THE EFFECT OF SUPPLEMENTATION METHOD ON SUPPLEMENT INTAKE AND PERFORMANCE OF STEERS GRAZING DORMANT TALLGRASS PRAIRIE

By

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TALLGRASS PRAIRIE

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Abstract: The objective of this research was to determine the effect of supplementation method (hand-fed vs. *ad libitum* access) on supplement intake and performance of beef steers grazing dormant tallgrass prairie. The experiment was conducted for 56 d in late winter in central Oklahoma. Angus x Hereford steers (n = 40; BW = 242.6 ± 3.6 kg) were randomly assigned to one of three supplementation methods; either control (**CON**; no supplement; n = 8), hand-fed (**HF**; n = 16), or self-fed (**SF**; n = 16). Both the HF and SF treatments received a supplement consisting of 80% soybean meal and 20% soybean hulls (TDN = 76.6 %, CP = 43.9 %; DM basis). Sixteen steers were assigned to the HF, where 4 steers received either 0.39, 0.78, 1.17, or 1.56 kg per day, fed 3 days per week in individual stanchions. Sixteen steers were assigned to the SF group and received supplement via the SmartFeed system (C-Lock Inc., Rapid City, South Dakota). The SmartFeed is a portable, self-contained system designed to measure individual feed intake. The SF group had *ad libitum* access to supplement, to which NaCl was added to achieve mean intake of approximately 1.0 kg/d. The overall mean intake of supplement in SF ranged from 0 to 1.21 kg per steer per day. The CV for the SF animal on mean intake was 50.8% and animal on day-to-day intake was 96.7%. The mean NaCl that was present in the SF supplement was 40.5% and NaCl intake averaged 0.39 kg/d. Steers were weighed weekly and ADG and supplement efficiency was regressed on supplement intake, supplementation method, and the interaction. No significant difference between treatment group was detected for ADG (P = 0.24) or supplement efficiency (P = 0.30) regressions. Aggregated CV of weekly intake with animal significantly ($P \leq 0.01$) decreased residual ADG and residual supplement efficiency. Steers grazing dormant tallgrass prairie with minimal change in weekly supplement intakes had a slightly greater ADG and supplement efficiency. Directly managing supplementation may be more efficient than traditional, self-fed approaches that rely on NaCl as a limiter.

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Format of Thesis

This Thesis is presented in the Journal of Animal Science style and formant, as outlined by the Oklahoma State University graduate college style manual. This type of format allows for the research in Chapter III be suitable for submission to scientific journals. That chapter has been prepared from the data collected to partially fulfill the requirements for the Master degree. This paper is completed with an abstract, introduction, materials and methods, results and discussion, implications, literature cited section, and corresponding tables and graphs.

Chapter I

Introduction

Tallgrass prairie is one of the most important forage resources in the Southern Great Plains. However, sometimes supplementation is required to correct nutrient deficiencies, preserve forage resources, improve forage consumption, or improve animal performance. Supplementation programs need to be accurate and effective in providing needed nutrients for growth in an economical manner. As labor cost increase and/or labor becomes less available, interest in using self-fed supplements will likely increase. However, self-feeding assumes that individual animal consumption will be uniform across a herd. With new technology we can now test this theory in greater detail while having a minimal effect on normal grazing habits.

The goal of this research was to measure the effects that different supplementation methods have on supplement intake, variation that can occur when using a self-fed system, and identify the performance response between supplementation methods. Chapter II will provide a review of literature discussing the grazing habits of cattle, the different supplement types that are commonly provided to cattle, the factors that influence supplement intake within a herd, and some ways to influence these types of behaviors using intake limiters in supplements. Chapter III investigates the effect of supplementation method (hand-fed vs. self-fed) on protein supplement intake, performance, and supplement efficiency for steers grazing dormant tallgrass prairie. Chapter IV provides a brief summary of this research.

Chapter II

Review of Literature

Introduction

Forage is the major dietary component of grazing production systems in the United States, including beef cow-calf and stocker operations. Grazing systems have reduced inputs of labor, equipment, and fossil fuels used compared with confinement feeding (Soder et al., 2008). However, Lubowski et al. (2006) states that availability of grazing lands has decreased by approximately 25% from 1945 to 2002, or 0.44%/yr, making land availability the limiting factor for expanding cattle herds. From 2002 to 2012 the rate of reduction for grazing lands in the United States has accelerated to 0.60%/yr (USDA-NASS, 2004; USDA-NASS, 2014). Rural areas of the United States have experienced a greater reduction in grazing lands during this time (2004 - 2014), with a 3.5% reduction in the Southern Great Plains (USDA-NASS, 2004; USDA-NASS 2014). Due to these reductions in grazing lands, increased efficiency of forage based systems is needed in order to remain productive and meet market demands. Understanding grazing behavior, forage types, and supplementation practices in the Southern Great Plains is prerequisite for improved grazing management.

Foraging Behavior

Domestic ruminant animals self-select their diet from the feed choices that are available to them (Hofmann, 1993). Dietary selection varies across all grazing species (Walker, 1994). The difference in selection is caused by morphological and physiological adaptations. Ruminant animals can be separated into different categories: concentrate selectors, intermediate feeders and grass/roughage feeders (Hofmann, 1993). Concentrate selectors (40% of ruminant species; include mule or white-tailed deer) evolved earlier and select for plants or plant parts that are rich in easily digestible and highly nutritious starch, protein, and fat (Hofmann, 1993). Intermediate feeders (35% of ruminant species; include goats) fall between roughage feeders and concentrate selectors on the evolution time line and can adapt dietary selection to varying forage conditions (Hofmann, 1989). Roughage selectors (25% of ruminant species; include cattle and sheep), evolved later and predominately consume grasses and other fibrous forages that are high in cell-wall content.

Forage Preference

Preference can be defined as the discrimination exerted by animals for sward components and selection, acting as a function of preference modified by physical constraints (Hodgson, 1982). These physical constraints are based on post-digestive feedback and the animal's ability to discriminate between alternative forage types, which leads to alternative forages consumed (Hodgson, 1982; Hofmann, 1989). Walker et al. (1994) noted that cattle and sheep have greater overlap in forage selection, with the majority of forage selected being grasses as opposed to goats' selection towards browse forages (Migongo-Bake and Hansen, 1987; Kronberg and Malechek, 1997; Sanon et al., 2007). However, if availability of grasses is lowered, sheep can efficiently consume browse forage (Valderrabano et al., 1996).

Cattle Grazing Behavior

Cattle have relatively broad muzzles, a cornified tongue tip designed for maximal consumption of forages at low biomass, and shorter lips (Van Soest, 1994; NASEM, 2016). Cattle do not have upper incisors and use their tongue as a prehensile organ. Forage is swept into the mouth with the tongue, pinched between the dental pad and lower teeth, and then torn away.

Cattle can seldom graze forages less than 12mm in height, due to these prehensile methods (Walker, 1994). Ingestion methods make cattle less selective compared to sheep and goats. Based on the large gastrointestinal capacity, cattle retain forages longer allowing for additional microbial fermentation and increased digestion of low quality roughages (Van Soest, 1994).

Diurnal Grazing Pattern

Over the course of each day, cattle have 3 to 4 grazing periods (Mayland et al., 1998). During the day, photosynthesis causes soluble sugars to accumulate in leaves (Gregorini et al., 2007). This causes the DM and nonstructural carbohydrate concentration to increase and results in a decreased NDF concentration and increased digestibility (Delagarde et al., 2000; Gregorini et al., 2007). The longest and most intense of the grazing periods occur right at dusk, which coincides with the accumulation of photosynthetic products like carbohydrates (Orr et al., 1997; Gregorini et al., 2007). Mayland et al. (1998) showed that cattle preferred tall fescue (*Festuca arundinacea*) and alfalfa (*Medicago sativia*) hay that was harvested at dusk compared to in the morning. Allowing animals to take advantage of the increased nutrient density of the forages later in the day has shown to reduced enteric methane emissions with improved digestion of forages, which may decease environmental impact (Gregorini, 2012). However, grazing during this time may reduce herbage regrowth heterogeneity and reduce digestive constraints for future grazing (Gregorini, 2012).

Winter Grazing Cattle

Each year, thousands of fall-weaned calves are backgrounded on either dormant native range or winter wheat pasture in the Southern Great Plains (Hersom et al., 2004). This allows for cattle convert these forages, otherwise useless to the human population, into high quality protein from land not suited for cultivation or civilization. This type of practice has also been known to reduces soil erosion and enhances soil carbon storage (O'Mara, 2012). Backgrounding cattle on forage-based diets before feedlot placement generally reduces the total harvested feed and labor required during the finishing phase. At the same time, this may lead to a decrease in total DMI and days on feed within the feedlot and increase HCW and ribeye area (Reuter and Beck, 2013).

Cattle that graze dormant native range prior to being placed on a high-grain finishing diet have improved gains over cattle that grazed winter wheat (Choat et al., 2003). This is due to compensatory gain, which leads to greater feed efficiency and improved carcass weights in a feed yard (Sainz et al., 1995; Choat et al., 2003). However, steers that graze winter wheat prior to finishing have reduced days on feed and an increased final live weight, carcass weight, and carcass quality when compared to cattle grazing dormant native range prior to feedlot placement. Virgona et al. (2006) showed that intensively grazing winter wheat can reduce wheat yields by up to 33%, providing evidence that grazing native range as the ideal alternative. However, increasing the entry BW of the cattle being placed on wheat pasture can reduce grazing time with no effect on wheat yield or feedlot entry BW (Virgona et al., 2006).

Limiting Nutrients

Cattle have nutrient requirements based on BW, production level, environmental conditions, and genetics (Kunkle et al., 2000). A large portion of scientific knowledge has been integrated and recorded in the Nutrient Requirements of Beef Cattle (NASEM, 2016). Conceptually, a nutritionist has the ability to identify the specific requirements for beef animal, determine the nutritional value of the forage, and design the ideal supplementation program that provides the adequate nutrients lacking in the forage. However, it is difficult to determine the nutritive value of the grazed foraged because of the selectivity of grazing ruminants (Kunkle et al., 2000). In addition, animals have different nutrient requirements based on individual production level and BW, so individual animal's day-to-day selection and intake is highly variable (Bowman and Sowell, 1997).

Generally, protein is considered to be the dietary component that is "first limiting" in diets consisting of low-quality forage (Koster et al., 1996). The deficiency in protein leads to a depression of digestibility and intake and a subsequent decrease in the performance of grazing animals (McCollum and Horn, 1990). However, in situations where protein requirements are met, supplementing energy may be required to further enhance animal performance. Therefore, the level of protein or energy that needs to be provided requires some judgment using the estimated variation in animal's selection, cost of those nutrients, and the effect on performance that is associated with a deficiency. Determining the balance of protein and energy still offers many challenges, but technology and procedures such as fecal analysis by near-infrared spectroscopy provided by Lyons et al. (1995) and blood urea nitrogen developed by Hammond et al. (1994) offer indicators for protein-energy balance in cattle diets.

Supplementation

Numerous experiments are dedicated to improving the gain of grazing animals while consuming low quality forages. Review articles by Horn and McCollum (1987) and McCollum and Horn (1990) summarize supplementation feeding strategy in greater detail.

Cattle grazing dormant range may encounter many deficiencies. In the Southern Great Plains native range is typically of low nutritive value (< 6% CP, DM basis) in late winter, which decreases the degradation of fibrous materials by ruminal microorganisms (Russell et al., 1992; Detmann et al., 2009). Therefore, supplementing cattle to provide sufficient protein, energy, minerals, and vitamins to balance the deficiencies from the forage is required to improve ADG and increase BW (Rusche et al, 1993). Corbett (1981) reported that supplementing protein increased energy or forage intake by increasing the ruminal DM turnover rate and improving digestion efficiency.

Supplement Type

Feeding proper amounts and types of supplements can improve the utilization of low-quality forage and improve production (Fleck et al., 1988: Ovenell et al., 1991). However, there is a deviation between expected and observed performance due to associative effects of supplementation upon intake and available nutrients from the total diet (Moore et al., 1999). When grazing forage, supplementation can increase or decrease forage intake. Supplying more TDN may result in a substitution effect where forage intake and digestibility is decreased. This inconsistency is associated with the relationship of TDN to CP in forages, an indication of the quantity of N compared to available energy (Moore et al., 1999). Bodine et al. (2000) and Bodine and Purvis (2003) found that the supplement type (protein or energy; starch or grain by-product) and level fed influenced the amount of rumen degradable protein (RDP). This amount of RDP provided may alter the amount of forage consumed and can either improve or hinder performance. Without adequate amounts of RDP being provided, reduced intake and digestibility of low-quality forages are expected (Bodine and Purvis, 2003).

Energy Supplementation

When forages are the only source of energy for growing cattle, growth rate can be less than desired to meet production goals, even when forage allow can provide adequate amounts of N for improved animal performance (CP > 6%). Providing an energy supplement could improve ADG of animals or stretch the forage supply and increase grazing time on pasture. To provide additional energy to the animal successfully, CP or N requirements must first be met, or decreased forage digestion and utilization can occur (Horn and McCollum, 1987).

Supplementing energy to grazing livestock can result in forage substitution (Horn and McCollum, 1987). This substitution is the change in forage intake per unit increase in energy supplement. The review paper by Moore et al. (1999) reported that supplements decreased forage intake when supplemental TDN intake was > 0.7% BW, when forage CP was greater than 6%, or when forage voluntary intake was > 1.75% BW. This substitution ratio becomes more pronounced with increasing forage digestibility (Horn and McCollum, 1987).

If N is adequately provided in the diet, either by forage or by protein supplement, an energy supplement can increase animal performance (Horn and McCollum, 1987; Kunkle et al., 2000). Horn and McCollum (1987) suggested offering energy supplement fed at 0.5% BW or less have little to no effect on forage substitution. Furthermore, Bowman and Sanson (1996) suggest that intake of energy supplement at 0.25% of BW had little to no effect on forage intake while increasing ADG.

With high-quality forages that exhibit a TDN to CP ratio less than 3:1 as stated by Hogan (1981), there is a need for an increase in energy in the rumen to establish a more effective ammonia utilization. Vogel et al. (1987) found that supplementing energy to cattle grazing wheat pasture has the potential to increase stocking densities without decreasing weight gains. This causes a forage sparring effect that adds stability to a very unstable forage that corrects the TDN:CP imbalance.

Energy Feeds

Providing an energy supplement may reduce forage intake and digestibility, a tradeoff that is more prevalent at higher levels of energy such as corn supplements (Horn and McCollum, 1987). Providing a high level of nonstructural carbohydrates (starch) in a supplement will decrease ruminal pH and reduce the growth of fibrolytic bacteria. However, Bowman and

Sanson (1996) concluded that supplement with fibrous by-products that are low in nonstructural carbohydrates will minimize that effect on forage intake and digestion.

Of the fibrous by-product feedstuffs, soybean hulls are the most commonly used (Marston et al., 1993). Soybean hulls are high in digestible fiber (≥77% TDN) and should increase energy intake with no effect on forage intake when supplemented to cattle on low-quality forages (Marston et al., 1993; Bowman and Sanson, 1996). Martin and Hibberd (1990) found that forage intake peaked with 1 kg of soybean hulls supplemented. Soybean hulls fed at a moderate level (at least 0.5% of BW) also enhances total tract digestibility of DM, OM and CP than forage alone (66.7% vs. 51.83%) (Orr et al., 2007). Despite being high in fiber content, soybean hulls produce greater concentrations of VFA averaging 168.4 mM L^{-1} compared to 150.4 mM L^{-1} from corn and 132 mM L^{-1} from hay alone (Nguyen et al., 2007). This is consistent with the diets from Anderson et al. (1988) (1.36 kg/d), Grigsby et al. (1992) (60% of total DMI), and Martin and Hibberd (1990) (1 to 3 kg/d) that fed soybean hulls at a rate of 1.36 kg/d, 60% of total DMI, and 1 to 3 kg/d respectively, had less negative effects on forage digestion or forage intake compared to corn-based supplements.

Protein Supplementation

Only providing energy concentrates is rarely a successful means of increasing the energy status of grazing livestock consuming forages low in N (< 6% CP). Insufficient N from the diet suppresses forage digestibility and intake and decreases the efficiency of metabolizable energy utilization (McCollum and Gaylean, 1985; MacRae et al., 1985). When performance is suppressed due to insufficient N provided by the forage intake, protein supplements are required to meet N deficiency.

McCollum and Galyean (1985) reported that 800 g/d of cottonseed meal fed to cattle on low-quality forages resulted in increased rate of forage degradation by 3.6% and particulate passage by decreasing turnover time by 4.3 h. The increase in particulate passage is the major factor associated with increased intake. Supplementing cattle with a high concentration of CP while grazing low-quality winter range can reduce BW losses that normally occur (DelCurto et al., 1990; Beaty et al., 1994; Hollingsworth-Jenkins et al., 1996). Mathis (1998) and Olson (1998) found that the reduced BW loss is primarily due to the increase in CP. Supplementing protein allows for the correction of the ruminal N deficiency, which improves forage (energy) intake (McCollum and Horn, 1990). Caton et. al. (1988) determined that protein supplementation can alter ruminal NH_3 and VFA concentrations, while improving passage rates and digestibly of forage with a slight increase on intake.

With low quality forages, protein available for ruminal degradation is limited, while a positive correlation exists between protein supplementation and forage consumption (Stockes et al., 1988; Koster et al., 1996). Koster et al. (1996) found that feeding a protein supplement that meets 11% (or 4 g/kg $BW^{.75}$) of degradable intake protein maximizes organic matter digestion of dormant tallgrass-prairie forages. However, it should be noted that when forage is inadequate in suppling RDP, ruminants have a salvage mechanism that exists to recover some of this N. Nitrogen supply from blood urea N can be recycled back to the digestive tract in order to sustain microbial synthesis that supple amino acids to the host animal (Van Soest, 1994). In both cattle and sheep, as much as 40 to 80% of urea produced by the liver can enter the gastrointestinal tract (Harmayer and Martens, 1980). Yet, the NASEM (2016) suggests that if this recycled N makes up a large percentage of the supply of ruminal N for a long period of time, protein requirements may prove to be inadequate, resulting in reduced or hindered performance.

Protein Feeds

Soybean meal is a good source of RDP and provides a significant performance response when supplemented (Stokes et al., 1988). The high content of RDP increased N and energy supply to the host. Mathis et al. (1999) found that supplementing soybean meal at approximately 0.3% BW/d to cattle grazing dormant native range can dramatically improve intake by 38.2 g/kg $BW^{.75}$ and total tract digestion by 9.9%. Stokes et al. (1988) reported that the microbial N and feed N flow into the small intestine of cows consuming low quality hay (4.7% CP) increased daily forage intake by 1.4 and 2.2 kg when fed 0.12 and 0.24% BW supplemental soybean meal.

Providing ruminally undegradable protein (RUP), such as direct fed amino acid (AA) or heat treated protein meals, as an alternative to RDP may delay ureagenesis, thus reducing the timing of N recycling and decrease performance. However, Bohnert et al. (2002) suggests that feeding RUP may support a more stable rumen environment by providing a constant N source to the rumen microbial from recycled N. This may result in improved forage intake and utilization by the animal, with the potential to reduce the need for protein supplements. This could be caused by moderating ammonia concentrations in the rumen, which provides a mechanism for sustained recycling of N (Bohnert et al., 2002).

Mineral Supplementation

Rarely can forages supply satisfactory amounts of minerals required for grazing livestock (McDowell, 1992). Many plants may not readily accumulate Se, Co or I to grow normally and Fe, Zn, Mn, Cu and Co are relatively low when compared to the required amounts by livestock (McDowell, 1992; Rode et al., 1993). Thus, it becomes necessary to provide supplement minerals to improve efficiency and production. The most common method for providing mineral supplements is by free-choice feeding (McDowell, 1992). This method assumes that livestock are capable of recognizing deficiencies in the diet and consume adequate amounts of mineral to rectify that deficiency (Rode et al., 1993). However, Arnold (1964) found that most animals exhibit little nutritional wisdom and select based on palatability rather than nutritional need, even when health is deteriorating and near death. Like many free-choice supplements, consumption of free-choice mineral mixtures may be highly variable and may not be influenced by mineral requirement (McDowell, 1992). A range of 0 to more than 1000 g/d on individual cattle consuming dicalcium phosphate was detected by Coppock et al. (1972) while measuring mineral intake for lactating dairy cows.

However, free-choice minerals still have some advantages. Fieser et al. (2007) found that combining an ionophore with free-choice mineral supplementation improved ADG over the negative control and non-medicated mineral groups. Thus, it may be advantageous if a ionophore was fed to grazing livestock with free-choice mineral, energy or protein supplementation.

Feeding Efficiency

Improved feed efficiency and practices that are associated with feeding strategies may be ideal for better animal performance. Production efficiency can be described as marketable output per unit of input, with each output being weighted by the relative economic importance (Berry and Crowley, 2013). Although feed efficiency in grazing systems is not synonymous with production efficiency, it plays a large role in increasing production efficiency by decreasing land resources required for food production.

Measuring feed efficiency as residual feed intake (RFI) of cattle in a backgrounding phase can prove to be beneficial to performance in the feed yard. Russell et al. (2016) found that the backgrounding phase diet can influence feed efficiency. Maintaining a similar diets of forage or grain through the backgrounding and finishing phase may improve ADG and G:F ratio through the finishing phase. However, there is a negative effect on performance when the diet is changed during the transition from backgrounding to the feed yard (Russell et al., 2016).

The accuracy of feed efficiency measurement can vary greatly among individuals. This variability can be attributed to activity level, methane production, tissue metabolism, and diet digestibility. Richardson et al. (2000) reported that activity level accounts for 10% of the variation in feed efficiency with cattle from an experiment with bulls and heifers measuring activity with the use of pedometers. Diet digestibility differences among individuals can be responsible for 10 to 14% of feed efficiency variation (Richardson and Herd, 2004). If digestibility and nutrient supply vary, Johnston et al. (2002) found that IGF-1 can be influenced as it markedly increases protein deposition in muscle. All of these factors may regulate protein activity, making it hard to find the mechanism that allow for positive effects on feed efficiency.

Animal Factors Influencing Intake

Several factors that influence an animal's acceptance of supplements and feeds are independent of palatability. Grazing animals are sometimes reluctant to try novel feeds, but this behavior can dissipate with time or in the presence of experienced animals (Bowman and Sowell, 1997). Furthermore, Bowman and Sowell (1997) noted that animals fed in groups often consume less feed and decrease daily variation of intake compared to animals fed individually.

Experience

Livestock often exhibit neophobia, a phenomenon where an animal rejects or consumes low amount of new feeds (Launchbaugh, 1995). While experiencing neophobia, animals undergo a period of low feed intake, followed by increased consumption which stabilizes over time. Neophobia has been expressed as a survival mechanism for avoiding over consuming of toxic plants (Launchbaugh, 1995). Variation in initial intake typically decreases with time (between 7 to 14 d), as animals go through the neophobic patterns when introduced to an unfamiliar supplement (Launchbaugh, 1995; Kunkle et al., 2000). Bowman et al. (1995) found that cattle consumption rate of supplement was 72% lower over an experiment when comparing 2-yr-old cows to 3-yr-old cows.

Animals that have experience consuming a particular feed are more likely to consume it, compared to their inexperienced counterparts. Early experience may increase intake of the introduced feeds at a later date. This was evident in the experiment conducted by Distel et al. (1994), where sheep had improved intake of low-quality forage as compared with inexperienced animals. Chapple et al. (1987) and Juwarini et al. (1981) found that it took sheep at least 2 wk longer to overcome neophobia and fear of the trough before consuming a grain based diet than those previously exposed.

Social Interaction

Social interaction of individual animals plays a fundamental role in supplement consumption by grazing animals. More aggressive and dominant animals typically have higher intake of supplements and can even force small timid animals away from the feeding area (Bowman and Sowell, 1997). However, it may be possible to alter these dominance patterns by changing to a self-fed method. This allows for animals to consume supplement at varying times throughout the day.

Cattle are normally gregarious animals and arrange into a hierarchy, based on their temperament and willingness to compete for limited resources (Phillips and Rind, 2002). Wagnon et al. (1966) reported strong dominance in mixed-breed cattle herds. When hand-feeding these cattle in large groups, the Angus influenced cattle held a social dominance over Herefords. Age can also alter this hierarchy. Older animals in a herd tend to have greater intake than younger animals, but this may vary and even change with different methods of supplement delivery (Kunkle, 2000). Bowman et al. (1995), found that older cattle had increased intake during first exposure to conventional lick-tanks in grazing cow herds. Interestingly, it has been reported that for sheep (Arnold and Maller, 1974) and cattle (Bowman et al., 1995), body size, did not influence social dominance.

It seems that supplementing animals in large groups (maximum competition) will increase the percentage of non-feeders (those not consuming supplement) and decrease individual intake. Webb et al. (1973) compared group feeding to individual feeding of a liquid supplement, and found that intake was lower (2.7 kg/d) for group-fed cows compared to the individually fed cows (3.7 kg/d). Kendall et al. (1983) different results in ewes, as average supplement intake was identical for individually supplemented (CV = 42%) and group-fed (CV = 40%), but saw a reduction in variation (CV = 39%) when meal based supplement was fed in troughs for grouped ewes.

Frequency of Supplementation

The frequency of supplementation is a greatly debated topic among nutritionists. The most common frequencies that have been studied are daily, every other day, and, 3, 2 or 1 weekly. Different frequencies may be an attempt to decrease variation by manipulating competition, decrease cost of the supplement delivery, achieve a target performance, or reduce labor (Kunkle et al, 2000). However, the frequency of supplementation that is chosen may be the result of the ideal intake or for dosing a feed additive, but in these cases forage quality is not the limiting factor on production.

Frequency of Energy Supplementation

Feeding grain-based supplements while cattle are grazing low-quality forage has been extensively researched (Wallace, 1988; Chase and Hibberd, 1989; Karchener and Adams, 1982). Wallace (1988) compared supplementing a low-protein grain cube (9.4% CP) at either 5.7 or 6.4 kg/wk to heifers on native range either daily or twice weekly, and observed no significant differences in weight gain. Chase and Hibberd (1989) compared supplementing corn daily or every other day at rates of 0.8 or 1.7 kg/d which resulted in a decrease in ruminal pH (6.35 compared to 6.42 respectively) by the different supplement frequencies, but returned to normal the next day for the alternative day feedings. The slight changes in pH or supplementation frequency did not influence OM intake. There was a significant ($P < 0.05$) 4% decrease in OM digestibility when the supplement was provided on alternate days. However, Karchener and Adams (1982) found a 34 kg gain advantage over a 10-wk period by supplementing 1.5 kg/d corn daily compared to alternate-day frequencies.

Frequency of Protein Supplementation

Pope et al. (1962) evaluated the effects of supplementing cottonseed meal (CP = 44%) at 3 to 8 kg/wk at various frequencies (every 2, 4 or 6 days). No difference among treatments was, although a numerical decrease in ADG was observed across all frequencies. A metabolism experiment conducted by Coleman and Wyatt (1982) evaluated the effect of supplementing 2.9 kg/wk of cottonseed meal fed daily, on alternate days, or every 4 d. For the treatments that received cottonseed meal, there was no effect on DMI or digestibility for steers fed average quality native range hay (7.9% CP). In the second experiment, feeding daily and alternative days had no effect on BW, as the control and treatment fed every 4 days' lost an average of 36.5 kg over the experiment. Bishop et al. (1992) measured blood metabolites when cottonseed meal (6.4 kg/wk) was supplemented daily or every 4 days with a low-quality hay diet. The steers fed daily had greater forage intake (6.67 compared to 5.18 kg/d), which was a result of increased OM digestibility, leading to increased blood glucose levels. However, steers fed every 4 days had improved N recycling and higher blood urea N than steers fed daily. This increased blood urea N suggests that those fed every 4 days had lower N excretion, but may hinder production due to AA degradation within muscle tissue (Lapierre and Lobley, 2001). When RDP (isolated soy-protein fed at 0.23 and 0.3% BW/d) was supplemented on alternate-days to lambs consuming low quality forage, it had little effect on forage intake (848 g/d) or total tract OM digestibility (55%) compared to daily supplementation (924 g/d and 50%) (Atkinson et al., 2009). This suggests that sufficient N was conserved and recycled to support microbial metabolism, while also providing adequate AA for tissue metabolism (Lapierre and Lobley, 2001).

Intake Variation

Efficient conversion of grazed pasture and supplementary feed into BW gain is essential for profitability of growing cattle in the Southern Great Plains. The effective response from a supplementation program is affected by the ability to decrease each animal's intake variation and to meet target supplement consumption by individual animals. Intake of supplement by herds is usually measured by dividing the supplement disappearance by the number of animals and then dividing by days (Bowman and Sowell, 1997). However, this method does not consider the variation of intake by individual animals or the potential problems if the supplement is not consumed at a consistent rate.

Schauer et al. (2005) found that decreasing the supplementation events of grazing cattle from daily to once every six days did not influence forage consumption or individual supplement intake of cottonseed meal (0.91 kg/d). The supplement intake variation was the same in both treatments (CV = 28%). This contrasts with findings by Huston et al. (1999) where there was

33% less variation in individual supplement intake when cattle were supplemented 3 times weekly compared to once weekly. This reported decrease was attributed to the increased supplement offered with the decreased frequency of supplement events.

Offering large amounts of supplement per animal decreases the variation in individual animal's supplement intake and reduce the amount of non-feeders. Unfortunately, offering larger quantities of supplement does not ensure that every animal will consume the designed amount and is not always economically feasible. Foot et al. (1973) found that the CV for supplement intake of ewes averaged 36%, but declined to 16% when supplemental allowance was increased 4.5 fold (100 g/d to 453 g/d).

Supplementation Effect on Foraging Behavior

Wagnon (1966) found that native pasture in early February was deficient in N (CP < 6%) and that there were zero non-feeders in a herd of beef cattle. However, as forage CP improved, non-feeders increased to 8.5%. The review by Stockdale (2000) reported that animals will more readily select for highly palatable feeds, and pasture forage intake decreased by 0.11 to 0.16 kg/kg of DM of supplement consumed. However, Brandyberry et al. (1991) conducted 2 experiments where an 28% CP supplement had no effect on forage intake during the summer or winter when forage N was adequate (CP = 8%) or low (CP = 5.9%). Ducker et al. (1981) found that increasing the grazing area per animal from 0.5 to 1.5 ewe/ha there was an increase of non-feeders from 15% to 37% among ewes supplemented a protein source. This suggests that the variation in individual supplement intake increases with greater forage availability, most likely due to the decrease in competition for limiting nutrients.

Limiters in Supplements

With the high cost of supplements and increased cost of labor there is interest in using self-fed supplements. There is also a perception is that self-feeding allows timid and slow-eating animals to consume their portion of the supplement. However, Bowman and Sowell (1997) suggest that this may not be the case. In reviewing delivery methods of grazing animals, it was determined that a greater variation in individual intake and higher incidence of non-feeders may occur when compared to commercial operations that use hand-feeding methods.

An *ad libitum* feeding system with an intake limiter may increase feeding efficiency. A review by Johnson (1976) established that hand-feeding regimens with large meals may result in diurnal fluctuations in ruminal fermentation that may decrease fiber digestion. Experiments by Kaufmann (1976) and Jensen and Wolstrup (1977) found that offering the daily feed in smaller portions or with a limiter may increase the frequency intervals and tends to have a stabilizing effect upon ruminal fermentation. However, meals do not need to be a specific size or fed at a given time, as the meal typically consumed continuously supplies nutrients to the host through evolved coping mechanism for short or long term events (Forbes and Gregorini, 2015). This is known in grazing ruminants where they typically consume their food over a series of discrete periods throughout the day (Gregorini, 2012). This type of feeding behavior supports the use of a free-choice supplement for grazing animals.

Huston et al. (1999) and Bohnert et al. (2002) suggest that protein supplementation can be offered at infrequent periods, while maintaining acceptable performance compared with daily supplementation. This infrequent supplementation can decrease labor input. A method for controlling these infrequent feedings is to use limiters. The most common limiter is sodium chloride (NaCl) but the use of calcium hydroxide or feather meal may also prove to be effective (Bowman and Sowell, 1997). Shauer et al. (2004) found that using NaCl (16%) or calcium-hydroxide (7%) to regulate supplement intake showed similar supplemental intakes compared to hand-fed groups averaging 2.69 kg/d. However, calcium hydroxide decreased livestock performance by 0.15 kg/d compared to steers fed hand-fed or NaCl-limited supplements (Shauer et al., 2004).

Sodium Chloride

Sodium and Cl are involved in maintaining the osmotic pressure, regulating water balance and controlling the acid-base balance (NASEM, 2016). Sodium chloride is used to meet both requirements of Na and Cl and Morris (1980) suggests that sodium is be fed between 0.06 to 0.1% BW in grazing beef cows. Including NaCl in supplements can effectively limit feed intake as demonstrated in several experiments (Riggs et al., 1953; Beeson et al., 1977; Schauer et al., 2004). Of the limiters, NaCl is the most common because it is readily available and generally safe. Meyer et al. (1955) found that feeding 0.77 kg/d or 9.33% of NaCl had no effect on ADG or dressing percentage for finishing steers when fed over an 84-day period. Also, Croom et al. (1982) found that if NaCl or NaCl plus 2% limestone fed to Hereford steers (BW = 272 kg) at an average intake of 0.51 kg/d showed a 7.4 and 8.9% increase in organic matter utilization over the control. Kunkle et al. (2000) found that cattle receiving NaCl-limited (from 25 to 35% NaCl) supplements performed similar to hand-fed treatments, with no reported problems. Some research has shown that the use of NaCl to reach a desired level of intake may not be precise, and some adjustments may be required (Riggs et al., 1953; Kunkle et al., 2000). Sodium chloride can also negatively affect forage digestibility when consumed at high levels (Moseley and Jones, 1974). Sodium chloride is also known to negatively affect fiber digestion if consumed at high levels (Moseley and Jones, 1974). To minimize the negative effect on forage digestion, 25%

NaCl inclusion in supplements have proven to regulate intake without negative effects on performance (Berger and Rasby, 2011).

When feeding NaCl as a limiter, Schneider et al. (1988) found that ruminants would consume approximately 17% more water. Croom et al. (1982) reported that the NaCl of saliva ($NaHCO_3$) increased when high NaCl diets were provided to feedlot steers. The combination of increased water intake and production of saliva NaCls would increase liquid dilution rates and could increase feed or forage intake. The increased liquid dilution rate of the rumen has shown to stimulate microbial growth and decrease the required substrate to maintain microbial process (Isaacson et al., 1975). This would increase the efficiency of ruminal fermentation. Phillips et al. (2014) concluded that high NaCl in the diets for sheep for long periods of time, can also limit the cadmium (toxic element) availability in the rumen. However, Schneider et al. (1988) found that NaCl reduces N retention and increases N losses through urination.

Monensin

Monensin is derived from strains of *Streptomyces cinnamonensis*, and was previously referred to as monensic acid. Monensin is provided to cattle as a sodium salt. Monensin was originally developed as a coccidiostat for poultry (Richardson et al., 1976), but later research showed the effect that monensin can have on bacterial fermentation. Monensin inhibits gram-positive bacteria, altering rumen metabolism by increasing N metabolism and improving the efficiency of energy metabolism. Since the mid-1970s approval of monensin for feedlot cattle, monensin has shown to improve feed efficiency by 6.4% by reducing DMI by an average of 0.27 kg/d and increasing ADG by 0.029 kg/d (Duffield et al., 2012). Monensin can also improve the animal's health and wellbeing by decreasing the risk of bloat and lactic acidosis (Schelling, 1984). Monensin effects on DMI within grazing cattle systems have seen slight to no changes (Azzaz et al., 2015).

Adding monensin sodium chloride to an already NaCl-limiting supplement has shown to decrease the required amount of NaCl to suppress supplement intake by 25 to 50% (Muller et al., 1986). This method should allow for fewer changes to the level of NaCl in the supplement that is needed to suppress intake. To support this, Paisley and Horn (1996) reported that with the addition of monensin, offering a self-fed supplement that contained 4.4% NaCl to stocker cattle on wheat pasture decreased supplement intake from 2.28 to 0.65 kg/d. This experiment also showed that there was less variation in daily supplement intake when monensin was included in the supplement.

In grazing experiments, ionophores have had inconsistent effects on forage intake and performance by cattle (Lemenager et al., 1978; Huston and Spiller, 1981; Pond and Ellis, 1981). Duffield et al. (2012) suggested that when utilizing greater forage-based diets with growing cattle, ionophores may have a greater effect on ADG, but possibly less effect on decreasing DMI. Huston et al. (1990) found that feeding lasalocid to range sheep showed no effect on forage intake but improved BW gains. However, Lemenager et al., (1978) observed a 16.5% decrease in forage intake while feeding monensin to lactating range cows with no observed change in BCS. This decrease in intake may result from rumen fill or a lag effect that occurs from decreased ruminal microorganism leading to slower digestion and passage rate.

In high forage diets there may be an increased number of ionophore-resistant fibrolytic bacteria (i.e. *F. succinogenes*) that offset the reduced number of ionophore-sensitive ruminal microbes (Azzaz et al., 2015). Also, ionophores may prolong retention time and help maintain normal fiber digestion (Lemenager et al., 1978). Haimoud et al. (1995) found that feeding an ionophore to lactating cattle on pasture decreased rumen digestion of OM and acid detergent fiber, but had no effect on forage intake or BW changes. However, Allen and Harrison (1979) found that digestion of fiber was relatively unaffected by feeding ionophores to sheep.

Calcium Chloride and Fats

Both calcium chloride and fats have been used to limit intake. Calcium chloride is required in smaller amounts, compared to NaCl, to regulate intake levels. As little as 2.5 to 5% have been shown to limit intake to 1% BW (Kunkle et al., 2000). However, calcium chloride is a corrosive and will supply additional calcium that can be problematic with high-calcium forages and(or) natural water sources.

Fats are an additional way to limit intake. Wise et al. (1965) found that in the first year of a 2-year experiment, 10% fat in a supplement can restrict intake level to 1% BW in steers being finished on pasture. The second year compared these effects to a 7 to 10% NaCl limited supplement where those receiving the fat-limited supplement reported intake was 0.79% compared to the 0.86% BW from the NaCl limited supplement. However, cattle receiving the fat-limited supplement gained 7% faster at a rate of 1.16 kg/d compared to the gain of the NaCl group’s 1.08 kg/d. Hart et al. (1971) found that supplementing fat at 10% inclusion of a ground corn supplement being fed to cattle grazing orchardgrass, only limited intake to 1.5%.

Compared to all other limiters, fats supply energy that can increase gains. However, for winter supplementation, fats have the disadvantage of increased cost and handling problems in cold weather. Too much fat intake can decrease digestion and cause scouring. Problems with imprecise intake control remain, and overconsumption of such supplements are expensive compared to lower-cost limiters, such as NaCl. Fats seem to be more useful for holding grain intake to 1 to 2% BW in cattle than for holding protein or energy supplements under 1 kg/d (Kunkle et al., 2000).

Comparing Feed Intake Systems

The rudimentary way to measure intake of feed or water has been to house animals individually and manually weigh consumption. Individually housing animals is labor intensive and may alter intake and performance results (Chapinal et al., 2007). Thanks to technological advances, systems have been developed to automatically evaluate feed intake and behavior. Examples of these systems include the GrowSafe (**GS**; GrowSafe System Ltd., Airdrie, Alberta, Canada) and Insentec monitoring systems (**IT**; Insentec, Marknesse, the Netherlands). The SmartFeed (**SM**; C-Lock Inc., Rapid City, SD) is a recently developed system that can be used to measure intake and feeding behavior of individual animals. These technologies have provided new methods to evaluate intake of diets and supplements.

GrowSafe

The GS feed intake and behavior monitoring system normally contains multiple feed bunks making it ideal for feedlot and dairy research. Each bunk is equipped with an antenna that identifies animals while at the feed bunk, load cells that measure feed consumption, neck bars that limit access so that only one animal may enter the feed bunk at a time, and data acquisition software to record the feeding behavior and intake data. This system measures individual feed disappearance by weighing the feed bunks continuously during the visit of each individual animal.

Insentec Monitoring System

The IT system enables researchers to monitor and influence the individual feed intake behavior of cattle. The Windows based IT management software provides the potential for analysis and research on feed and water intake (Chapinal et al., 2007). The system consists of a galvanized feeding gate, an access slide that has the ability to push out animals or restrict specific animals, and sensors for animal identification. Each feeder is equipped with an access gate and RFID tag reader that can be programmed to allow specific animals to access a feed bin and two infrared sensors that record the presence of an animal in the feeder (Tolkamp et al., 2000). This system is large and bulky, making it ideal for stationary research in feedlots or dairies.

SmartFeed

The SM is a self-contained system designed to measure total daily feed or supplement intake from individual animals. This system is smaller, portable, and more versatile compared to the GS and IT, making it ideal for use in grazing experiments. The SM equipment comes with a large feed bin suspended over load cells and an RFID tag reader which continuously logs data to determine feed intake per visit per animal. As the animal's head enters the feed bin, the tag is read and the weight of the bin is recorded. Once the animal is finished consuming feed and removes its head, the bin is weighed and intake is calculated in real time from the difference in beginning weight and the weight once the animal removes their head. The SM system can be linked to Wi-Fi so data is uploaded periodically. New additions such as head gates to restrict specific animals and the ability to use solar panels for power make it better suited for grazing research compared to other intake systems.

Implications of Literature Review

There have been numerous experiments focused on improving production in order to accommodate the decreasing land available for grazing. The most common of these is to utilize supplementation programs to improve efficiency. Supplements are used to correct nutrient deficiency, extend forage supplies, deliver feed additives, and alter foraging behavior of grazing animals (Kunkle et al., 2000). Adding a supplement or feed additive program to a grazing system has been shown to improve overall efficiency (Horn and McCollum, 1987; McCollum and Horn, 1990; Morsy et al., 2012). Ionophores are the most common feed additive to improve feed efficiency by reducing DMI and potentially improving ADG (Bretschneider et al., 2008).

Often to accurately measure intake levels, animals need to be individually penned and fed separately. This method is accurate but labor intensive and dissimilar to a production setting where animals are allowed to socialize. The SM is the well suited to measure supplement intake in a pasture setting. The SM allows for real time measurements of individual feeding events within a self-fed system. However, problems may arise when attempting to deliver supplements at a consistent rate to each individual animal.

A large amount of variation in supplement intake exists with each delivery method. Supplement delivery method has the potential to alter competition and may improve the efficiency of supplement programs (Bowman and Sowell, 1997; Kunkle et al., 2000). Schauer et al. (2005) found that infrequently supplementing is a beneficial alternative and lowers labor and fuel costs compared to daily supplementing cattle. Whereas delivering supplement through a self-fed system by limiting intake through limiters (i.e. NaCl, calcium hydroxide, feather meal) have been used to decrease competition, allowing for timid animals to consume adequate amounts of supplement, but this may increase the variation in individual supplement intake (Bowman and Sowell, 1997; Schauer et al, 2004). Sodium chloride may be the best limiter for supplementation programs due to its abundance, affordability and easy access, as well as the ability to regulate intake to similar ranges of hand-fed groups with little alteration to ADG (Nelson et al., 1951; Archer et al., 1952; Riggs et al., 1953; Schauer et al., 2004).

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Chapter III

Effect of supplementation method on supplement intake and performance of individual beef steers grazing dormant tallgrass prairie

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ABSTRACT: The objective of this experiment was to determine the effect of supplementation method (hand-fed vs. *ad libitum* access) on supplement intake and performance of beef steers grazing dormant tallgrass prairie. The experiment was conducted for 56 d in late winter in central Oklahoma. Angus x Hereford steers (*n* = 40; BW = 242.6 ± 3.6 kg) were randomly assigned to one of three supplementation methods; either control (**CON**; no supplement; *n* = 8), hand-fed (**HF**; *n* = 16), or self-fed (**SF**; *n* = 16). Both the HF and SF treatments received a supplement consisting of 80% soybean meal and 20% soybean hulls (TDN = 76.6 %, CP = 43.9 %; DM basis). Sixteen steers were assigned to the HF, where 4 steers received either 0.39, 0.78, 1.17, or 1.56 kg per day, fed 3 days per week in individual stanchions. Sixteen steers were assigned to the SF group and received supplement via the SmartFeed system (C-Lock Inc., Rapid City, South Dakota). The SmartFeed is a portable, self-contained system designed to measure individual feed intake. The SF group had *ad libitum* access to supplement, to which NaCl was added to achieve mean intake of approximately 1.0 kg/d. The overall mean intake of supplement in SF ranged from 0 to 1.21 kg per steer per day. The CV for the SF animal on mean intake was 50.8% and animal on day-to-day intake was 96.7%. The mean NaCl that was present in the SF supplement was 40.5% and NaCl intake averaged 0.39 kg/d. Steers were weighed weekly and ADG and supplement efficiency was regressed on supplement intake, supplementation method, and the interaction. No significant difference between treatment group was detected for ADG (P = 0.24) or supplement efficiency (P = 0.30) regressions. Aggregated CV of weekly intake with animal significantly ($P \leq 0.01$) decreased residual ADG and residual supplement efficiency. Steers grazing dormant tallgrass prairie with minimal change in weekly supplement intakes had a slightly greater ADG and supplement efficiency. Directly managing supplementation may be more efficient than traditional, self-fed approaches that rely on NaCl as a limiter.

Key Words: hand-fed, intake, performance, self-fed, SmartFeed, supplement efficiency

Introduction

The objective of this experiment was to determine the effect of supplementation method (hand-fed vs. self-fed) on supplement intake, performance, and supplement efficiency of individual beef steers grazing dormant tallgrass prairie.

In the Southern Great Plains, tallgrass prairie serves as the primary forage for ruminants, particularly cattle, throughout much of the year. However, during the dormant season (winter) nutritive value is low (Bodine and Purvis, 2003), necessitating supplementation to maintain optimal production. Research indicates that protein supplements improve forage intake and performance (Horn and McCollum, 1987; Bowman and Sowell, 1997). Supplementation must accurately and effectively provide the proper nutrients for growth in an economical manner (Bowman and Sowell, 1997). Utilizing the most accurate and effective method to supplement cattle may reduce labor costs, improve animal welfare, and reduce the cost of grazing (Reuter and Moffet, 2016).

As cost of supplement and labor increases, there has been an interest in using self-fed supplementation methods. Self-feeding methods assume that livestock are capable of recognizing deficiencies in the diet and will consume adequate amounts of supplement to rectify that deficiency from forages (Rode et al., 1993). A primary concern when administering self-fed supplements is ensuring that intake is maintained at the desired level (Bowman and Sowell, 1997). Sodium chloride has shown to effectively limit supplement intake (Beeson et al., 1977; Schauer et al., 2004). However, variation among animals is large (Bowman and Sowell, 1997). Further, Moseley and Jones (1974) reported that forage digestibility can be negatively impacted when NaCl is fed at high levels. However, few experiments have investigated the effects of these issues on efficiency of self-fed supplementation as compared to hand-fed cattle.

Materials and Methods

All experimental protocols were approved by the Oklahoma State University Institutional Animal Care and Use Committee (ACUP# AG-16-4).

Experiment Site

The 56-d (February 5, 2016 – April 1, 2016) experiment was conducted at the Oklahoma State University Blue Stem Research Range, 11 km southwest of Stillwater, OK (long 36°03'N, lat 97°12'W; elevation, 331m; Payne County). Frost-free growth period is from April to October (Bodine and Purvis, 2003). Annual precipitation averages 74.2 cm with 70% falling between the months of May and October (NOAA, 2017). Mean daily temperature ranged from 8.2° to 16.1°C during the experimental period (NOAA, 2016). Animals grazed 122.2 ha of native tallgrass prairie during the experiment, divided into 2 pastures. The site is characterized as tallgrass savannah and is in good condition (Bodine and Purvis, 2003). Predominate plants included big bluestem (*Andropogon gerardii*), Switchgrass (*Panicum virgatum*), indiangrass (*Sorghastrum nutans*), and little bluestem (*Schizachyrium scoparium*), and introduced forages, such as old world bluestem (*Bothriachloa ischaemum*). Prior to the experiment, pastures were deferred from May, 2015 to January, 2016. Livestock had *ad libitum* access to drinking water from both ponds and piped water in both pastures. Ten 0.09 – m^2 quadrates were clipped on d -7, oven dried at 50°C for 120 h and weighed to estimate forage mass and forage allowance (**Table 1**).

Animals

Forty, fall-weaned Angus x Hereford steers (242.6 ± 3.6 kg initial BW; **Table 4**) were used in this experiment. These steers came from Oklahoma State University Range Cow South Range Research Unit near Stillwater, OK. On arrival, steers were given an electronic identification tag and treated for parasites according to label directions (Ivomec, Merial Limited, London, U. K.). Steers were not implanted prior or during the experiment. The 40 steers were selected from a herd of 63 for disposition and adaptability to the feeding equipment. All steers were randomly allotted to treatments one wk prior to the initial start date. Steers were weighed individually, once per week on validated scales starting on day 1.

Experimental Diets and Feeding

The protein supplement consisted of 80% soybean meal and 20% soybean hulls (TDN = 76.6, CP = 43.9%; DM basis; **Table 2**). Hentges et al. (1967) suggested that pelleting decreases the effectiveness of NaCl as a limiter, therefore supplement was offered in the meal form. This may increase the effect that NaCl has on intake, lower NaCl inclusion rates, and limit the NaCl effect on decreasing the OM digestion (Moseley and Jones, 1974; Schauer et al., 2004).

Steers were trained to enter individual feeding stalls by offering each steer 0.91 kg of the protein supplement 3 times per wk for a 5-week period prior to the beginning of the experiment and 1 wk prior to treatment allotments. Steers were assigned to a treatment group by complete randomization. Treatments are as followed: control (**CON**; *n* = 8), self-fed group (**SF**; *n* = 16), and hand-fed group (**HF**; *n* = 16). The CON were housed with the HF and received 0 kg/d of supplement. Of the 16 in the HF, 4 steers were each randomly assigned to one of four intake levels; 0.39, 0.78, 1.17, or 1.56 kg per day. The HF steers were fed 3 days per week in individual stanchions and given 45 minutes to consume the supplement (all steers completely consumed the allotted amount every feeding). The HF levels were designed to incorporate the large intake variation expected with the SF group. The SF steers had *ad libitum* access to the supplement for the duration of the 56-d period, but intake was regulated by the inclusion of NaCl. Intake was calculated weekly for the SF group and NaCl inclusion was adjusted to attempt to meet the mean intake level of the HF (approximately 1.0 kg/d). The percentage of NaCl in the supplement in the SF was 25, 30, and 45% for 1-7, 8-14, and 15-56 d, respectively. The SF intake levels were measured using the SmartFeed system (C-Lock Inc., Rapid City, South Dakota). During the week prior to start of the experiment, all animals were allowed time for acclimation to treatment. The 2 groups were rotated between the two pastures every wk to limit any potential effect of pasture.

Self-Feeding System

The SmartFeed is a self-contained system designed to measure feed intake from individual animals and has been previously described by Reuter et al. (2017). This system is portable, making it effective for measuring supplementation in pasture setting. The system consists of a large 79 x 71 x 86 cm feed bin suspended by load cells and a radio-frequency identification tag reader that continuously logs data to determine the feed intake per visit by each animal. The system calculates intake in real time and uploads data via Wi-Fi. This system allows for the experimental unit to be steer rather than pasture. All steers in the SF group had access to the SmartFeed equipment one wk prior to and during the experiment.

The supplement that was available to the SF group was a mixture of NaCl and protein supplement. Additional supplement was placed in the SmartFeed every 3-4 d, when supplement amount became less than 5 kg. The supplement that was placed in the SmartFeed was weighed on a separate scale. Orts were taken every 7 d, dried in a 50°C oven and weighed to measure supplement disappearance. Once orts were removed, the SmartFeed scale was calibrated using a 20 kg weight.

Statistical Analysis

Data were analyzed using the linear model procedures and figures were produced from R (R Core Team, 2016). The linear models contained feeding method, supplement intake, and the method x intake interaction. Controls were added to the HF and SF linear models. Sodium chloride content was subtracted from raw supplement intakes to evaluate actual protein supplement intake. Weekly body weights were regressed over time to estimate ADG for each steer. Animal was the experimental unit as each steer reported an individual intake and ADG (Adams et al., 2000). All means were obtained and separated using pairwise *t*-tests. Statistical significance was declared at $P \leq 0.05$ and tendencies were at $0.05 < P \leq 0.10$. Dependent variables analyzed included supplement intake, ADG, and supplement efficiency (G:F). Supplement efficiency was calculated as gain compared to mean of the CON, divided by kg of protein supplement consumed. One animal appeared to be an outlier, so a Cook's D outlier test was used and that individual animal's values for intake, ADG, and supplement efficiency were removed from the SF before data analysis.

Results and Discussion

Climatic Conditions

From February 5 through April 1, precipitation at the experiment site was 8.8 cm, which is similar to the 8.9 cm long term (17 yr) average precipitation for this period (NOAA, 2017). The average temperature at this time was 10.3℃, 3.9℃ greater than the long-term (17 yr) average (NOAA, 2017).

Forage Mass and Forage Allowance

Forage mass for the pastures was 4405 ± 696 and 4216 ± 523 kg DM/ha respectively (**Table 1**). These are similar to the winter average of 4090 kg/ha reported by Bodine and Purvis (2003) and from Soil Survey Staff (2016), which indicate total forage production is > 4000 kg/ha for native range in Central OK. Forage allowance was calculated by (forage mass x ha) / (mean BW x steer No.) (Bodine and Purvis, 2003). Forage allowance averaged 50.7 ± 3 kg of DM/kg of BW at the beginning of the experiment and did not appear to limit animal performance (Sollenberger et al., 2005). Bodine and Purvis (2003) estimated diet quality based on chemical composition from these pastures during an identical time and concluded that supplementation would be required to optimize performance of steers. New growth of forage began about d 42 and was available for the final 14 d of the experiment.

Supplement Intake

Supplement intake for HF remained constant throughout the entirety of the experiment, with no orts or refusals. The average intake for the HF was 0.97 ± 0.11 kg/d or 0.39 ± 0.04 % BW. As the amount of protein supplement that was offered increased, there was an increase in consumption rates. No plateau in intake was observed from the designed amounts, but one could expect a plateau to occur at greater quantities as found by Beaty et al. (1994), when CP supplied by the supplement exceeds 30 or 31% of total DMI. Sodium chloride intake was removed from all reported intake levels for SF. Supplement intake for the SF group averaged 0.68 ± 0.09 kg/d or 0.25 ± 0.03 % BW. The SF mean daily intake for the entire experiment ranged from 0 to 1.21 kg/d.

Even with NaCl inclusion, mean and % BW protein supplement intake was different between the HF and SF groups ($P \leq 0.05$; **Table 3**). Schauer et al. (2004) found that keeping a consistent level of NaCl has little influence on cattle's individual intake for extended periods. They found that over 2 yr, a protein supplement that contained 16% NaCl produced intakes similar to hand-feeding supplements during the first year, but not the second. For these reasons, NaCl percentage in a supplement needs to be continually adjusted to ensure intake remain consistent (Kunkle et al., 2000). Totusek et al. (1971) and Rush et al. (1972) reported that altering NaCl levels between 20 and 29.5% successfully limited a natural protein supplement intake to 1.25 kg/d for winter range cows. This is also in agreement with Beeson et al. (1957) that recommend that NaCl levels in supplement be adjusted over time to meet targeted intake. The inclusion rates of NaCl for this experiment were modeled after previous research findings and the suggestion to alter NaCl inclusions each week based on the prior week's intake levels (Kunkle et al., 2000).

The maximum and minimum intake observed for a single day within the SF group varied anywhere between 2.78 to 0 kg, respectively (**Figure 1**). This large variation resulted in a 50.8% CV of the daily intake levels, with a rate of non-feeders (steers consuming no supplement during the experiment) being 12.5%. This CV is consistent with Kendall et al. (1983) and Kendall et al.

(1980), in which a CV range of 31 to 63% was found while feeding either a block or meal supplement *ad libitum* to ewes and grazing heifers. This CV is also in agreement with Holst et al. (1994) that reported an average CV of 47% among hand-fed sheep consuming a meal based supplement. However, the day-to-day CV for the SF intake was 96.7%. Although this CV for day-to-day is high, it is lower than the CV of 144, 132, or 107% seen with feeding a molasses-urea supplement for sheep, ewes, or cattle, respectably, grazing pasture (Lobato et al., 1980; Ducker et al., 1981; Bowman et al., 1995).

The percentage of non-feeders usually decreases, while average intake level increases with increased exposure time to supplements (Entwistle and Knights, 1974; Coombe and Mulholland, 1983). However, over the length of the experiment, the SF average supplement intake decreased at a rate of 0.02 kg/d ($P < 0.01$; **Figure 1**). The average intake from the first week was 1.31 ± 0.03 kg/d, and the average from the final week was 0.34 ± 0.01 kg/d. This decrease might be due to increasing quality of forage or from the initial increase in NaCl content.

Sodium Chloride Intake in the SF Group

` Sodium chloride averaged 40.5 ± 0.01% of the supplement that was offered to the SF group over the 56-d experiment. Sodium chloride has been shown to effectively limit supplement intake in past research (Nelson et al., 1951; Archer et al., 1952; Riggs et al., 1953; Schauer et al., 2004) and it is suggested by Kunkle et al. (2000) that a NaCl inclusion at 25 to 35% would not affect OM digestion or passage rates. However, for the mean intake level to be identical to HF group, NaCl inclusion was slightly greater for this experiment.

The NaCl intake averaged 0.40 ± 0.01 kg/d or 0.16 ± 0.01% BW/d for the SF group which is slightly higher than the recommendation from Kunkle et al. (2000) range of 0.05 to 0.15% BW. Over the duration of the experiment, NaCl intake decreased at a rate of 0.004 kg/d

($P < 0.01$). Similar to supplement intake, NaCl day-to-day intake was also highly variable (CV = 78%; **Figure 2**). Since the depression of intake is highly variable, this indicates that cattle that ate less supplement due to its dilution with NaCl could have caused the animals to consume more forage, similar to the findings from Perry et al. (1986). Chicco et al. (1971) and Muller et al. (1986) summarized that changes that occur in availability and quality of forages, supplement formulation, NaCl level and water availability require a large degree of flexibility to achieve ideal intake levels with optimal performance.

Average Daily Gain

Evaluation of the linear model for the two methods' (**Figure 5**), no method or method by intake interaction effect was detected on ADG ($P \geq 0.24$). As predicted, intake had a significant effect on ADG ($P < 0.001$). Both treatment groups displayed improved animal performance, similar to the research reported by other researchers (McCollum and Horn, 1990; Owens et al., 1991; Moore et al., 1999; Bodine and Purvis, 2003).

The CON group ADG was added to each of the regression models. The CON ADG is – 0.135 ± 0.06 kg/d ($P = 0.06$). Among the HF group, reported ADG was 0.37 ± 0.14 kg/d, but ranged from -0.02 to 0.68 kg/d (**Table 4**). Supplement intake was associated with increased ADG ($P < 0.01$) in the HF method. Average daily gain will improve by 0.47 ± 0.01 kg/d per unit of intake ($R^2 = 0.83$; **Figure 3**). Bodine and Purvis (2003), Van De Kerckhove et al. (2011), and the performance of cattle that that received no supplementation from this experiment, forage CP is estimated to be low (CP ≤ 6%).

The SF group ADG was 0.13 ± 0.05 kg/d, with a range of -0.18 to 0.58 kg/d (**Table 4**). Regression analysis of the effect of intake on ADG shows tendencies for a positive linear relationship with each additional kg of intake using the SF method. This may result in ADG increasing by 0.37 ± 0.14 kg/d per unit of intake ($P < 0.001$; $R^2 = 0.40$; **Figure 4**). From the 2 non-feeders within the SF group, ADG was - 0.18 ± 0.01 kg/d. The results in the SF group are similar to Karn (2000) who observed increased gains of 0.13 kg/d by grazing steers fed a barley-based supplement in the Norther Great Plains.

Supplement Efficiency

Supplement efficiency was calculated as the additional gain over the CON (steers that did not receive any supplement; $n = 8$) per kilogram of supplement consumed (**G:F**; **Table 4**). For the supplement efficiency calculations, the 2 non-feeders from the SF group removed from the data set. The CON group reporting an ADG of -0.135 kg/d.

There was no method, supplement intake, or method by intake interaction ($P \geq 0.30$; $R^2 = 0.20$; **Figure 6**) for supplement efficiency. The average supplement efficiency between the methods was 0.48 ± 0.04. This value is similar to the review by McCollum and Horn (1990) for protein supplement conversions in grazing livestock. Our estimates for supplement efficiency remained greater than the 0.33 k/d gain per kg of supplement intake that is commonly seen with a N deficiency (McCollum and Horn, 1990). This indicates that a greater response than could be attributed to the energy supplied by the supplement alone (positive associate effect) was occurring, similarly to the soybean meal treatment from Bodine and Purvis (2003), who reported supplement efficiency of 0.67 kg/d of gain per kg of intake. If the efficiency is less than 0.2 kg/d of gain per kg of supplement intake, the N deficiency would not exist, and at this time the supplement intake is replacing some component of the basal diet. This type of efficiency is more commonly reported with some energy supplementation (McCollum and Horn, 1990).

Supplement efficiency for the HF groups averaged 0.54 ± 0.04 kg/d of gain per kg of intake. If transformed into supplement conversion, 1.85 kg/d of added supplement intake for every kg of added BW gain. From the HF group, the additional gain at a rate that was at the high end of typical protein supplements indicate that N may have been deficient in relation to the energy supplied by the forage. The responses in ADG and supplement conversion are similar to when animals are deficient in N and a greater response occurs when this deficiency is addressed by supplementation (McCollum and Horn, 1990; Bodine and Purvis, 2003).

Supplement efficiency for the SF group averaged 0.42 ± 0.17 kg/d of gain per kg of supplement intake. If transformed into supplement conversion, 2.38 kg/d of added supplement intake for every kg/d of added BW gain. The HF and SF groups reported similar mean supplement efficiency ratios ($P = 0.16$). However, the supplement efficiency for the SF group had a large variation between animals (CV = 61%), where the HF group did not (CV = 33%).

While digestion was not measured during this experiment, Moseley and Jones (1974) found that high levels of NaCl used to regulate intake can negatively alter fiber and protein digestion. This may be evidenced from the difference in the conversion efficiencies between the HF and SF groups. Schauer et al. (2004) found similar supplement efficiency rates when comparing NaCl-limited diets to hand-feeding, but this was largely due to the lower NaCl content (16 %), which allowed the steers to consume more and to compensate for the digestion differences.

Weekly Intake Variation

Supplement intake was aggregated to weekly intake to calculate CV of weekly intake within animal (**Table 3**). The HF was designed to receive no weekly variation in intake (0%), whereas the SF steers CV was 54.4% and varied from 0 to 87% (**Figure 7**). The 0% CV within the SF group was from the non-feeders. Regression analysis was done to identify the effects that CV of weekly intake within animal had on ADG and supplement efficiency. Intake had significantly ($P < 0.01$) influenced the regression lines previously, so residuals from a regression on supplement intake were calculated for both ADG and supplement efficiency and used in the regression. Through linear analysis, there is an effect from the interaction of residual ADG and CV of weekly intake within animal ($P \leq 0.01$; **Figure 8**). As CV of weekly intake within animal increases, residual ADG decreases. Likewise, a significant effect occurred between residual supplement efficiency and CV of weekly intake within animal ($P < 0.01$; **Figure 9**). As the CV of weekly intake within animal increases, there is a decrease in residual supplement efficiency.

Implications

Protein supplementation to steers grazing dormant tallgrass prairie increased weight gain on dormant tallgrass prairie in the Southern Great Plains. The ability for NaCl to regulate supplement intake showed to meet an ideal intake, but this level may need to be adjusted over time to ensure the mean intake does not vary. However, using NaCl in a self-fed scenario showed a great variation in supplement intake levels over the length of the experiment. Allowing animals access to self-fed supplements does not ensure that they will consume the supplement. Hand-feeding a supplement to steers grazing dormant tallgrass prairie shows to minimize the weekly intake variation and the variations effect on ADG and supplement efficiency. Overall, when technology becomes commercially available, directly managing supplementation may be more efficient than relying on traditional, NaCl-based intake-limiting approaches. Additional research is needed to identify the effects of the different supplementation methods on grazing behavior, forage intake, and day-to-day variations.

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Table 1. Forage mass and forage allowance.

	E. Native	W. Native	SEM
Ha/pasture	63.6	58.6	---
Forage mass, kg of DM/ha	4405	4216	457.9
Forage mass, kg of DM/steer	14007.9	12352.9	1398.9
Forage allowance, kg of DM/kg of BW[a]	57.7	50.9	6.0

[a]Calculated for each pasture from the mean forage mass/ha from each pasture multiplied by the total number of hectares grazed per pasture and divided by the quantity of mean steer BW at the start of the experiment multiplied by the average number of steers grazing each pasture.

Table 2. Ingredient and nutrient content of supplement.

	Supplement
Ingredients, % As-Fed	
Soybean Meal	80
Soybean Hulls	20
Nutritive values, % of DM[a]	
DM, %	90.3
NE_m, Mcal/kg	82.1
NE_g, Mcal/kg	53.6
Crude protein, %	43.9
TDN, %	76.6

[a]Estimated using tabular nutritive values (NASEM, 2016).

Table 3. Supplement intake of steers grazing dormant tallgrass prairie for 8 weeks.

	Treatments				
	Control	Hand-Fed	Self-Fed	SEM[a]	*P* – Values[b]
Supplement Intake					
kg/d	---	0.97	0.68	0.08	0.05
% BW	---	0.39	0.25	0.03	< 0.001
CV, %[c]					
Mean intake	---	---	50.8	---	---
Day-to-day	---	---	96.7	---	---
Weekly	---	0	54.4	4.64	< 0.001

[a]SEM = Standard error of the means; $n = 39$.

[b]*P* – values represent the significant differences.

[c]CV is the ratio of the standard deviation to the mean; $CV = \sigma / \mu$. The CV represents the coefficient of variation within the mean intake.

Table 4. Performance and supplement efficiency of steers grazing dormant tallgrass prairie for 8 weeks.

	Treatments				*P* – Values[1]		
Items	Control	Hand-Fed	Self-Fed	SEM[a]	Method[c]	Intake	Method x Intake
Steers, No.	8	16	15	---	---	---	---
Initial BW, kg	238.8	236.9	252.2	3.63	0.17	0.25	---
ADG, kg/d	-0.14[x]	0.37[z]	0.13[y]	0.04	0.72	< 0.001	0.24
Supplement efficiency[b]	---	0.54	0.42	0.04	0.70	0.32	0.30

[x, y, z]Means in a row without common superscript tend to differ ($P < 0.10$)

[a]SEM = Standard error of the means; $n = 39$.

[b]Supplement efficiency calculated as kilograms of added daily gain, greater than the control, divided by the kilograms of supplement intake.

[c]The methods included in the linear analysis are the hand-fed and self-fed. The control group was added to both linear models to improve accuracy.

[1]Method = main effect from the supplementation method; Intake = main effect from the amount of supplement intake; Method x Intake = interaction effect of method and intake.

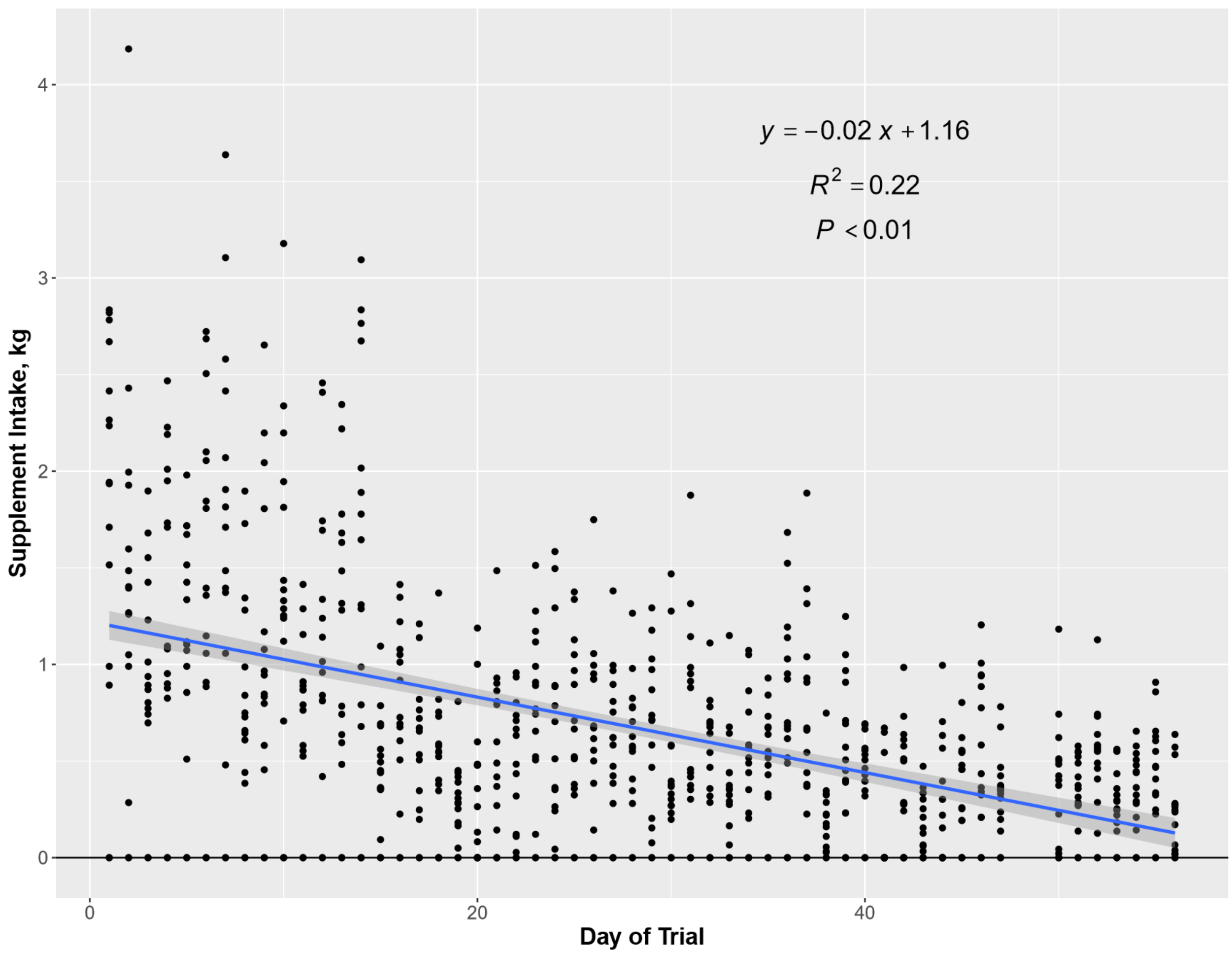

Figure 1. Self-fed supplement intake per steer over the 56-d experiment; *n* = 15. Sodium chloride content was removed from intake levels. The line represents the regression with a 95% confidence band. The $P < 0.01$ represent the *P*-value for the day of trial and supplement intake interaction.

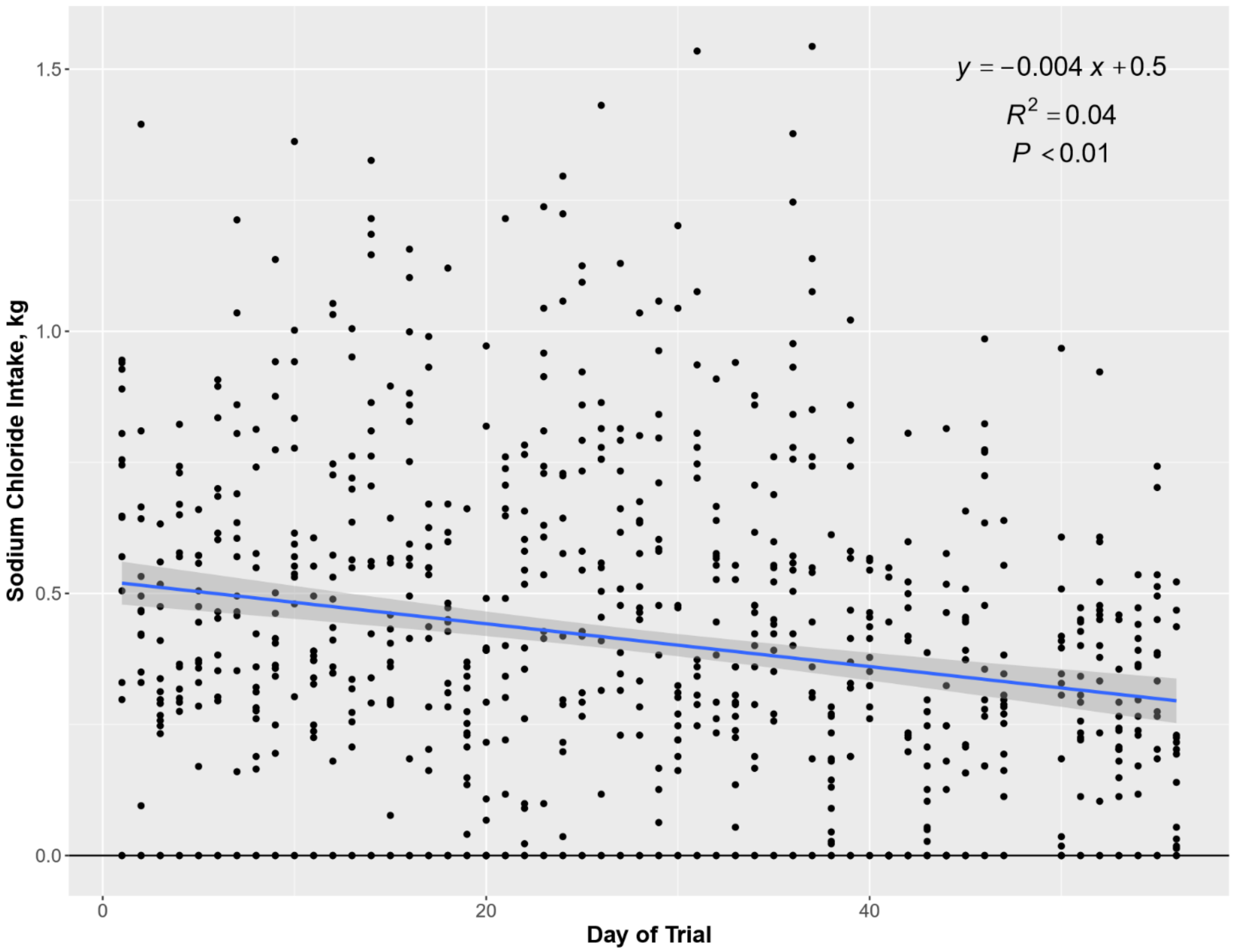

Figure 2. Sodium chloride intake per steer within the SF group over the 56-d experiment; *n* = 15. The line represents the regression with a 95% confidence band. The $P < 0.01$ represent the *P*-value for the day of trial and NaCl intake interaction.

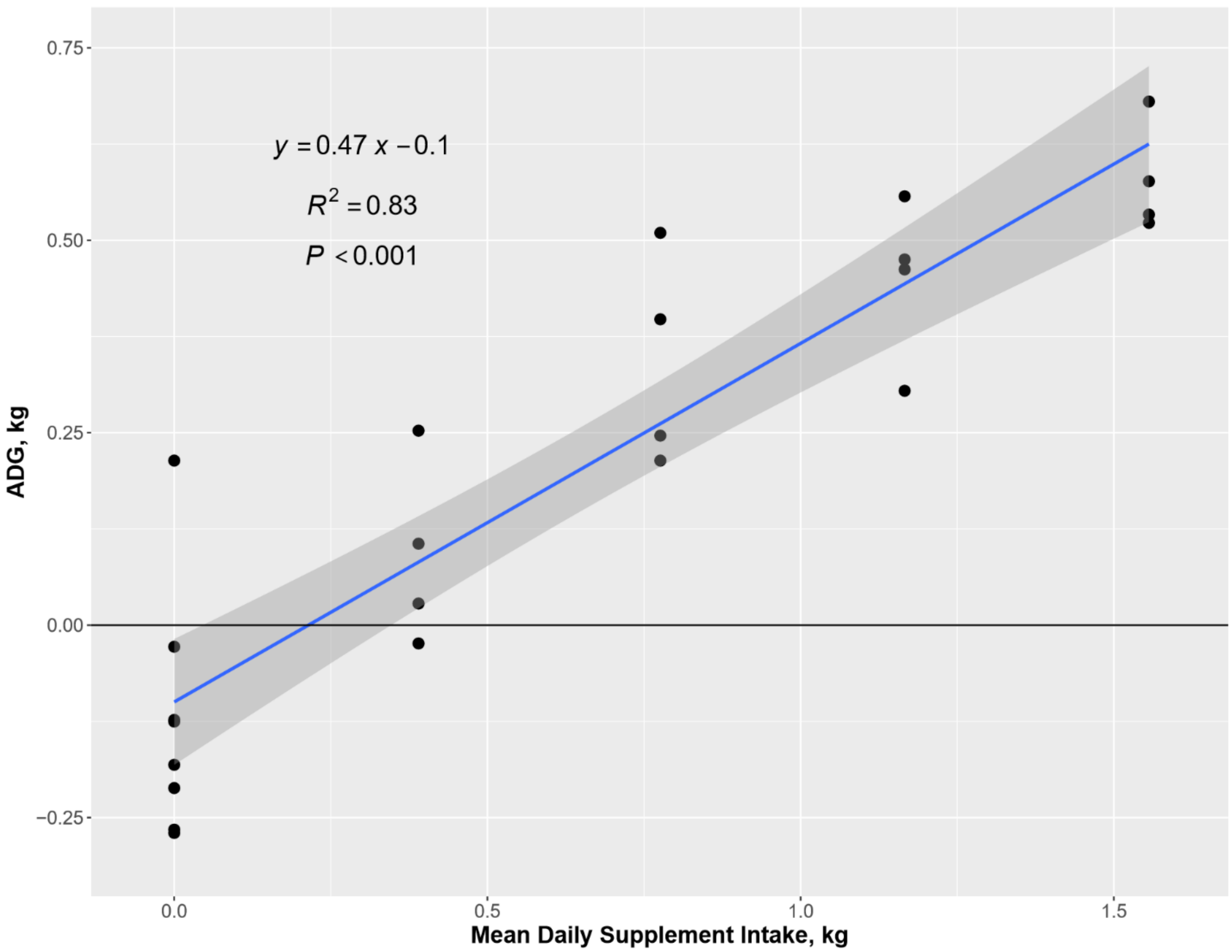

Figure 3. The ADG within the hand-fed group represented by the different mean daily intakes; n = 24. The line represents the regression with a 95% confidence band. The $P < 0.001$ represent the P-value for the mean daily supplement intake and ADG interaction.

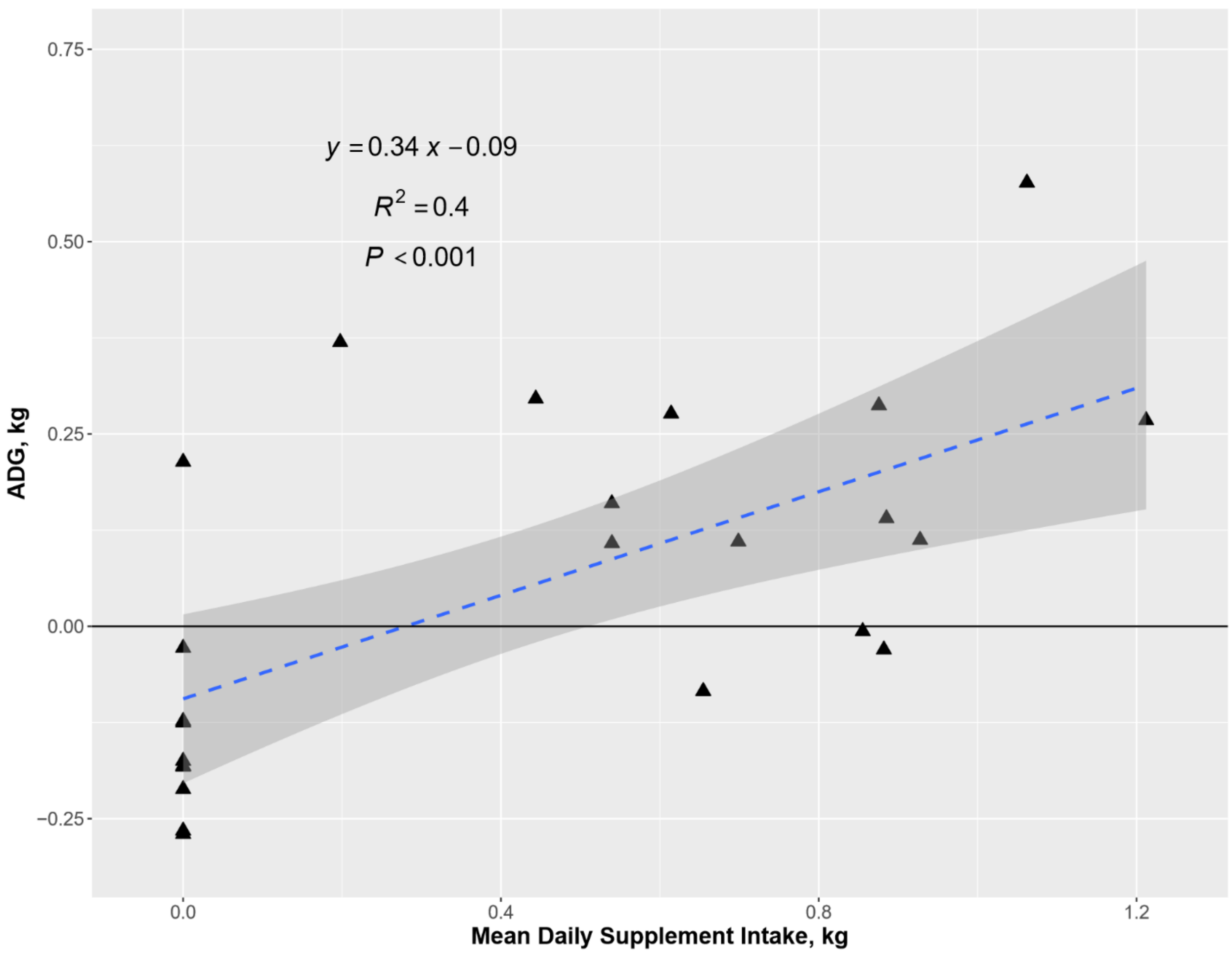

Figure 4. The ADG within the self-fed group represented by the different mean daily intakes; *n* = 23. The line represents the regression with a 95% confidence band. The $P < 0.001$ represent the *P*-value for the mean daily supplement intake and ADG interaction.

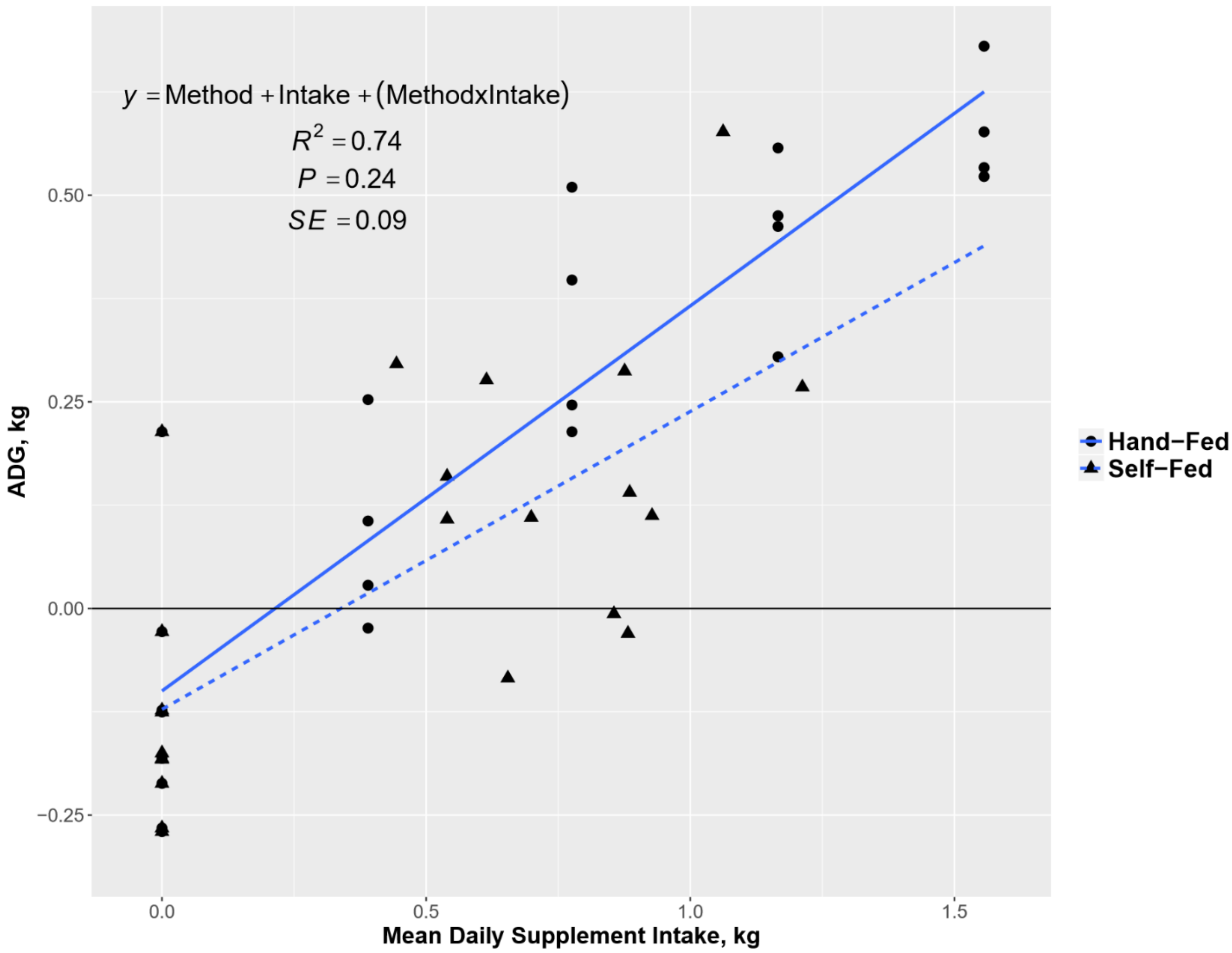

Figure 5. Expected ADG from the varying levels of mean daily intake from both supplementation methods. Model includes main effect from method, main effect from intake, and the interaction between the method and intake. As mean supplement intake increases, the hand-fed group has a numerical increase per unit of intake. The $P = 0.24$ and SE = 0.09 represent the *P*-value and standard error for the interaction term between the method and intake, and the effect on ADG.

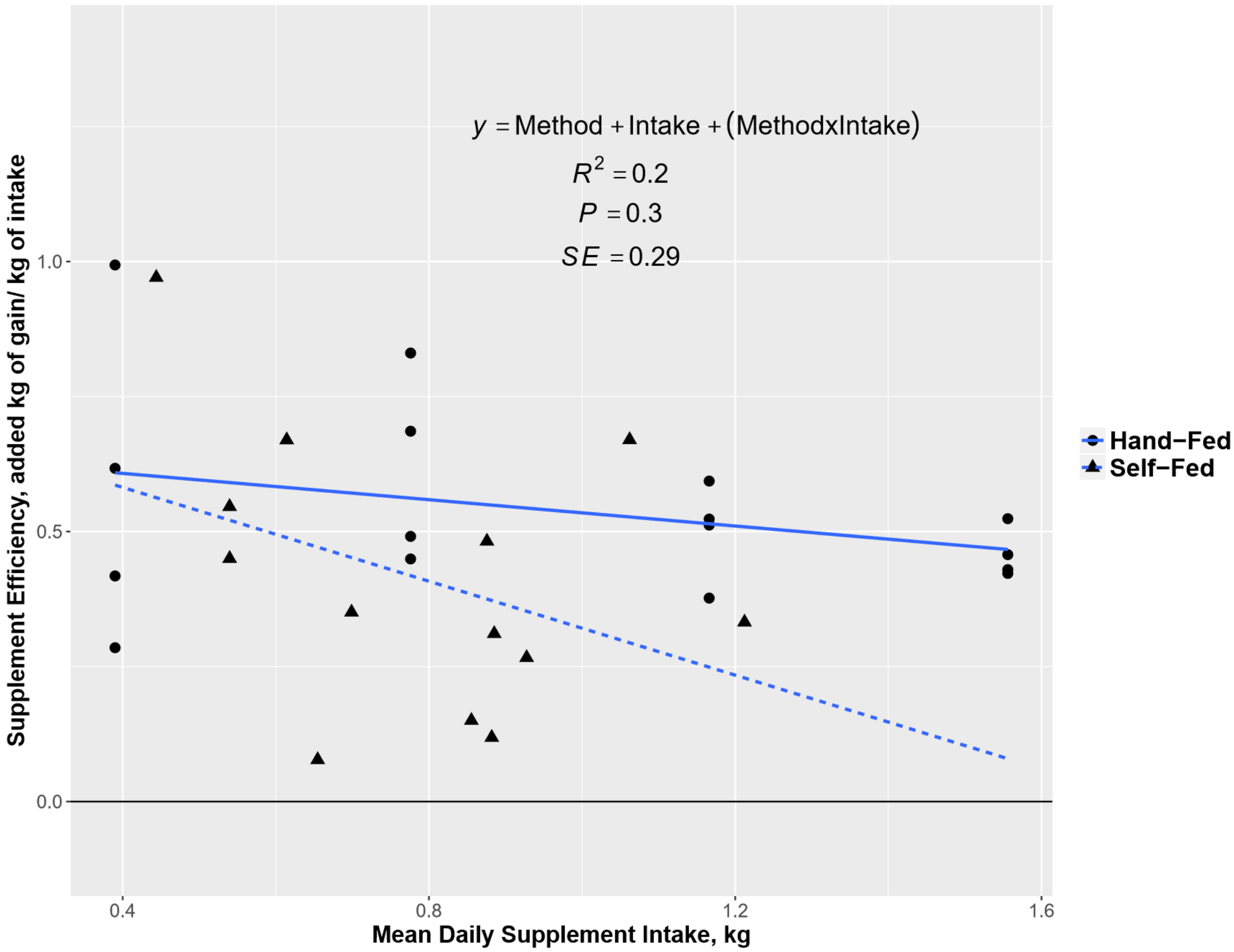

Figure 6. Expected supplement efficiency (G:F) from the varying levels of mean daily intake from both supplementation methods. Model includes main effect from method, main effect from intake, and the interaction between the method and intake. As daily supplement intake increases, the hand-fed group has a numerical improvement for gain per unit of intake. The P = 0.30 and SE = 0.29 represent the P-value and standard error for the interaction term between the method and intake, and the effect on G:F.

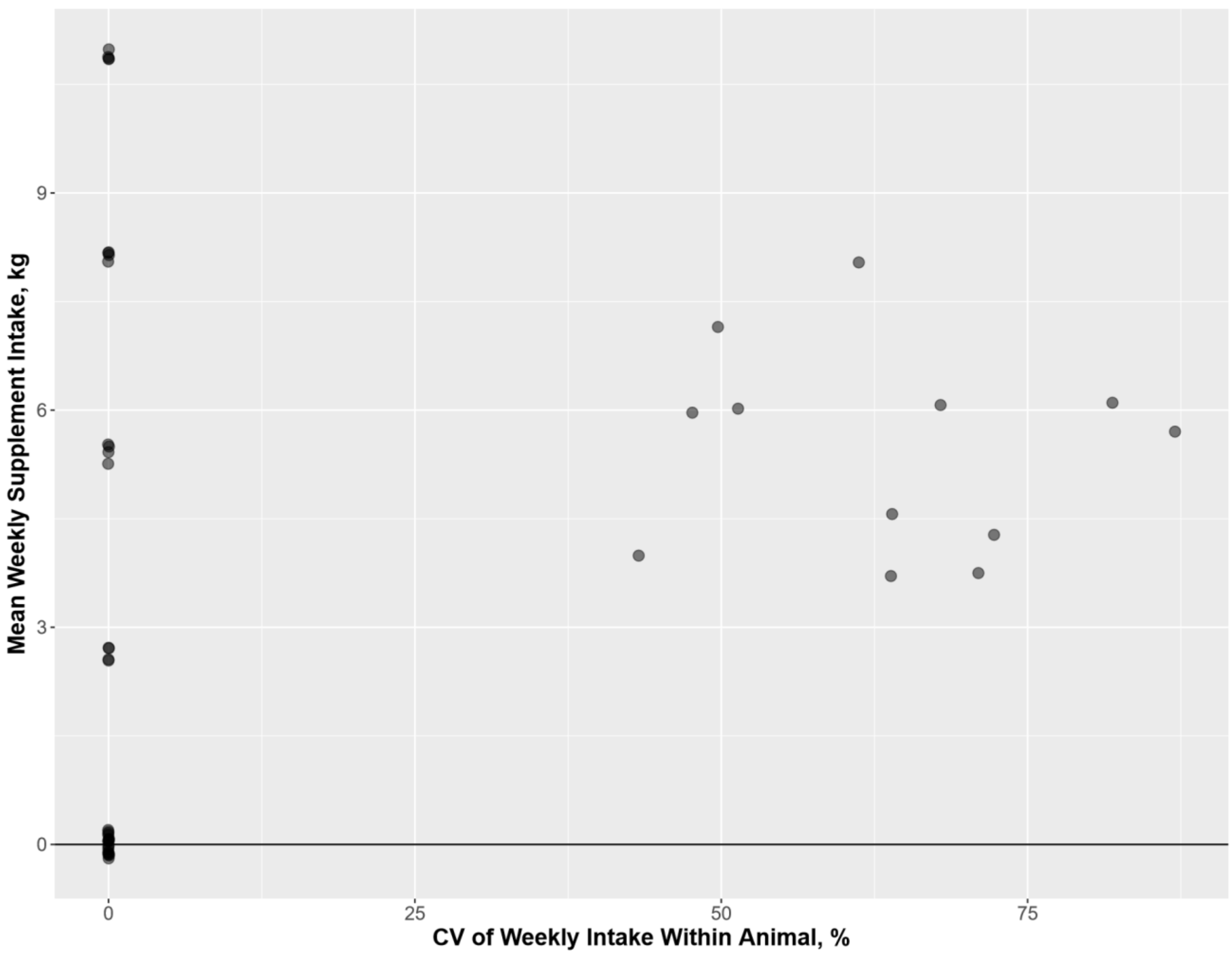

Figure 7. The mean weekly supplement intake represented by the CV of weekly intake within animal; *n* = 39.

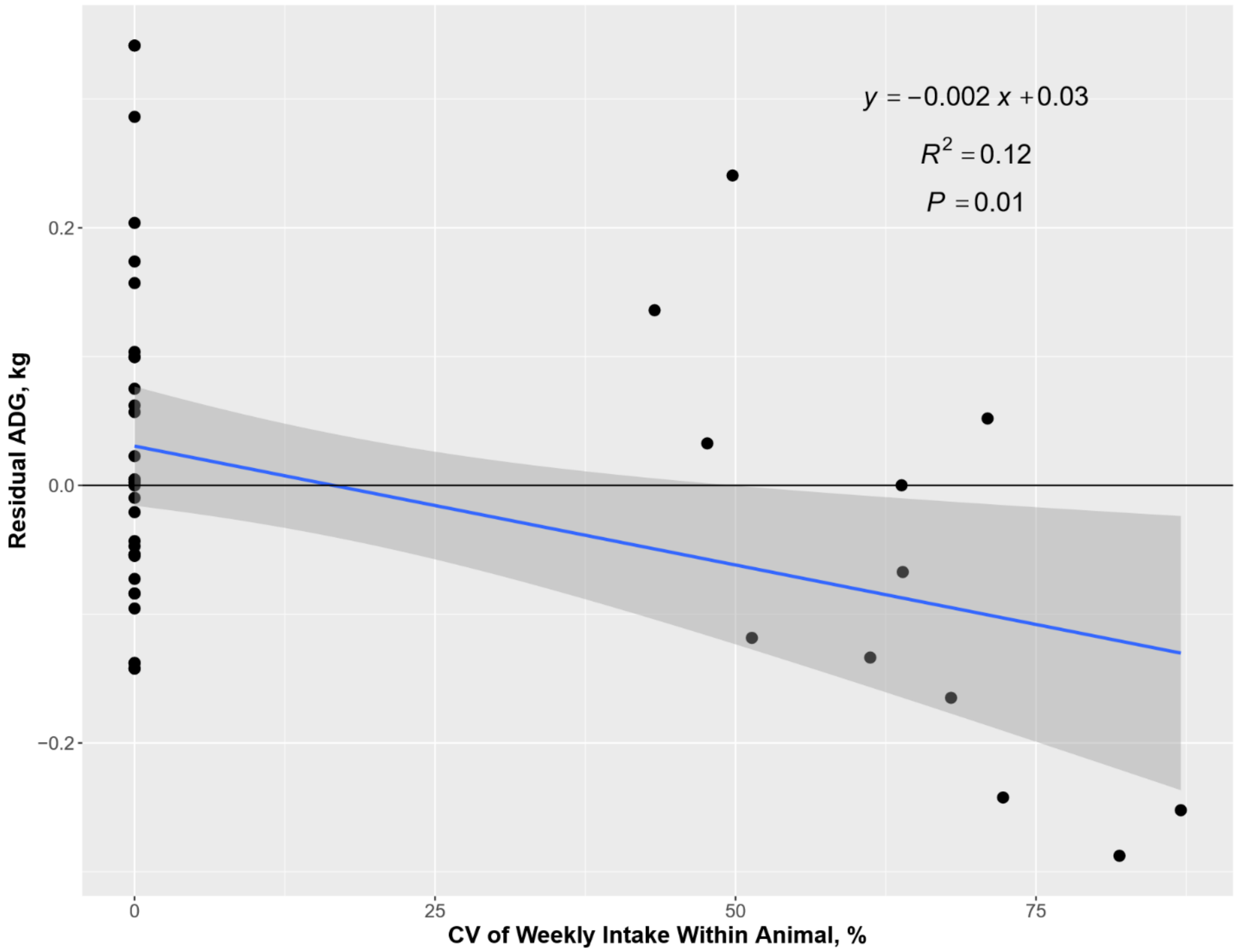

Figure 8. The residual ADG within the animals represented by the different CV of weekly intake within animal; $n = 39$. The line represents the regression with a 95% confidence band. The $P = 0.01$ represent the P-value for the animal intake within week CV and residual ADG interaction.

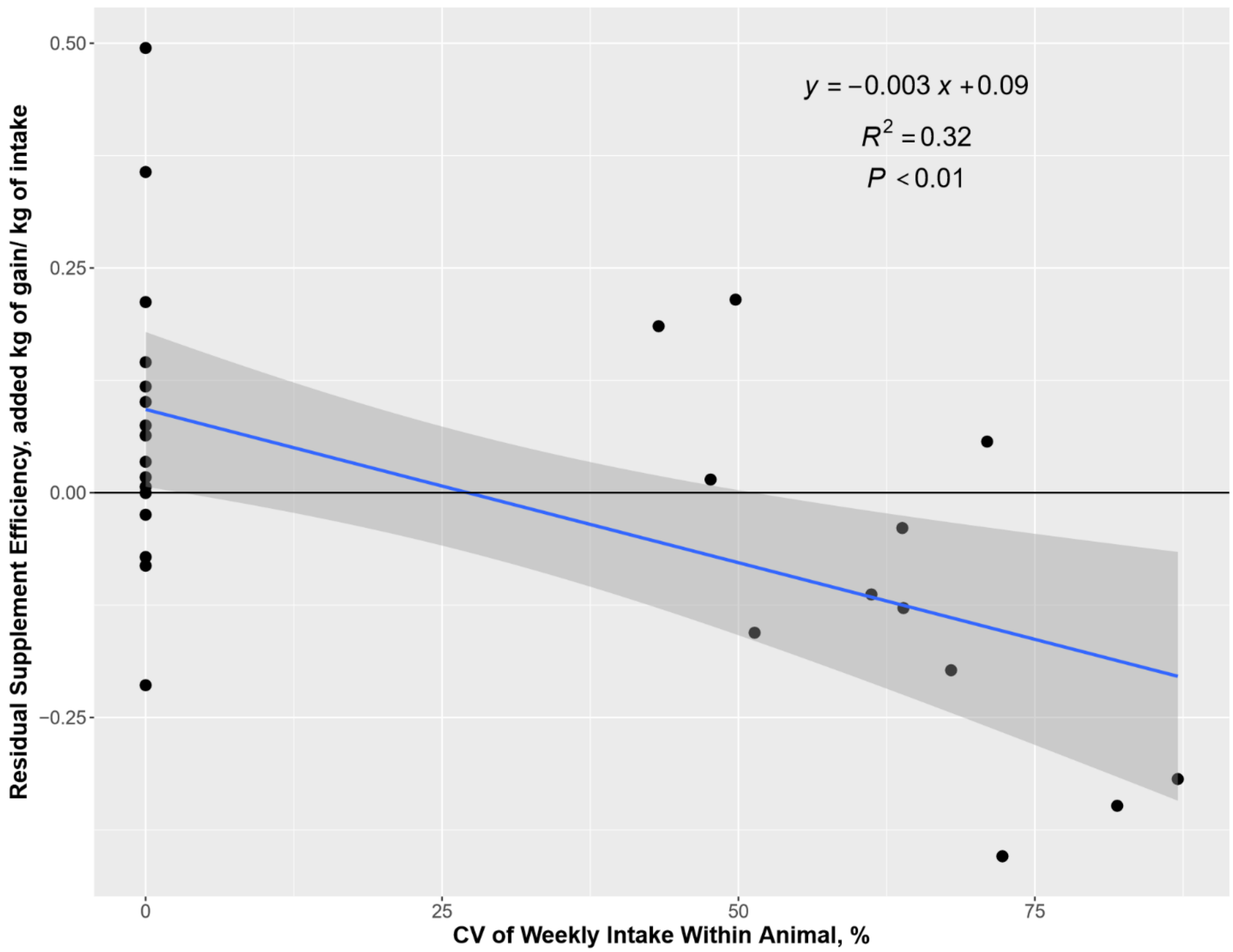

Figure 9. The residual supplement efficiency (G:F) within the animal represented by the CV of weekly intake within animal; $n = 29$. The line represents the regression with a 95% confidence band. The $P < 0.01$ represent the P-value for the mean daily supplement intake and supplement efficiency (G:F) interaction.

Chapter IV

Summary and Conclusion

The major goal from stocker cattle producers is to maximize cattle performance while improving the utilization of available forages. During the dormant season when tallgrass prairie is low in nutrients, providing a protein supplement becomes the ideal way to improve forage digestion and subsequent ADG. However, to achieve precession supplementation, the way that the supplement is provided as means to decrease labor cost while improving animals wellbeing. The research that is reported in this thesis was conducted to evaluate supplementation methods effects on steer performance, intake, and supplement efficiency.

A performance experiment was conducted over the late winter season to determine the effects that each supplementation method had on supplement intake and steer growth performance for stocker calves that were grazing dormant tallgrass prairie. The 3 treatment groups were control, hand-fed, and self-fed. The self-fed group intake was limited with the use of NaCl. Hand-feeding a supplement to steers grazing dormant tallgrass prairie shows to minimize the weekly intake variation. This decrease in weekly supplement intake variation may result in slightly greater ADG and supplement efficiency. To conclude, directly managing supplementation may be more efficient than relying on traditional, NaCl-based intake-limiting approaches.

VITA

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Master of Science

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