/hd/d. Our current study found that cattle with similar forage allowance and no energy supplementation gained 1.61 kg/hd/d. A portion of the increased gain observed in the control group of our study could possibly be credited to monensin intake from mineral consumption, however, it is unlikely that the monensin was responsible for the total 0.41 kg of additional gain. Fieser et al. (2007) found a 0.28 kg increase in ADG for cattle receiving monensin-containing mineral on wheat pasture.

Energy supplementation proved to be more effective for increasing ADG when forage mass was limited ($P = 0.053$; **Figure 4.**). A 0.34 kg/hd/d increase in gain was achieved through the utilization of a 50% soybean hull, 50% wheat middling supplement at 0.5 to 0.55% of midpoint BW when forage mass was restricted to levels of 1.75 kg DM/kg BW. Such information indicated that producers can potentially increase the performance of stocker cattle grazing limited forage mass through providing an energy supplement.

Supplement Conversion

Supplement conversion ratios are important in ensuring the feasibility of feeding a supplement. Past research has produced supplement conversion ratios ranging from 2.4 to 6.4 kg of feed needed for an additional kg of gain (Fieser et al, 2003, 2007; Horn et al., 1995, 2006). These ratios were observed utilizing a monensin carrier in the form of a mineral or pelleted feed. The supplement conversion ratio for our low forage allowance group correlated with the previous research values at 4.51 kg of supplement needed for an additional kg of gain. The supplement conversion ratio for HFA, 11.55, was much greater than previous studies (Fieser et al, 2003, 2007; Horn et al., 1995, 2006) but similar to observations found by Utley and McCormick (1975, 1976) and Elder (1967). Beck et al. (2013) found a plateau for ADG in wheat cattle around 3.5 kg DM/kg BW. Cattle in high forage allowance treatment groups received 3.51 kg DM/kg BW of daily forage, creating little room for an increase in gain from a supplement. The forage mass in the HFA groups reaching quantities above Beck et. al (2013) plateau level in FA above which improved gain response is unlikely, could be responsible for the higher supplement conversion ratio.

The higher conversion ratio observed for cattle provided adequate herbage allowance indicates supplement was utilized more efficiently when forage mass was limited (*P* = 0.015; **Figure 5.**). The data gathered suggests that energy supplementation may not be feasible for producers with high forage allowance if input costs of the feed are larger than additional gain achieved.

Forage Intake

Forage intake in our study was much lower than expected, averaging 2.03% of midpoint BW. Horn (2006) reported forage intake ranges of 2.8 % to 3.0% BW for steers grazing wheat pasture. Scaglia et al. (2009) reported DMI values of 2.6% BW for cattle grazing ryegrass and being supplemented with 0.5% BW of pelleted corn gluten feed at 1200 hours, similar to the treatments of our study. The use of an external marker to calculate forage intake could potentially contribute to the low DMI values observed in our study. De Souza et al. (2015) reported that TiO_2, the marker used in our study, underestimated both DM and OM digestibility. The ranges for fecal recovery for TiO_2 also varied from ranges of 90% to 108% in previous studies (Titgemeyer et al., 2001; Glindemann et al., 2009; De Souza et al., 2015).

A numerical 0.41% BW forage-only DMI decrease was observed from cattle receiving HFA and supplementation (*P* = 0.14; **Figure 6.**). The decrease in DMI observed in our study from supplementation was in agreement with results from previous studies. Schreck et al. (2017) observed a decrease in DMI by 0.6% BW for cattle grazing green-chopped forage and being supplemented a corn-based energy supplement. Intake data from our study, along with previous literature, suggests that supplementation of wheat pastures can allow producers to increase stocking rates and reduce forage allowance by decreasing forage intake by cattle.

Grazing Behavior

Grazing behavior in our study was measured to observe differences in grazing patterns between treatments groups of with varying forage masses and supplementation protocols. Cattle allocated to HFA groups tended to have 69 less minutes of daily standing time than cattle in LFA pastures (*P* = 0.078; **Figure 10.**). The larger standing time in pastures with LFA indicates that cattle had to graze longer to achieve an adequate amount of forage consumption. Data from our study reported less various in standing time than past research has shown. Scarnecchia et al. (1985) reported differences in grazing time of up to 275 minutes for cattle receiving adequate herbage mass and cattle with limited herbage mass. The average standing time for cattle in LFA treatments was 12 minutes greater than the maximum grazing time for cattle reported by Stobbs (1975). The higher value, in relation to maximum grazing time reported in previous studies, indicates cattle may not have been grazing the entire time of standing. More data would be needed to record the actual amount of time cattle spend grazing in pastures containing limited or adequate wheat forage.

Cattle allocated to pastures in HFAS had greater daily lying bouts. Cattle in treatment groups with LFA had over three additional lying bouts with the addition of supplementation (*P* = 0.015; **Figure 11**) compared with HFA. The increase in lying bouts from additional FA indicates that the cattle reached their fill sooner, and more often, than cattle with LFA. The increase in lying bouts from the LFAS treatment indicates that the cattle could be utilizing the wheat forage more efficiently through increasing ammonia nitrogen incorporation into microbial protein (Branine and Galyean, 1990).

We found no treatment effects on the quantity of steps cattle took in a 24-hr time period (P = 0.682; **Figure 12.**) indicating steps are independent of forage allowance and supplementation.

Mineral and Supplement Intake

Horn et al. (2005) reports calcium as the macromineral of main concern for wheat pasture grazing. Ruminal motility can be compromised by Ca deficiencies, therefore, Horn et al. (2005) suggests supplementing 10 g/hd/d of Ca to cattle on wheat pasture. With an average mineral consumption of 96 g/hd/d in our study, cattle received 26.8 g of supplemented calcium from mineral consumption. The effect of monensin on cattle performance has been researched in prior studies and was not an objective for the current study. From previous data, assumptions can be derived that additional gains from monensin consumption in this study potentially increased ADG up to 0.28 kg (Horn et al., 1995; Fieser et al., 2007).

A high-fiber energy supplement was utilized in our study to ensure that cattle had no major issues from pH depression occasionally observed from concentrate supplementation in cattle. Anderson et al. (1988) reported decreased fermentation issues from greater ruminal pH levels by feeding energy supplements high in fiber. No cattle were treated for bloat in year one of our study and three cattle were treated for mild bloat in year two.

Conclusions

Energy supplementation provided to wheat stocker cattle generally increases daily gains of cattle. Based on this study, energy supplementation, utilizing a fiber-based concentrate, would effectively increase cattle performance. The data concludes a larger increase in daily gains is accomplished in cattle grazing pastures with limited forage allowance. Supplementation conversion also proved to be more efficient for cattle grazing pastures with low forage allowance. Dry matter intake observed in the study indicated higher stocking rates could potentially be maintained through the utilization of energy supplementation from the forage mass preservation.

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APPENDICES

APPENDIX A

R Code for Statistic Models of Study

```
install.packages("devtools")
devtools::install_github("tidyverse/googlesheets4")
install.packages("lubridate")
install.packages("googlesheets4")
install.packages("tidyverse")
install.packages("nlme")
install.packages("lme4")
install.packages("MuMIn")
library(tidyverse)
library(googlesheets4)
library(lubridate)
library(lme4)
library(nlme)
library(MuMIn)


this.gs <- "https://docs.google.com/spreadsheets/d/1z1-oRJv_ka1oVZdlkda-
rDJ_lPn1DNj_S6u-OLt4w3Q/edit?pli=1#gid=569333322" #input your googlesheet ID
from the URL from where you view the googlesheet
data <- googlesheets4::sheets_get(this.gs)
packamy.sheet <- read_sheet(data, sheet = "Stocking")

###treatments
treats.2018 <- read_sheet(data, sheet = "Stocking", range = "A1:G9") %>%
  select(-(2:5)) %>%
  rename(Paddock = Pasture) %>%
  mutate(Paddock = as.character(Paddock)) %>%
  mutate(project.year = "2018")

treats.2019 <- read_sheet(data, sheet =  "Stocking2019", range = "A1:G9") %>%
  select(-(2:5)) %>%
  rename(Paddock = Pasture) %>%
  mutate(Paddock = as.character(Paddock)) %>%
  mutate(project.year = "2019")
```

```
treats <- treats.2018 %>% rbind(treats.2019)
rm(treats.2019)

###Cattle BW
cattleBW.2018 <- read_sheet(data, sheet =  "CattleBW", na = c("", "#N/A")) %>%
  mutate(EID = as.character(EID)) %>%
  mutate(VISID = as.character(VISID)) %>%
  mutate(project.year = "2018") %>%
  select(VISID, EID, project.year, Source, Paddock, everything()) %>%
  gather(6:18, key = "date", value = "BW")

cattleBW.2019 <- read_sheet(data, sheet =  "CattleBW2019", na = c("", "#N/A")) %>%
  mutate(EID = as.character(EID)) %>%
  mutate(VISID = as.character(VISID)) %>%
  mutate(project.year = "2019") %>%
  select(VISID, EID, project.year, Source, Paddock, everything()) %>%
  gather(6:27, key = "date", value = "BW")

cattleBW <- cattleBW.2018 %>%
  rbind(cattleBW.2019)

rm(cattleBW.2019)

cattleBW.2020 <- cattleBW %>%
  mutate(Paddock = as.character(Paddock)) %>%
  mutate(date = substr(date, 4, 14)) %>%
  mutate(date = as.Date(date)) %>%
  mutate(BW = BW / 2.205) %>%
  left_join(treats) %>%
  filter(Paddock != "grazer") %>%
  filter(date >= as.Date("2018-11-18")) %>%
  arrange(VISID, date) %>%
  group_by(VISID) %>%
  mutate(gain = (BW - lag(BW)),
        days = as.integer((date - lag(date)))) %>%
  mutate(adg.week = gain / days) %>%
  mutate(day.of.year = yday(date)) %>%
  mutate(day.from.sept.1 = day.of.year - yday("2018-09-01")) %>%
  mutate(day.from.sept.1 = ifelse(day.from.sept.1 < 0, day.from.sept.1 + 365,
day.from.sept.1))

##intial & final BW means
FBW1_19 <- cattleBW.2020 %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'Y') %>%
  filter(project.year == '2019') %>%
```

```
  filter(date == '2020-02-04')


FBW2_19 <- cattleBW.2020 %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'N') %>%
  filter(project.year == '2019') %>%
  filter(date == '2020-02-04')

FBW3_19 <- cattleBW.2020 %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  filter(project.year == '2019') %>%
  filter(Feed == 'N') %>%
  filter(date == '2020-02-04')

FBW4_19 <- cattleBW.2020 %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  filter(Feed == 'Y') %>%
  filter(project.year == '2019') %>%
  filter(date == '2020-02-04')

FBW1_18 <- cattleBW.2020 %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'Y') %>%
  filter(project.year == '2018') %>%
  filter(date == '2019-02-04')


FBW2_18 <- cattleBW.2020 %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'N') %>%
  filter(project.year == '2018') %>%
  filter(date == '2019-02-04')

FBW3_18 <- cattleBW.2020 %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  filter(project.year == '2018') %>%
  filter(Feed == 'N') %>%
  filter(date == '2019-02-04')

FBW4_18 <- cattleBW.2020 %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  filter(Feed == 'Y') %>%
  filter(project.year == '2018') %>%
  filter(date == '2019-02-04')
```

```
final_BW2 <- cattleBW.2020 %>%
 ###filter(date == '2019-02-04')%>%
 filter(date == '2020-02-04')

final_BW <- cattleBW.2020 %>%
 filter(date == '2019-02-04')

final_BW3 <- final_BW %>%
 full_join(final_BW2)

BW <- final_BW3 %>%
 full_join(summary.data)

this.lm.mixed <- lme( BW ~ fa.grazers*Feed, random = ~ 1|project.year, BW)
summary(this.lm.mixed)

initial_BW2 <- cattleBW.2020 %>%
 filter(date == '2018-11-26')

initial_BW <- cattleBW.2020 %>%
 filter(date == '2019-11-25')

inital_BW3 <- initial_BW %>%
 full_join(initial_BW2)

IBW <- inital_BW3 %>%
 full_join(summary.data)

this.lm.mixed <- lme( BW ~ fa.grazers*Feed, random = ~ 1|project.year, IBW)
summary(this.lm.mixed)

IBW1 <- cattleBW.2020 %>%
 filter(`FA_kgDM/kgBW` == 1.5) %>%
 filter(Feed == 'Y') %>%
 filter(project.year == '2018') %>%
 filter(date == '2018-11-26')

IBW2 <- cattleBW.2020 %>%
 filter(`FA_kgDM/kgBW` == 1.5) %>%
 filter(Feed == 'N') %>%
 filter(project.year == '2018') %>%
 filter(date == '2018-11-26')

IBW1 <- cattleBW.2020 %>%
 filter(`FA_kgDM/kgBW` == 3.5) %>%
 filter(Feed == 'Y') %>%
```

```
  filter(project.year == '2018') %>%
  filter(date == '2018-11-26')

IBW1 <- cattleBW.2020 %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'N') %>%
  filter(project.year == '2018') %>%
  filter(date == '2018-11-26')

cattle.treats <- cattleBW.2020 %>%
  select(VISID, project.year, Paddock) %>%
  distinct() %>%
  left_join(treats)

forage.intake <- read_sheet(data, sheet =  "FecalTi", range = "A1:G49") %>%
  select(VISID, Forage_IntakeDM_Kg) %>%
  mutate(VISID = as.character(VISID)) %>%
  right_join(cattle.treats)

cattle.treats <- cattle.treats %>%
  left_join(forage.intake)


ggplot(cattleBW.2020, aes(day.from.sept.1, BW)) +
  geom_point() +
  geom_smooth() +
  ylab("Bodyweight (Kg)") +
  xlab("Day from September 1st")


### calc ADG by regression

bw.adg <- cattleBW.2020 %>%
  group_by(VISID) %>%
  do(model = lm(BW ~ date, data = .)) %>%
  broom::tidy(model) %>%
  filter(term == "date") %>%
  select(VISID, estimate) %>%
  rename(adg = estimate)

cattle.treats <- cattle.treats %>%
  left_join(bw.adg)

rm(bw.adg)

cattle.mid.BW <- cattleBW.2020 %>%
```

```
  group_by(VISID) %>%
  summarize(mid.BW = mean(BW, na.rm = T))

cattle.treats <- cattle.treats %>%
  left_join(cattle.mid.BW)

rm(cattle.mid.BW)

summary.data <- cattle.treats %>%
  mutate(forage.dmi.bw = Forage_IntakeDM_Kg / mid.BW) %>%
  group_by(project.year, Paddock, Feed, `FA_kgDM/kgBW`) %>%
  summarize(adg = mean(adg),
           mid.BW = mean(mid.BW),
           forage.dmi.bw = mean(forage.dmi.bw, na.rm = T))

adg.atintake.1.5.2018 <- summary.data %>% filter(`FA_kgDM/kgBW`== 1.5 & Feed ==
"N" & project.year == "2018") %>% ungroup() %>%  summarize(mean = mean(adg))
%>% as.numeric()
adg.atintake.3.5.2018 <- summary.data %>% filter(`FA_kgDM/kgBW`== 3.5 & Feed ==
"N" & project.year == "2018") %>% ungroup() %>%  summarize(mean = mean(adg))
%>% as.numeric()
adg.atintake.1.5.2019 <- summary.data %>% filter(`FA_kgDM/kgBW`== 1.5 & Feed ==
"N" & project.year == "2019") %>% ungroup() %>%  summarize(mean = mean(adg))
%>% as.numeric()
adg.atintake.3.5.2019 <- summary.data %>% filter(`FA_kgDM/kgBW`== 3.5 & Feed ==
"N" & project.year == "2019") %>% ungroup() %>%  summarize(mean = mean(adg))
%>% as.numeric()

summary.data <- summary.data %>%
  mutate(control.ADG = ifelse(project.year == "2018" & `FA_kgDM/kgBW`== 1.5,
adg.atintake.1.5.2018, 0)) %>%
  mutate(control.ADG = ifelse(project.year == "2018" & `FA_kgDM/kgBW`== 3.5,
adg.atintake.3.5.2018, control.ADG)) %>%
  mutate(control.ADG = ifelse(project.year == "2019" & `FA_kgDM/kgBW`== 1.5,
adg.atintake.1.5.2019, control.ADG)) %>%
  mutate(control.ADG = ifelse(project.year == "2019" & `FA_kgDM/kgBW`== 3.5,
adg.atintake.3.5.2019, control.ADG)) %>%
  mutate(scr = ifelse(Feed == "Y",  3.3*0.9*0.454 / (adg - control.ADG), NA))

ggplot(summary.data, aes(x=`FA_kgDM/kgBW`, y = adg, color = Feed)) +
  geom_point(aes(size = .01))

summary.data %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'Y') %>%
```

```
  summarize(mean(adg))
summary.data %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'N') %>%
  summarize(mean(adg))

## forage allowance

fa <- read_sheet(data, sheet = "FA") %>%
  mutate(Paddock = as.character(Paddock),
         project.year = ifelse(Date < "2019-06-01", "2018", "2019")) %>%
  mutate(day.of.year = yday(Date)) %>%
  mutate(day.from.sept.1 = day.of.year - yday("2018-09-01")) %>%
  mutate(day.from.sept.1 = ifelse(day.from.sept.1 < 0, day.from.sept.1 + 365,
day.from.sept.1))


fa.mean <- fa %>%
  group_by(Paddock, project.year) %>%
  summarize(fa = mean(FA, na.rm = T),
          fa.grazers = mean(`FA-grazers`, na.rm = T),
             Mass = mean(Mass, na.rm = T)) %>%
          full_join(treats)

fa.2018 <- fa %>%
  filter(project.year == "2018") %>%
  summarize(Mass = mean(Mass, na.rm = T))

fa.2019 <- fa %>%
  filter(project.year == "2019") %>%
  summarize(Mass = mean(Mass, na.rm = T))

fa.bothyears <- fa.2019 %>%
  full_join(fa.2018)

fa.mean %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'N') %>%
  summarize(mean(Mass))
fa.mean %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'Y') %>%
  summarize(mean(Mass))
```

```
ggplot(fa.mean, aes(x = project.year, y = Mass)) +
  geom_boxplot(size = 1.5, alpha = 0.8) +
  xlab("Project Year") +
  ylab("Forage Mass, kg/ha") +
  ##scale_x_continuous(breaks = unique(fa.2018$day.from.sept.1)) +
  ###facet_wrap(~project.year) +
  ggsave("forage.mass.png", width = 6, height = 3)

summary.data <- summary.data %>%
  left_join(fa.mean)

## 2-year model with actual fa
summary.data %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  summarize(mean(fa.grazers))
summary.data %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  summarize(mean(fa.grazers))

### model for ped data
this.lm <- lm(standing.minutes ~ Feed*`FA_kgDM/kgBW`, ped.data.summary)
summary(this.lm)


### main models for study


### model for year as a random effect for main trial- all treatments
this.lm.mixed <- lme(adg ~ fa.grazers*Feed, random = ~ 1|project.year, summary.data)
summary(this.lm.mixed)
  r.squaredGLMM(this.lm.mixed)


###model for year as a random effect for DMI trial: 2019-2020 data needed
this.lm.mixed <- lme(forage.dmi.bw ~ fa.grazers*Feed, random = ~ 1|project.year,
summary.data)
summary(this.lm.mixed)
r.squaredGLMM(this.lm.mixed)


### ADG x FA graph for both years
ggplot(summary.data , aes(x = fa.grazers, y = adg)) +
  geom_point(aes(color = Feed), alpha = 0.7, size =3) +
```

```
  geom_smooth(method = "lm", aes(color = Feed), se=F) +
  xlab("Forage allowance, kg DM / kg BW") +
  ylab("ADG, kg") +
  scale_color_discrete(name = "Supp", labels = c("None", "1.5 kg")) +
  ggsave("adg.png", width = 6, height = 3)

### model for forage allowance and feed  on cattle ADG performance?
this.lm <- lm(scr ~ fa.grazers,  + project.year, summary.data)
summary(this.lm)



### Forage Allowance x DMI interaction graph
ggplot(summary.data , aes(x = fa.grazers, y = forage.dmi.bw*100)) +
  geom_point(aes(color = Feed), alpha = 0.7, size = 2) +
  geom_smooth(method = "lm", aes(color = Feed), se=F) +
  xlab("Forage allowance, kg DM / kg BW") +
  ylab("Forage DMI, % of BW") +
  scale_color_discrete(name = "Supp", labels = c("None", "1.5 kg")) +
  ggsave("adg.png", width = 6, height = 3)


### Average FA for treatments
summary.data %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  filter(project.year == '2018') %>%
  filter(Feed == 'Y') %>%
  summarize(mean(fa.grazers))
summary.data %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  filter(Feed == 'Y') %>%
  filter(project.year == '2019') %>%
  summarize(mean(fa.grazers))

summary.data %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(project.year == '2018') %>%
  filter(Feed == 'Y') %>%
  summarize(mean(fa.grazers))
summary.data %>%
  ungroup() %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  filter(Feed == 'Y') %>%
```

```
  filter(project.year == '2019') %>%
  summarize(mean(fa.grazers))

## Stocking Density

SD18 <- read_sheet(data, sheet = "GrazingDays")

SD1 <- SD18 %>%
  filter(Pasture == '1')%>%
  mutate(SD = ((HeadCount)/ 2.71))

SD2 <- SD18 %>%
  filter(Pasture == '2')%>%
  mutate(SD = ((HeadCount)/ 3.32)) %>%
  full_join(SD1)

SD3 <- SD18 %>%
  filter(Pasture == '3')%>%
  mutate(SD = ((HeadCount)/ 3.6)) %>%
  full_join(SD2)

SD4 <- SD18 %>%
  filter(Pasture == '4')%>%
  mutate(SD = ((HeadCount)/ 2.41)) %>%
  full_join(SD3)

SD5 <- SD18 %>%
  filter(Pasture == '5')%>%
  mutate(SD = ((HeadCount)/ 5.14)) %>%
  full_join(SD4)

SD6 <- SD18 %>%
  filter(Pasture == '6')%>%
  mutate(SD = ((HeadCount)/ 5.1)) %>%
  full_join(SD5)

SD7 <- SD18 %>%
  filter(Pasture == '7')%>%
  mutate(SD = ((HeadCount)/ 4.9)) %>%
  full_join(SD6)

SD8 <- SD18 %>%
  filter(Pasture == '8')%>%
  mutate(SD = ((HeadCount)/ 3.88)) %>%
  full_join(SD7)
```

```
SD19 <- read_sheet(data, sheet = "GrazingDays2019")

###########  Pedometer Data

ped.data <- read_sheet(data, sheet =  "PedometerData", na = c("", "#N/A")) %>%
  mutate(VISID = as.character(VISID)) %>%
  group_by(Feed, `FA_kgDM/kgBW`)

this.lm <- lm(scr ~ `FA_kgDM/kgBW`,  + standing.minutes, ped.data)
summary(this.lm)

data <- googlesheets4::gs4_get(this.gs)

ped.data <- read_sheet(data, sheet =  "PedometerData", na = c("", "#N/A"), col_types =
"c") %>%
  mutate(`FA_kgDM/kgBW` = as.numeric(`FA_kgDM/kgBW`),
         Date = as.Date(Date, '%m/%d/%y'),
         Steps = as.numeric(Steps),
         Lying_Bouts = as.numeric(Lying_Bouts),
         `Standing(hrs,min,sec)` = ifelse(str_length(`Standing(hrs,min,sec)`) == 7,
                                   str_c("0", `Standing(hrs,min,sec)`, sep=""),
`Standing(hrs,min,sec)`),
         standing.minutes = as.numeric(str_sub(`Standing(hrs,min,sec)`, 1,2)) * 60 +
           as.numeric(str_sub(`Standing(hrs,min,sec)`, 4,5)) * 1  +
           as.numeric(str_sub(`Standing(hrs,min,sec)`, 7,8)) / 60,
         `Lying(hrs,min,sec)` = ifelse(str_length(`Lying(hrs,min,sec)`) == 7,
                                str_c("0", `Lying(hrs,min,sec)`, sep=""),  `Lying(hrs,min,sec)`),
         lying.minutes = as.numeric(str_sub(`Lying(hrs,min,sec)`, 1,2)) * 60 +
           as.numeric(str_sub(`Lying(hrs,min,sec)`, 4,5)) * 1  +
           as.numeric(str_sub(`Lying(hrs,min,sec)`, 7,8)) / 60,
  ) %>%
  select(VISID, Feed:Date, Steps, Lying_Bouts, standing.minutes, lying.minutes)

ped.data %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  filter(Feed == 'Y') %>%
  summarize(mean(Lying_Bouts))
ped.data %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  filter(Feed == 'N') %>%
  summarize(mean(Lying_Bouts))

ped.data.summary <- ped.data %>%
  group_by(Pasture, `FA_kgDM/kgBW`, Feed) %>%
  summarise(Steps = mean(Steps),
            standing.minutes = mean(standing.minutes),
```

```
          Lying_Bouts = mean(Lying_Bouts))


this.lm <- lm(Steps ~ `FA_kgDM/kgBW`*Feed, ped.data.summary)
summary(this.lm)

this.lm <- lm(standing.minutes ~ `FA_kgDM/kgBW`*Feed, ped.data.summary)
summary(this.lm)

this.lm <- lm(Lying_Bouts ~ `FA_kgDM/kgBW`*Feed, ped.data.summary)
summary(this.lm)


#### Line Graph for Standing Mintues
ggplot(ped.data.summary , aes(x =`FA_kgDM/kgBW` , y = standing.minutes)) +
  geom_point(aes(color = Feed), alpha = 0.7, size =3) +
  geom_smooth(method = "lm", aes(color = Feed), se=F) +
  xlab("Forage Allowance, Kg DM/Kg BW") +
  ylab("Daily Standing Minutes") +
  scale_color_discrete(name = "Supp", labels = c("None", "1.5 kg")) +
  ggsave("adg.png", width = 6, height = 3)

### Line Graph for Lying Bouts
ggplot(ped.data.summary , aes(x =`FA_kgDM/kgBW` , y = Lying_Bouts)) +
  geom_point(aes(color = Feed), alpha = 0.7, size =3) +
  geom_smooth(method = "lm", aes(color = Feed), se=F) +
  xlab("Forage Allowance, Kg DM/Kg BW") +
  ylab("Daily Lying Bouts") +
  scale_color_discrete(name = "Supp", labels = c("None", "1.5 kg")) +
  ggsave("adg.png", width = 6, height = 3)

###Line Graph for Steps
ggplot(ped.data.summary , aes(x =`FA_kgDM/kgBW` , y = Steps)) +
  geom_point(aes(color = Feed), alpha = 0.7, size =3) +
  geom_smooth(method = "lm", aes(color = Feed), se=F) +
  xlab("Forage Allowance, Kg DM/Kg BW") +
  ylab("Daily Steps") +
  scale_color_discrete(name = "Supp", labels = c("None", "1.5 kg")) +
  ggsave("adg.png", width = 6, height = 3)


###Boxplot for individual cattle observations
ggplot(ped.data, aes(x = VISID, y = standing.minutes)) +
  geom_boxplot() +
  ylab("Daily Sanding Minutes") +
  xlab("Animal ID")
```

```
ggplot(ped.data, aes(x = VISID, y = Lying_Bouts)) +
  geom_boxplot() +
  ylab("Daily Lying Bouts") +
  xlab("Animal ID")


###Supplement Conversion Ratio

AAAA.18 <- summary.data %>%
  ungroup() %>%
  filter(Feed == 'Y') %>%
  filter(project.year == '2018') %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  summarize(mean(adg))

AAAA.19 <- summary.data %>%
  ungroup() %>%
  filter(Feed == 'Y') %>%
  filter(project.year == '2019')%>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  summarize(mean(adg))

AAA.18 <- summary.data %>%
  ungroup() %>%
  filter(Feed == 'N') %>%
  filter(project.year == '2018') %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  summarize(mean(adg))

AAA.19 <- summary.data %>%
  ungroup() %>%
  filter(Feed == 'N') %>%
  filter(project.year == '2019') %>%
  filter(`FA_kgDM/kgBW` == 3.5) %>%
  summarize(mean(adg))

HFA_SCR.18 <- 1.5/(AAAA.18 - AAA.18)

HFA_SCR.19 <- 1.5/(AAAA.19 - AAA.19)

LFA_SCR.18 <- 1.5/(AA.18- A.18)

LFA_SCR.19 <- 1.5/(AA.19 - A.19)

SCR.dataframe <- read_sheet(data, sheet = "SCR")
```

```
AA.18 <- summary.data %>%
  ungroup() %>%
  filter(project.year == '2018') %>%
  filter(Feed == 'Y') %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  summarize(mean(adg))

A.18 <- summary.data %>%
  ungroup() %>%
  filter(project.year == '2018') %>%
  filter(Feed == 'N') %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  summarize(mean(adg))

A.19 <- summary.data %>%
  ungroup() %>%
  filter(project.year == '2019') %>%
  filter(Feed == 'N') %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  summarize(mean(adg))

AA.19 <- summary.data %>%
  ungroup() %>%
  filter(project.year == '2019') %>%
  filter(Feed == 'Y') %>%
  filter(`FA_kgDM/kgBW` == 1.5) %>%
  summarize(mean(adg))

this.lm.mixed <- lme(SCR ~ FA, random = ~ 1|Year, SCR.dataframe)
summary(this.lm.mixed)
r.squaredGLMM(this.lm.mixed)

ggplot(SCR.dataframe , aes(x =FA , y = SCR)) +
  geom_point() +
  geom_smooth(method = "lm", se=F) +
  xlab("Forage Allowance, Kg DM/Kg BW") +
  ylab("Supplement Conversion Ratio")
```

APPENDIX B

Tables

Table 1. Average Monthly Temperatures and Precipitation near Stillwater, OK for Year One and Year Two of Study

	Mean Temperature ℃			Total Precipitation, mm		
Item	Year one	Year two	Normal[1]	Year one	Year two	Normal
September[2]	23	26	23	80	165	98
October[4]	15	13	16	119	99	83
November[3]	9	7	10	23	67	61
December	4	6	4	93	12	44
January	3	5	3	67	82	34
February	3	5	5	50	29	43

[1]Normal temperature and precipitation averages obtained for Stillwater, OK: U.S. Climate Data, https://www.usclimatedata.com/climate/stillwater/oklahoma/united-states/usok0507
[2]Planting dates: September 20th – 22nd, 2018 and September 16th – 18th, 2019
[3,4]First freeze occurred November 5th in YR1 and October 12th in YR2

Table 2. Randomized Treatment Groups for Year One and Year Two of Study

Pastures (2.7 to 5.1 ha)	Forage Allowance (kg DM/kg BW)	Supplement (1.5 kg/hd/d)	Treatment Group
	Year One		
5	3.5	1.5	HFAS
6	3.5	0	HFAC
7	3.5	1.5	HFAS
4	3.5	0	HFAC
8	1.5	1.5	LFAS
3	1.5	0	LFAC
2	1.5	1.5	LFAS
1	1.5	0	LFAC
	Year Two		
1	3.5	1.5	HFAS
5	3.5	0	HFAC
2	3.5	1.5	HFAS
6	3.5	0	HFAC
4	1.5	1.5	LFAS
3	1.5	0	LFAC
8	1.5	1.5	LFAS
7	1.5	0	LFAC

[1]LFAC = Low Forage Allowance Control, LFAS = Low Forage Allowance Supplementation, HFAC = High Forage Allowance Control, HFAS = High Forage Allowance Supplementation

Table 3. A & M Wheat Balancer R Mineral

Active Drug Ingredient		
Monensin		1600 g/ton
Guaranteed Analysis		
Calcium, minimum		12.20%
Calcium, maximum		14.60%
Phosphorus, minimum		2.50%
Salt, minimum		14.40%
Salt, maximum		17.20%
Potassium, minimum		0.70%
Copper, minimum	ppm	400
Selenium, minimum	ppm	26.40
Zinc, minimum	ppm	1,800
Vitamin A, minimum	IU per lb	150,000
Vitamin D, minimum	IU per lb	10,000
Vitamin E, minimum	IU per lb	50

Table 4. Energy Supplement Nutrient Analysis[1]

Soybean Hulls	50%
Wheat Middlings	50%
Nutrient Composition:	
NEm (Mcal/kg)	1.9
NEg (Mcal/kg)	1.3
TDN (% DM)	77.7
Fat (% DM)	8.4
ADF (% DM)	26.7
NDF (% DM)	29.6
CP (% DM)	13.2

[1]Near infrared spectrometry was used to analyze the energy supplement at Oklahoma State University Ruminant Nutrition Lab

Table 5. Treatment Effects on Cattle Performance[1]

	Low Forage Allowance		High Forage Allowance		*P* – Values[3]		
	Con	Sup	Con	Sup	FA Effect	Sup Effect	FA*Sup Effect
Forage Mass, Kg DM/ha	1627	1586	1825	1996	$P = 0.308$	$P = 0.756$	$P = 0.603$
Forage Allowance, Kg DM/Kg BW	1.77	1.72	3.49	3.53	---	$P = 0.999$	---
Stocking Density, steer/ha[2]	3.19	3.16	1.87	1.99	---	---	---
Initial BW, Kg	253	245	246	249	---	---	---
Final BW, Kg	329	347	343	372	$P = 0.001$	$P = 0.203$	$P = 0.604$
Average Daily Gain, kg/d	1.13	1.47	1.62	1.75	$P = 0.000$	$P = 0.004$	$P = 0.053$
Supplement Conversion Ratio	N/A	4.51	N/A	11.45	$P = 0.015$	---	---
Dry Matter Intake, % midpoint BW	1.94	1.94	2.33	1.92	$P = 0.035$	$P = 0.372$	$P = 0.14$
Standing Time, min/d	772	692	667	659	$P = 0.078$	$P = 0.187$	$P = 0.433$
Lying Bouts, bouts/d	8.3	11.5	14.2	12.8	$P = 0.002$	$P = 0.012$	$P = 0.015$
Steps, steps/d	2965	2794	2856	2445	$P = 0.581$	$P = 0.815$	$P = 0.682$

[1]Fifty six test steers (8 pastures) were used in fall/winter of 2018; and 41 test steers (8 pastures) were used in fall/winter of 2019
[2]Stocking density included put and take grazers to achieve designed FA
[3]Significance was achieved at $P \leq 0.05$
High Forage Allowance = 3.51 Kg DM/Kg BW
Low Forage Allowance = 1.75 Kg DM/Kg BW
Con = control groups receiving no supplementation
Sup = groups receiving 1.5 kg/hd/d of energy supplement

Table 6. Winter Wheat Pasture Nutrient Analysis[1]

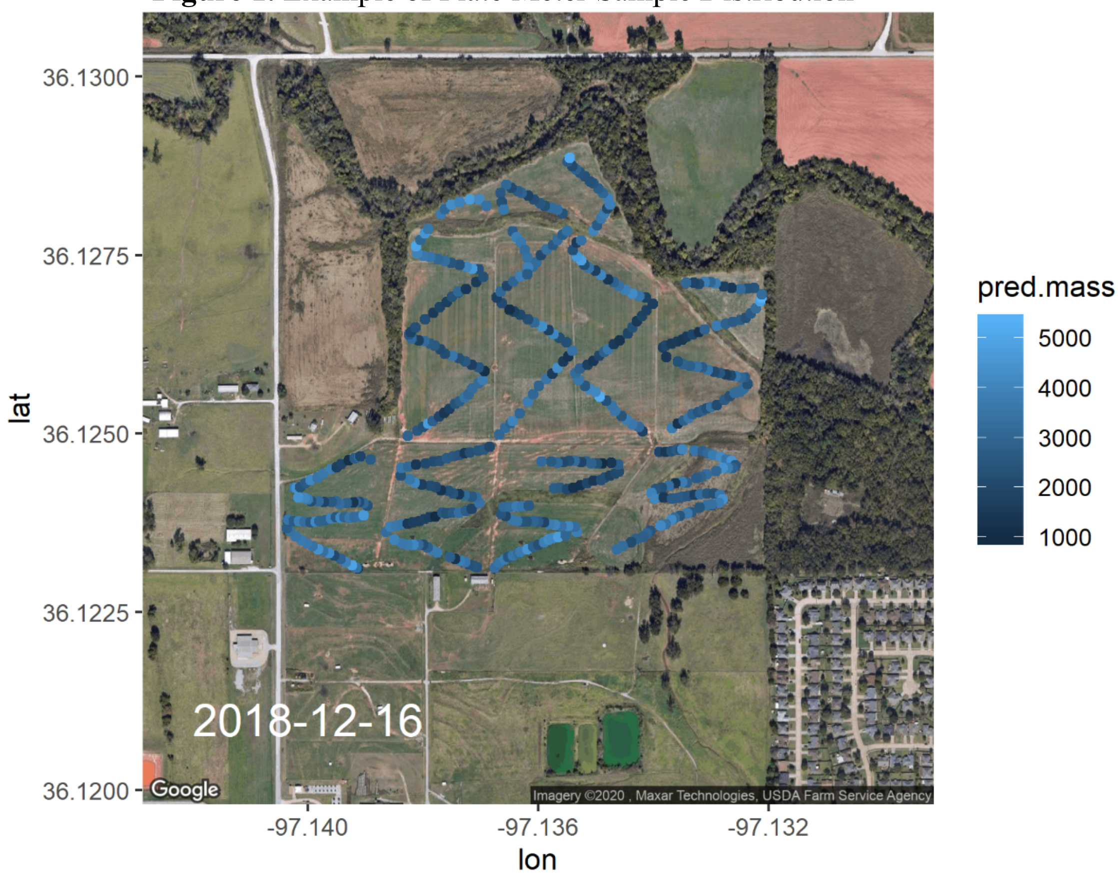
Nutrient Composition:	
DM (% AF)	30.2
TDN (% DM)	71.3
NEm (Mcal/kg)	1.7
NEg (Mcal/kg)	1.1
NDF (% DM)	46.0
ADF (% DM)	23.7
CP (% DM)	23.5

[1]Near infrared spectrometry was used to analyze the wheat forage at Oklahoma State University Ruminant Nutrition Lab

APPENDIX C

Figures

Figure 1. Example of Plate Meter Sample Distribution



pred.mass = quantity of mass in kg that the plate meter is predicting per measurement
Each blue dot represents a single plate meter measurement

Figure 2. Pasture Forage Mass over Year One and Year Two of the Study

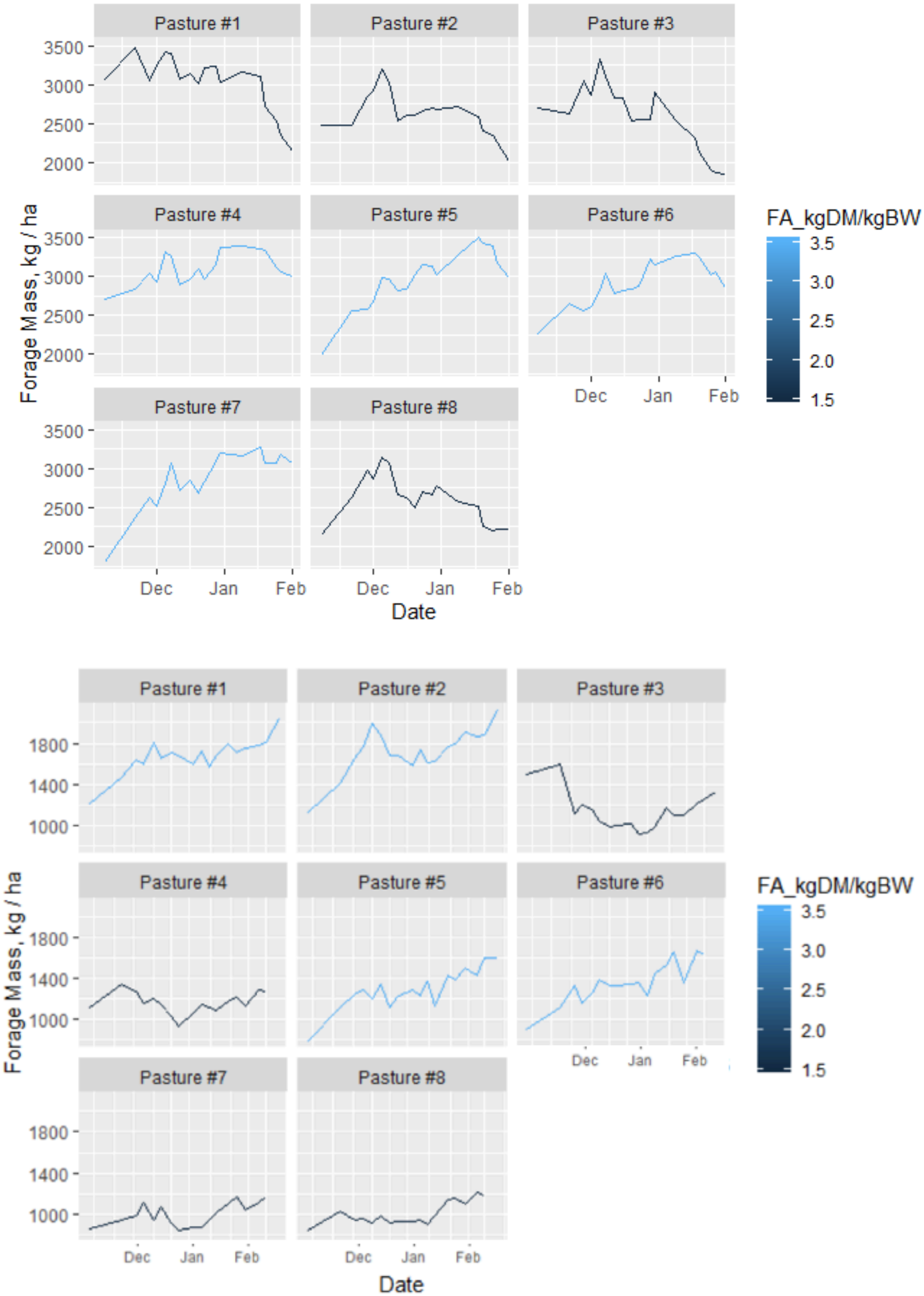


Figure 3. Cattle Bodyweights over Both Years of the Study

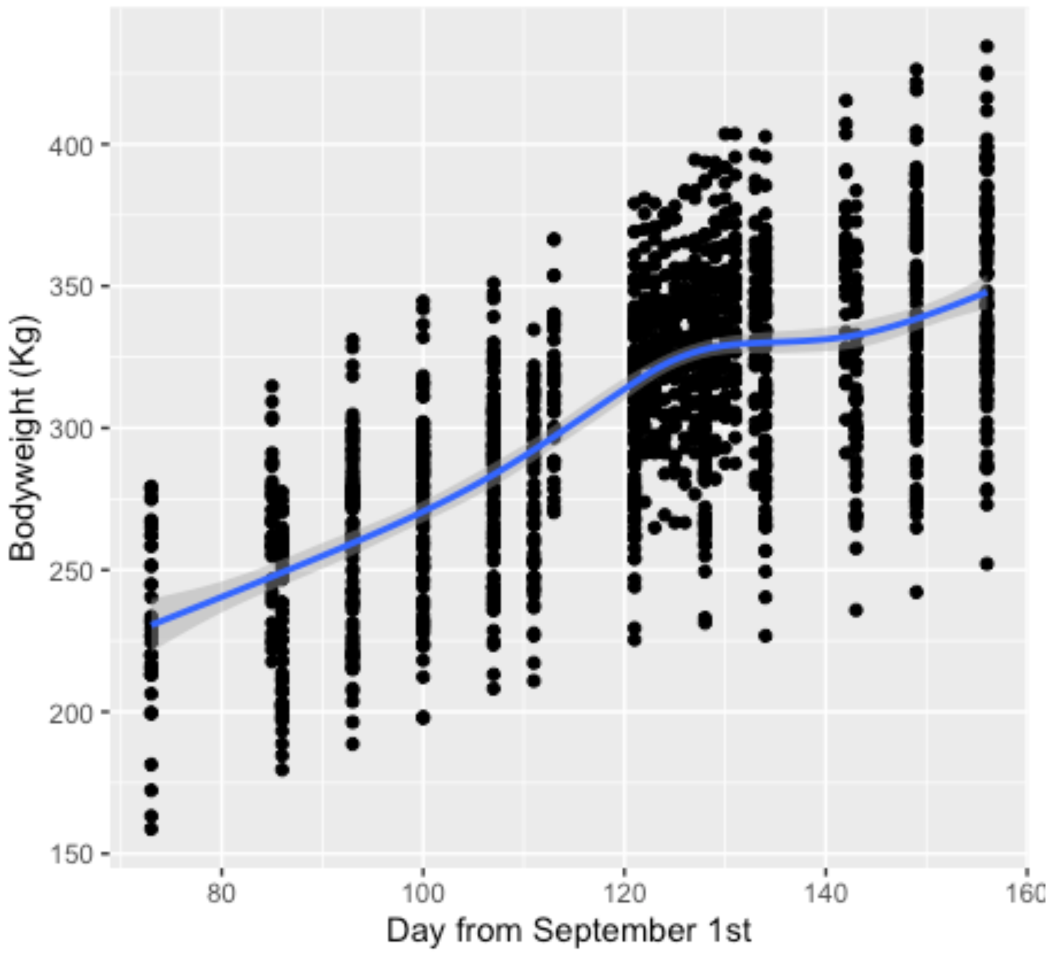
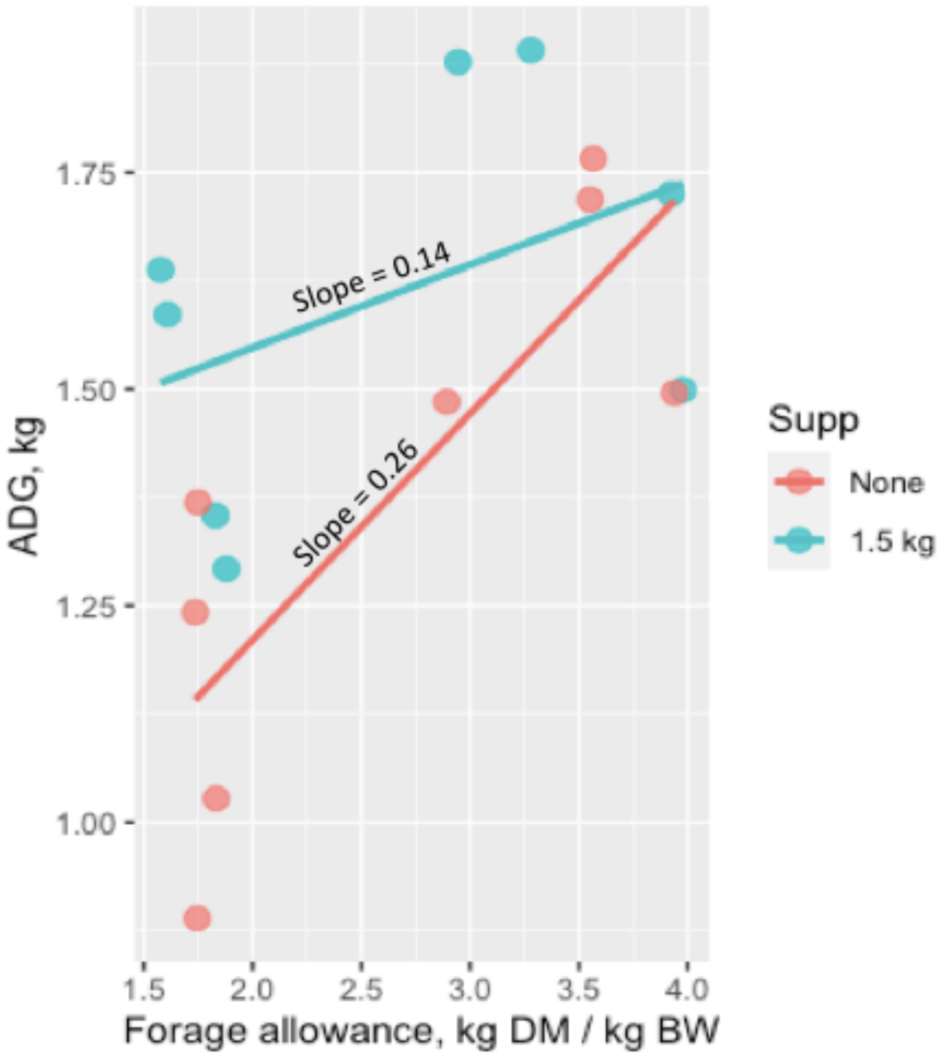
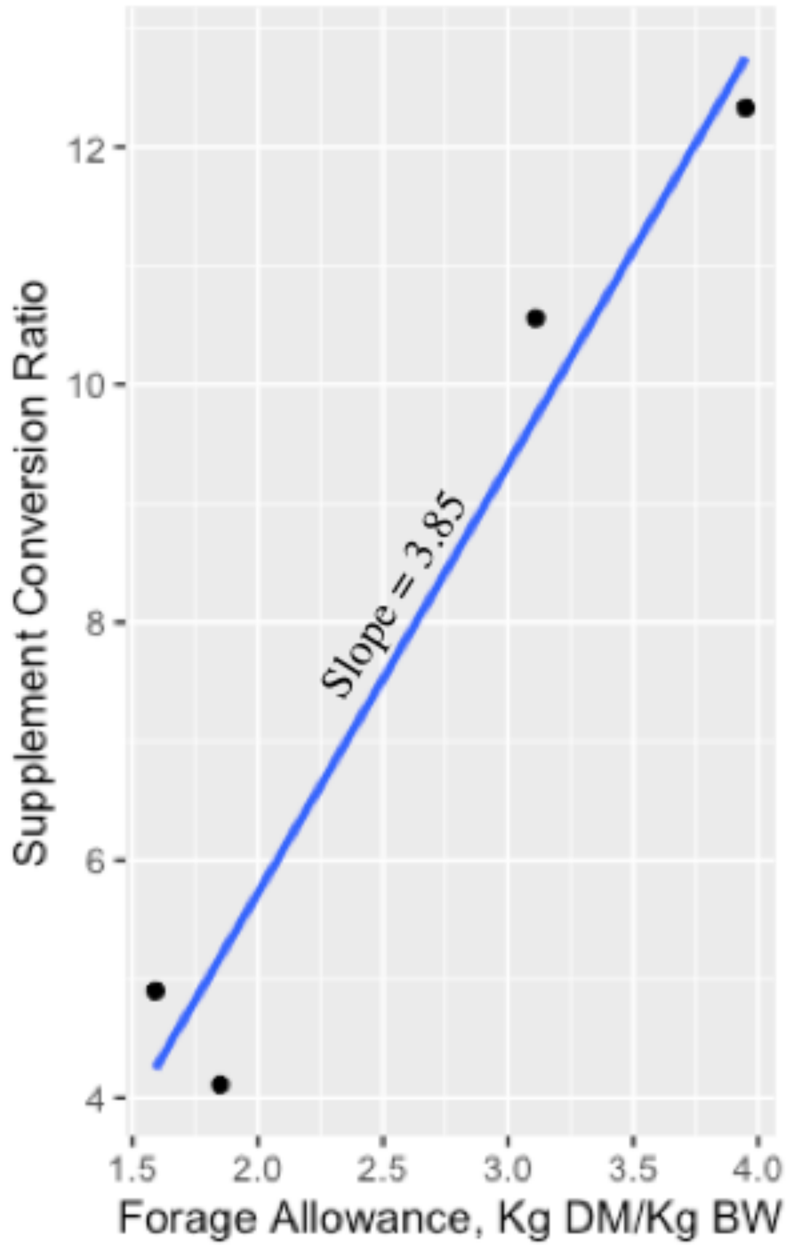


Figure 4. Effect of Forage Allowance and Supplementation on ADG



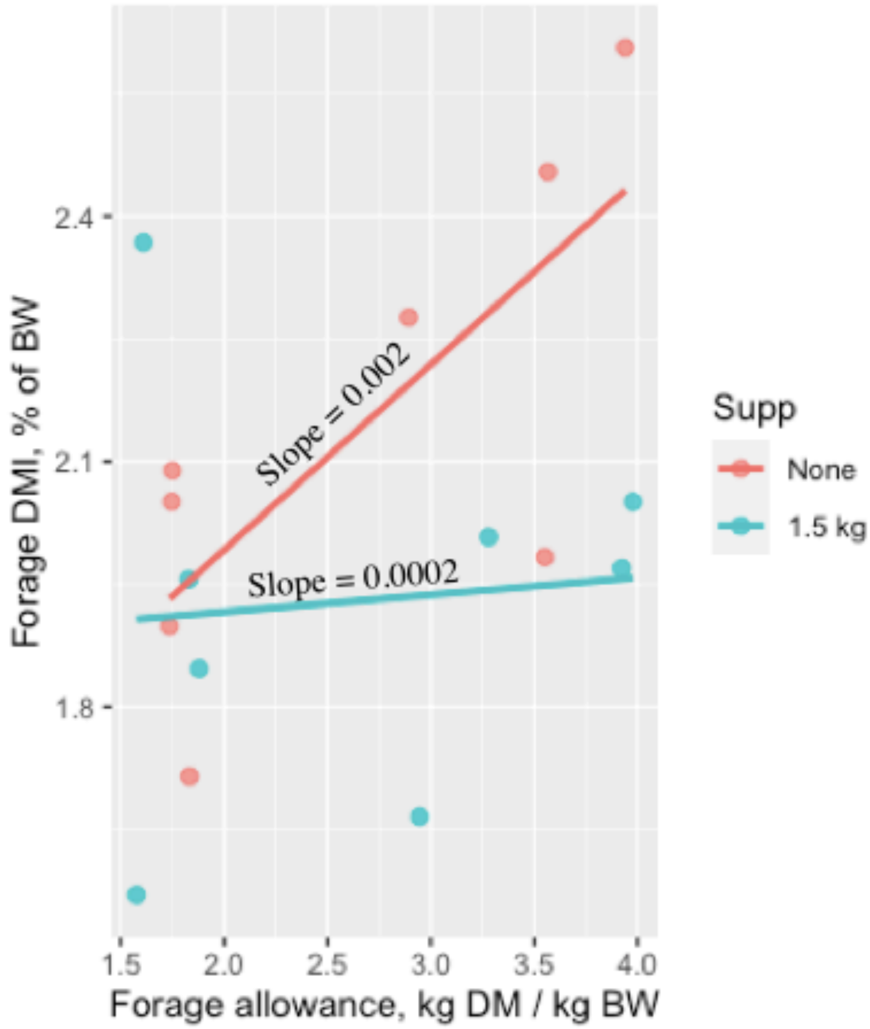
The interaction of forage allowance and supplementation significantly affected ADG of cattle. ($P = 0.05$)

Figure 5. Effect of Forage Allowance on Supplement Conversion Ratio



Forage allowance significantly affected supplement conversion ratio (P = 0.015)
Larger conversion ratio = lower efficiency of supplement

Figure 6. Effects of Forage Allowance and Supplementation on DMI



The interaction of forage allowance and supplementation marginally affected DMI of cattle. ($P = 0.14$)

Figure 7. Duration of Daily Lying Bouts

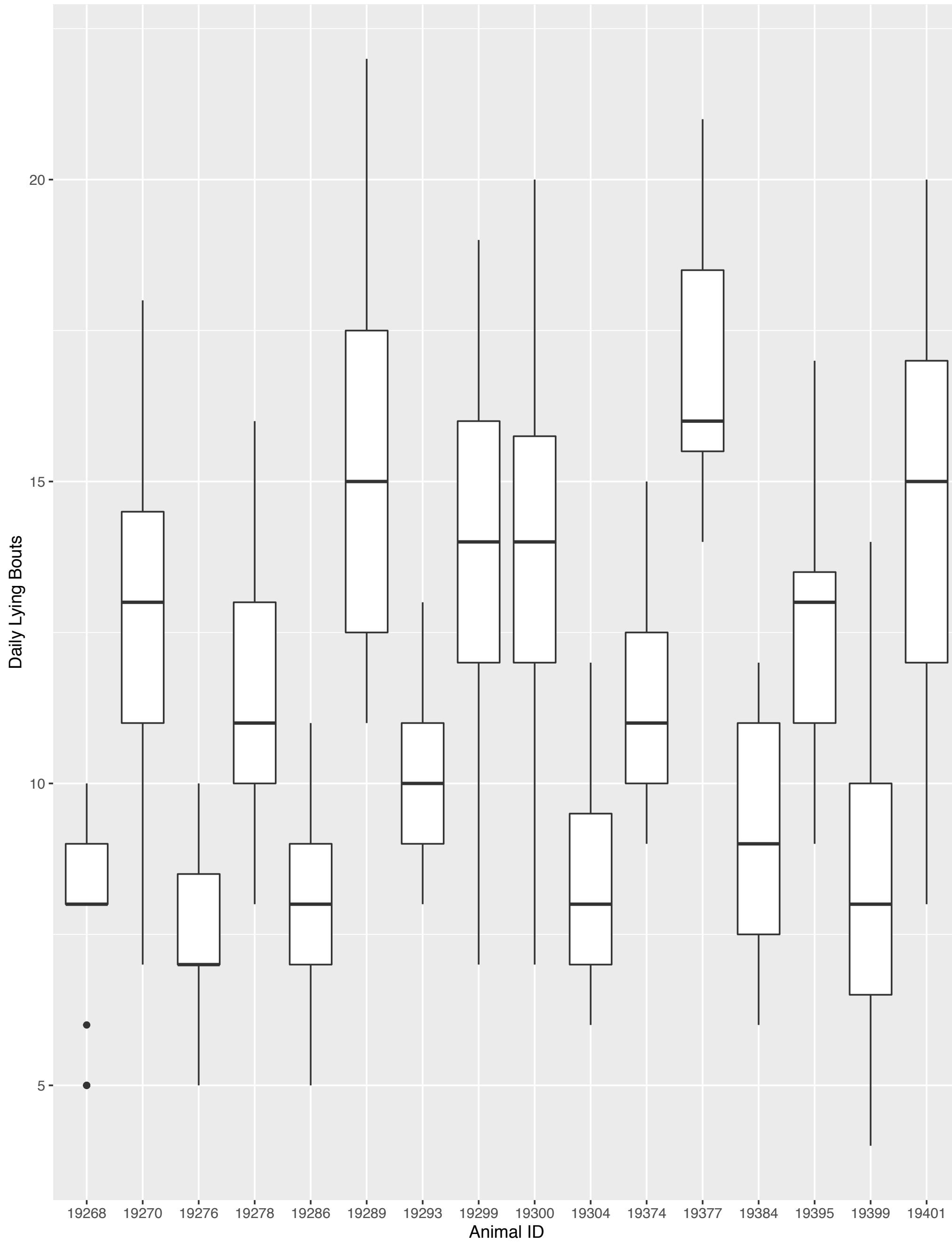


Figure 8. Duration of Daily Standing Time

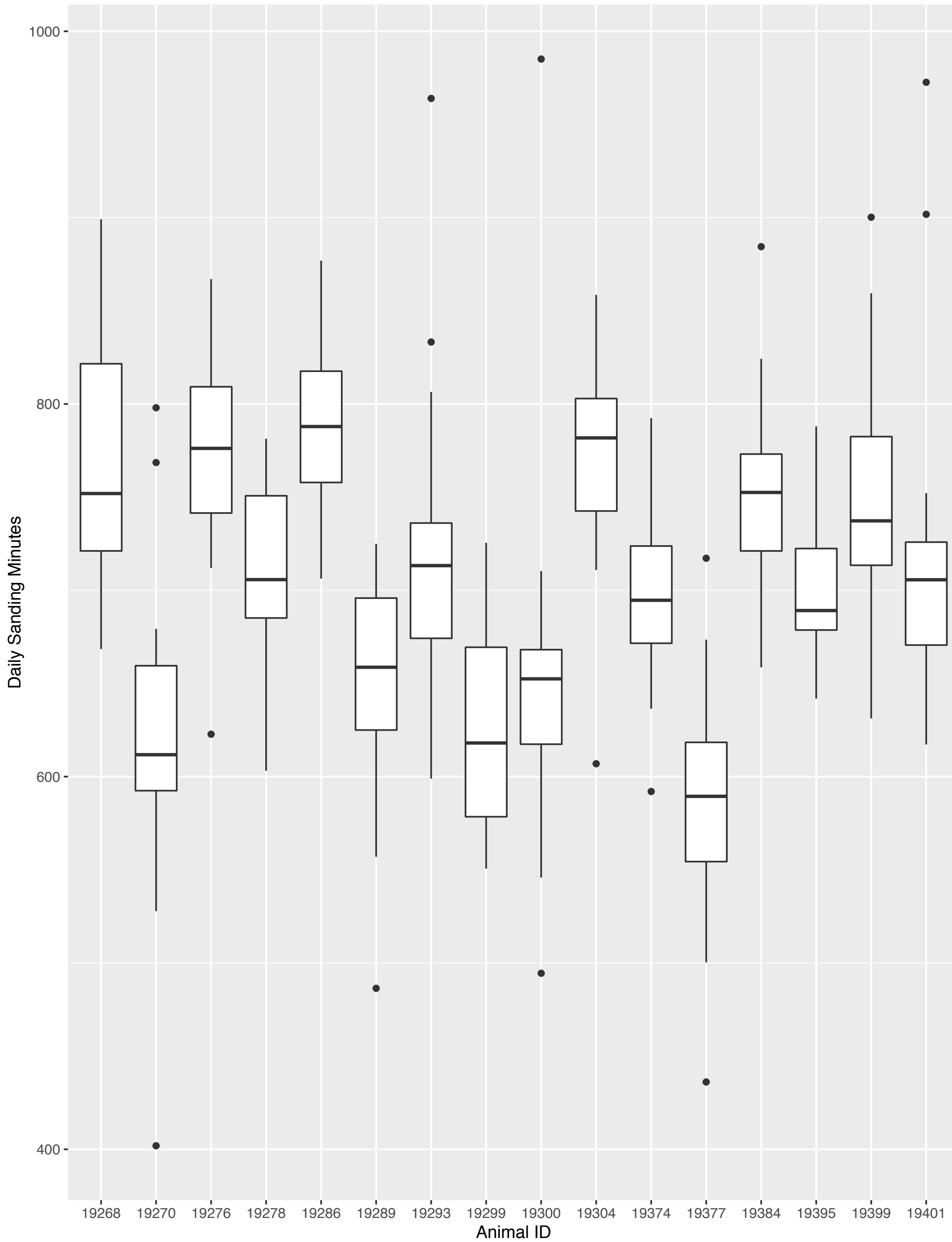


Figure 9. Quantity of Daily Steps

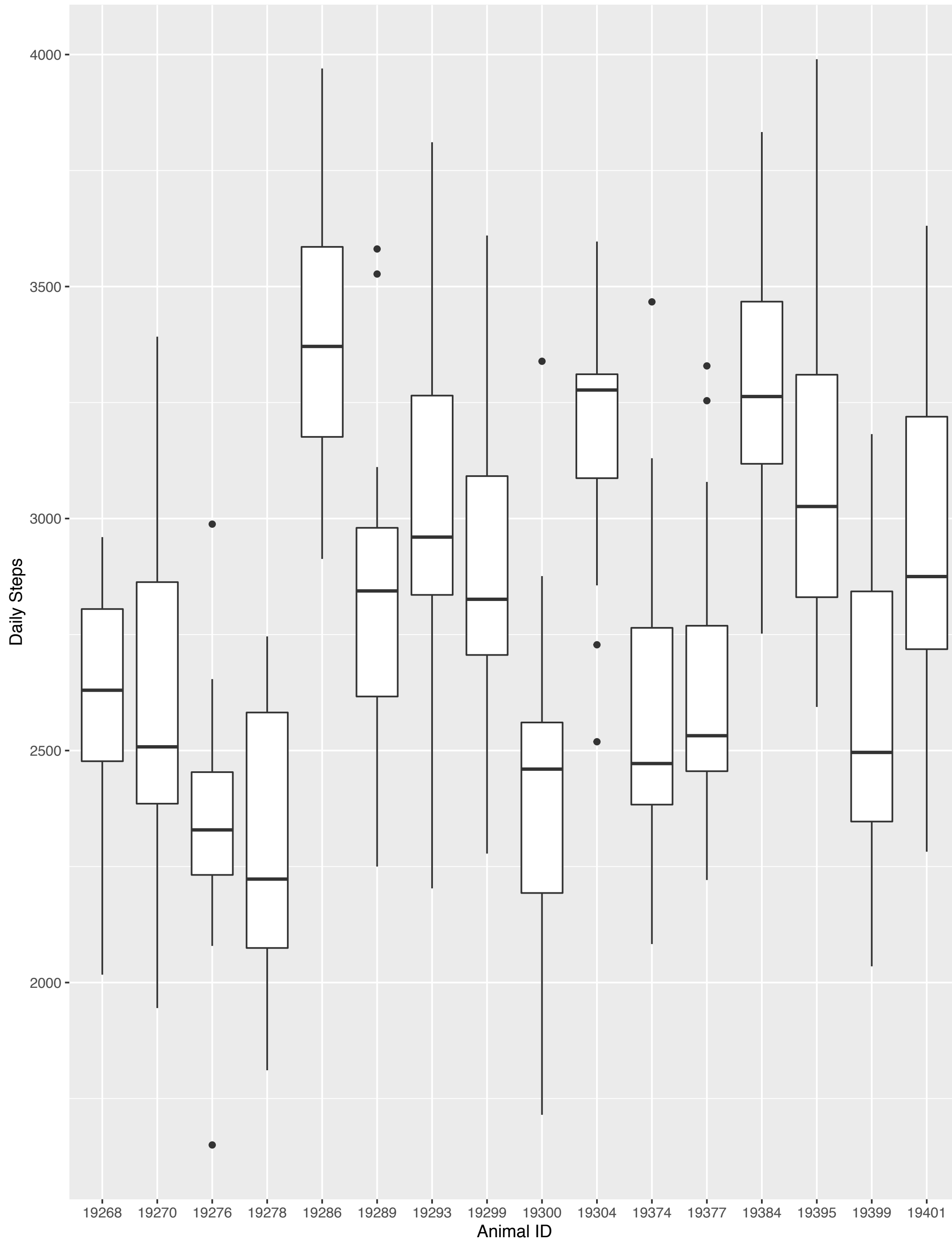
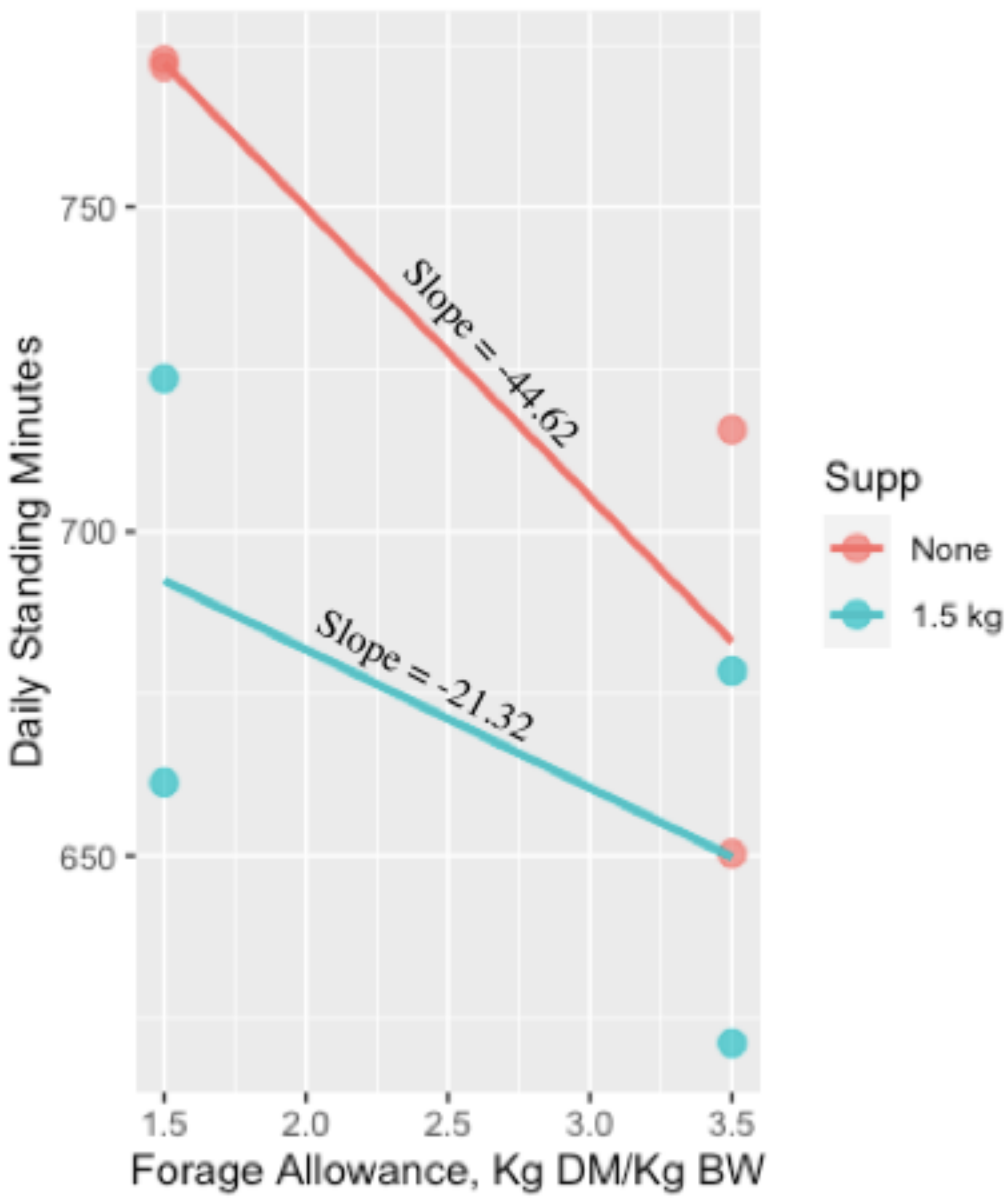
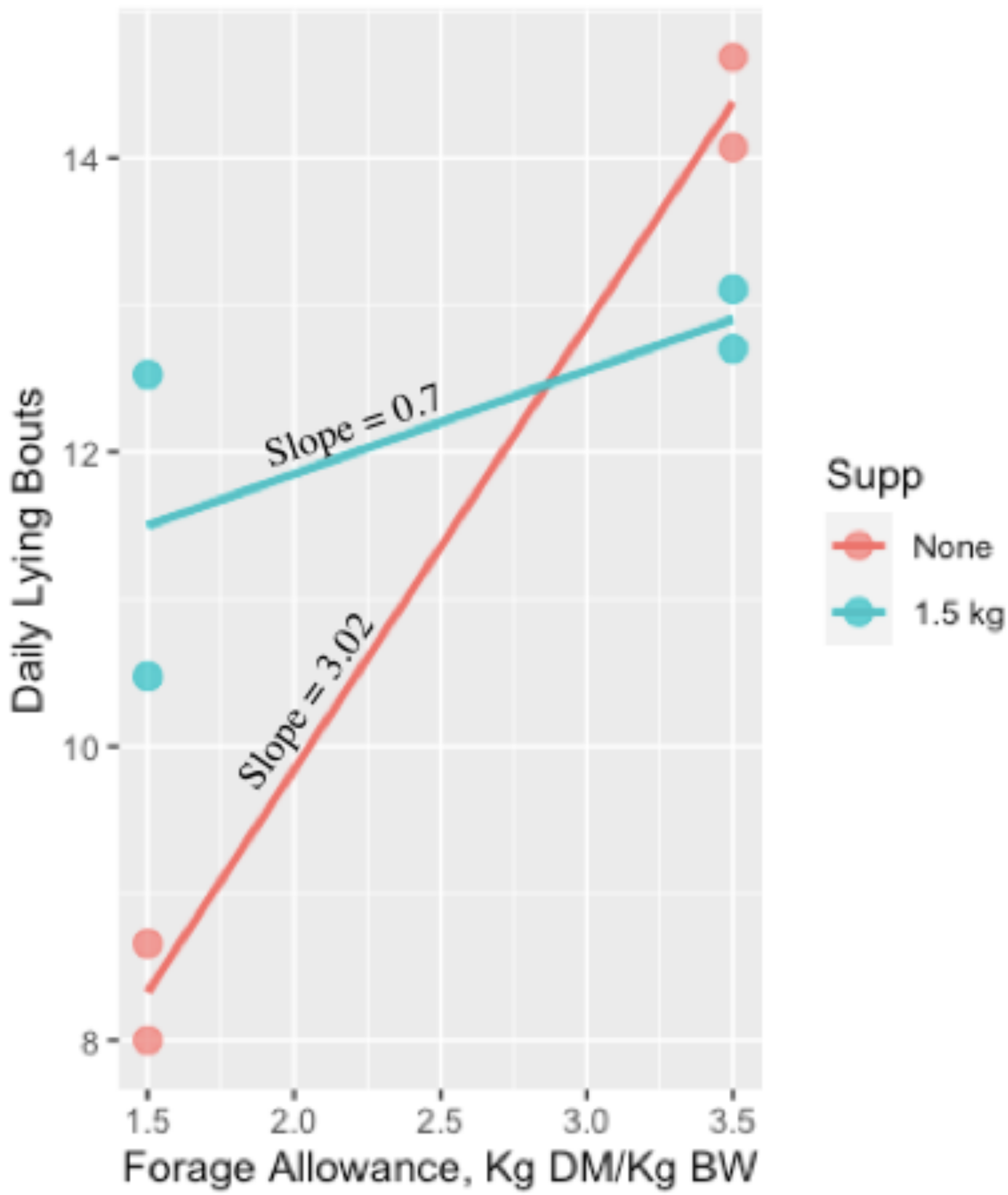


Figure 10. Effects of Forage Allowance and Supplementation on Daily Standing Time



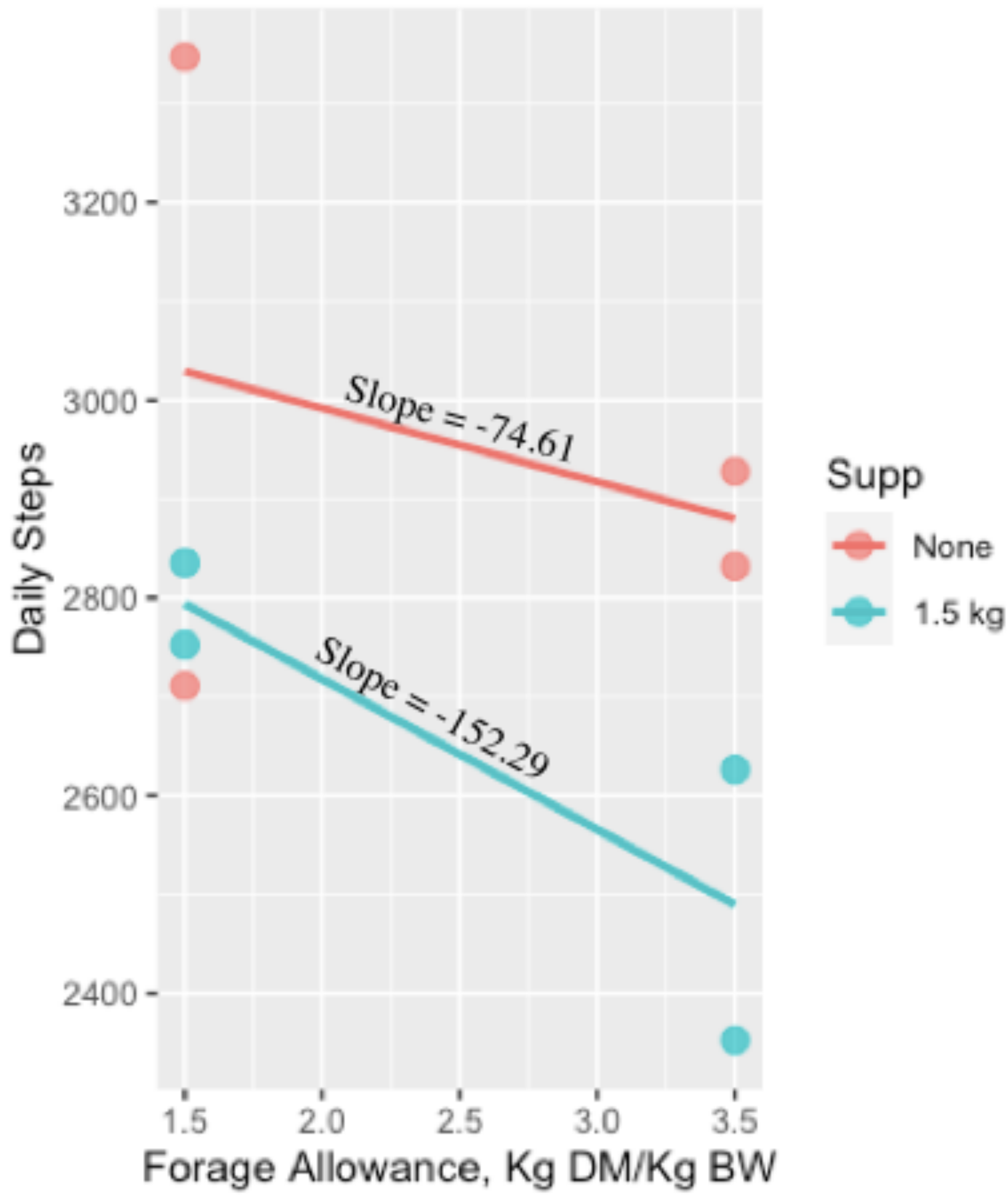
The interaction of forage allowance and supplementation did not affect daily standing time of cattle. (P = 0.433)

Figure 11. Effects of Forage Allowance and Supplementation on Daily Lying Bouts



The interaction of forage allowance and supplementation significantly affected daily lying bouts in cattle. ($P = 0.015$)

Figure 12. Effects of Forage Allowance and Supplementation on Daily Steps



The interaction of forage allowance and supplementation did not affect daily steps taken by cattle. ($P = 0.682$)

VITA

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