SUPPLEMENTATION OF DRIED DISTILLERS' GRAINS CUBES TO CATTLE: EFFECTS ON FORAGE INTAKE AND DIGESTIBILITY, GRAZING PERFORMANCE, AND SUBSEQUENT FEEDLOT PERFORMANCE AND CARCASS CHARACTERISTICS

By

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Abstract: Experiment 1 compared chemical composition and disappearance kinetics of loose and extruded dried distillers' grains (DDG), as well as evaluated DDG cube supplementation rate on DMI and digestibility for growing cattle consuming ad libitum bermudagrass (*Cynodon dactylon*) hay. Charolais-cross heifers (n = 23) received either no supplement, or DDG at 0.90, 1.81, or 3.62 kg/d. Extrusion increased ($P \leq 0.01$) fat and TDN, immediate solubility and effective degradability of DDG DM, and decreased ($P \leq 0.01$) NDF and ADF. Increased supplementation linearly and quadratically decreased ($P < 0.01$) hay DMI and DMD, respectively, but linearly increased ($P \leq 0.01$) total DMI and DMD. Each year of experiment 2 (year 1 = 155d, year 2 = 182d), 140 steers were randomly assigned to 1 of 9 tall fescue (*Festuca arundinacea*)/bermudagrass pastures (7.2 ± 2.90 ha) to evaluate DDG cubes on forage and steer performance, and profitability. Treatments (n = 3 pastures/treatment) included: 1) Fertilized Control (FC), no supplement/fertilized pastures; 2) Fertilized Supplement, 3-d/wk fed 2.9 kg DDG/fertilized pastures; or 3) Supplement (S), 5-d/wk fed 0.75% BW/d DDG /unfertilized pastures. Biomass was greatest ($P < 0.01$) in September both years. Fertilization increased ($P < 0.01$) CP and decreased ($P \leq 0.02$) ADF and NDF relative to S in early summer. Supplemented animals had heavier ($P \leq 0.01$) mid-summer and final BW than FC. Late and total gains were greater ($P < 0.01$) for S than FC and FS. Supplementation had greater ($P < 0.01$) cost of gain and gross returns, but least ($P < 0.01$) net returns. Experiment 3 used year 1 steers to evaluate carryover effects of supplementation on feedlot performance and carcass characteristics. Supplemented animals required fewer DOF ($P < 0.01$) than FC, and DMI and feed costs were lower ($P < 0.01$) for S than FC and FS. Gains were greater for FC and FS from d0-84 ($P = 0.02$) than S. At harvest, FC had lower YG ($P = 0.01$) than FS, and greater DP ($P < 0.01$) than supplemented animals. There were no differences in harvest BW ($P = 0.23$) or other carcass characteristics ($P \geq 0.17$).

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CHAPTER I

REVIEW OF LITERATURE

Introduction

In the United States, the beef industry relies heavily on forage as the primary feedstuff for growing cattle. Backgrounding cattle on pasture after weaning is a common management strategy in order to grow calves to heavier weights before entering the finishing phase of production. Therefore, the quality of forage consumed must be adequate to efficiently achieve production goals. Mixed warm- and cool-season perennial forage species are commonly used for stocker cattle on pasture in the southern United States (Franzluebbers et al., 2013a), providing moderate to high-quality forage for grazing cattle.

Although forage remains the primary feedstuff for growing cattle, management strategies such as pasture fertilization or supplementation are often implemented to improve animal performance and forage production. Routine application of nitrogen (**N**) fertilizer on introduced pastures increases forage biomass and forage crude protein (**CP**; Gadberry et al., 2009). However, feeding a supplement high in rumen undegradable protein (**RUP**) may be a suitable alternative due to the significant cost of N fertilization in direct association with production of introduced forages (Phillips and Coleman, 1995). Additionally, supplemental concentrate as a source of protein and energy is typically required for growing cattle consuming low-quality forages, as the energy consumed from the forage alone is often inadequate to meet performance goals (Moore et al., 1999). Supplementing grains tend to be high in starch content, which negatively affects forage digestibility, but by-products of grain milling and distilling industries are often moderate in protein with lower starch content (Morris et al., 2005) and provide a source of highly degradable fiber as an energy source to ruminants.

Regardless of the supplement source, the effects of the supplement utilized on forage intake and digestibility are important to consider when formulating a supplementation regimen. Internal and external markers are commonly utilized to estimate forage intake and digestibility. Although there are advantages and disadvantages to using internal and external markers, the marker system provides valuable information to ensure the supplement regimen employed is efficient and does not have negative effects on the utilization of forage by cattle.

Introduced Forage Species

The mid-20th century marked the transformation from primarily forested land and native forages to planted grasslands composed of introduced forage species in the southern United States (Hoveland, 2000). The shift towards increased utilization of introduced forages was a strategic approach to improve pasture quality and sustainability of livestock production (Simpson and Langford, 1996). Today, stocker cattle often graze introduced pastures to facilitate increased gains from the high-quality forage (Simpson and Langford, 1996), with bermudagrass (*Cynodon dactylon*) and tall fescue (*Festuca* *arundinacea*) being the dominant species in the southeastern United States (Franzluebbers et al., 2013a).

Bermudagrass

Bermudagrass is a warm-season, perennial forage of tropical origin that is well adapted to hot, dry climates and typically reaches maximum productivity between May and September in the southeastern United States (Ball et al., 2007). Warm-season, or C_4, grasses typically contain reduced concentrations of CP and soluble carbohydrates, but increased concentrations of cell wall components relative to cool-season, or C_3, grasses (Coleman et al., 2004). Maturity of all forages has long been associated with reduced nutritive value. With increased maturity of bermudagrass, forage yields tend to increase while CP and digestibility are significantly decreased (Ball et al., 2007). In addition, mature warm-season grasses have lower concentrations of nutrients than mature cool-season grasses due to the relative nutrient concentrations when immature (Coleman et al., 2004).

Nitrogen fertilization is a means of improving forage quality. Burton et al. (1959) observed significantly lower total available carbohydrate and higher CP content when bermudagrass was fertilized at a rate of 896 kg N/ha compared to a rate of 112 kg N/ha. However, cellulose and lignin content were not directly altered by increased fertilization in their study. Therefore, the indirect effects of N fertilization may have a greater influence on nutritive value and composition of forages due to the possibility of delayed or accelerated maturation (Blaser, 1964). Increased forage CP content due to N fertilization suggests efficient utilization of N by bermudagrass. When fertilized at a rate of 112 kg N/ha, Prine and Burton (1956) observed 88.4% of the fertilizer N was converted into CP in bermudagrass, thus confirming the efficient N utilization.

Tall Fescue

Tall fescue is a cool-season, perennial forage that is primarily adapted to the transition zone of the United States, which is between the zones best adapted for cool- and warm-season forages (Sleper and West, 1996). Although a cool-season species, tall fescue typically reaches maximum productivity between March and July (Ball et al., 2007). Additionally, the drought tolerance and ability of tall fescue to survive in the summer climate conditions has proven to be beneficial in the early summer while warm-season bermudagrass comes out of dormancy (Franzluebbers et al., 2013a; Corbin et al., 2019). Compared to warm-season perennial grasses, cool-season perennial grasses such as tall fescue are typically of greater nutritive value and have longer seasonal productivity (Ball et al., 2007). More specifically, Matches (1979) reported tall fescue to have approximately 3 to 7% greater CP content and 5 to 17% greater DMD than warm-season grasses. Although nearly all tall fescue grazed in the southern United States is infected with an endophyte toxin associated with poor animal performance, the changes in forage nutritive value have been reported to be independent of the toxic endophyte (Sleper and West, 1996; Burns, 2009). Regardless, the incorporation of warm-season grasses in tall fescue pastures and/or providing grazing cattle with supplemental concentrate have become common management strategies to overcome such issues (Sleper and West, 1996). As with most perennial forages, increased forage yields and CP content have been associated with N fertilization of tall fescue (Matches, 1979). When N fertilizer was applied to tall fescue, Sweeney and Moyer (2014) reported a 22% increase in forage yield, as well as a 35 and 10% increase in forage CP and DMD, respectively, compared to non-fertilized tall fescue. However, when grown in combination, bermudagrass tends to benefit more from N fertilization when applied in the late spring and early summer (Ball et al., 2007). Overall, the combination of warm- and cool-season grasses in grazing systems has been a commonly utilized management strategy for improved forage quality and animal performance throughout the entirety of the grazing season (Kallenbach et al., 2012).

Summer Grazing

Pastures containing introduced forage species can be advantageous for summer stocker cattle as they have been associated with expedited growth and performance of livestock due to the higher quality of forage (Simpson and Langford, 1996). Additionally, introduced pastures with both warm- and cool-season forages allows for season long utilization of nutrients and more sustainable production (Franzluebbers et al., 2013a). When forage production and quality of a mixed tall fescue and bermudagrass system was compared to a mixed tall fescue and legume system, Kallenbach et al. (2012) observed approximately 5,000 kg/ha more forage and a tendency for CP concentration to be increased in the mixed tall fescue and bermudagrass pastures. In addition to the greater consistency in forage quality and improved capability of supporting season long grazing compared to native forages, the utilization of mixed-species introduced pastures can promote greater stocking rates, although greater input costs may be required (Phillips and Coleman, 1995). For instance, McLaren et al. (1983) reported 66% greater forage production and an approximately 40% greater stocking rate throughout the grazing season when tall fescue pastures were overseeded with bermudagrass compared to when the same forage species were grazed in separate pastures. Franzluebbers et al. (2013b) determined from a series of studies that mixed tall fescue and bermudagrass pastures were superior to pure bermudagrass pastures in terms of forage quality, as indicated by a lower carbon:nitrogen ratio in the mixed-species pastures. Additionally, routine application of N fertilizer on introduced pastures has been a common management strategy resulting in increased forage biomass and CP content (Gadberry et al., 2009). When high rates of different sources of N fertilizer were applied to tall fescue-bermudagrass pastures, Franzluebbers et al. (2013a) reported improved forage and animal production as a majority of the applied N elucidated in steer BW gains and soil organic matter. However, application of N fertilizer has long been a primary contributor to the greater input costs for the management of introduced pastures during the summer grazing season. Therefore, research focused on supplementation of protein and energy to cattle grazing introduced forage species, as an alternative to N fertilization, is pertinent due to increased costs of fertilization and its environmental impacts (Corbin et al., 2019).

Supplementation

Supplemental concentrate as a source of protein and energy is typically required for growing cattle to meet performance goals. When consuming forage-based diets supplementation for cattle is a common management strategy to alleviate nutrient deficiencies, conserve forage, enhance forage utilization, and improve animal performance (Kunkle et al., 2000).

Supplementation on Pasture

Cattle grazing introduced pastures are oftentimes provided supplemental concentrate as a protein and energy source to improve animal performance. When it comes to perennial forage species, such as bermudagrass and tall fescue, it tends to be difficult to achieve maximum animal performance due to the lack of forage energy content (Blaser, 1964). Additionally, cattle grazing introduced pastures may experience a metabolizable protein (**MP**) deficiency in the early summer as a result of excess rumen degradable protein (**RDP**) commonly associated with immature forages; however, supplementation of RUP could alleviate the issue (Drouillard and Kuhl, 1999; Klopfenstein et al., 2001; Creighton et al., 2003). When heifers grazing smooth bromegrass were provided supplemental concentrate high in both RUP and energy, MacDonald et al. (2007) reported increased weight gains compared to heifers that received supplements high in either RUP or energy. Similarly, steers grazing mixed warm- and cool-season pastures in the summer experienced greater average daily gains (**ADG**) when supplemented with a sourced of RUP (Creighton et al., 2003).

Supplementation for Hay-Fed Cattle

When growing cattle are maintained on grass hay, protein and energy supplementation is typically required, as the hay alone may not supply adequate amounts of energy to achieve optimal animal performance (Moore et al., 1999). Although similar to grazing situations, nutritive quality of hay tends to be lower than that of growing pasture. Nevertheless, RUP supplementation is a common management strategy to improve performance for both hay-fed and grazing cattle. Gadberry et al. (2010) supplemented protein and energy to steers consuming low-quality tall fescue hay and observed a cubic increase in ADG with increased supplementation rate. Additionally, Morris et al. (2005) reported a linear increase in ADG with increased supplementation rate for heifers consuming both low- and high-quality hay.

Dried Distillers' Grains

Dried distillers' grains (**DDG**) are a by-product of ethanol production and have become a commonly utilized supplement for growing cattle due to the higher energy and RUP content. During the ethanol production process, starch is removed from the DDG and the remaining product contains significantly increased concentration of nutrients (Spiehs et al., 2002; Stock et al., 1999). Moreover, Spiehs et al. (2002) compared the nutritive value of loose DDG from 10 ethanol production plants in Midwestern US and calculated coefficients of variation for CP, crude fat, crude fiber, and nitrogen-free extract to all be less than 10%.

Several studies have been conducted to evaluate the effects of loose DDG supplementation on the performance of growing cattle. When supplemented loose DDG, calves grazing bermudagrass produced 98.5 kg/ha more BW compared to calves grazing without supplementation (Gadberry et al., 2010). Similarly, supplementation of loose DDG for steers grazing smooth bromegrass resulted in approximately 0.28 kg/d greater ADG than steers not supplemented (Watson et al., 2012). In addition, stocker steers consuming bermudagrass during the summer grazing season experienced a quadratic increase in final BW with increased supplementation of loose DDG (Smith et al., 2019). Overall, DDG may be an effective alternative to traditional sources of supplemental concentrate that is consistent in nutritive value and allows for improved animal performance.

A novel extrusion process has enabled the production of a stable DDG cube that provides advantages for supplementing cattle on pasture, such as reduced loss of product to wind and soil mixing common when feeding loose DDG on the ground in pastures. However, research evaluating supplementation of extruded DDG cubes is almost nonexistent.

Supplementation Rate on Forage Intake

Although growing cattle are oftentimes provided supplemental concentrate, the supplement type and quantity provided tend to have associative effects on forage intake (Moore et al., 1999). A supplement is considered to have negative associative effects when supplementation results in reduced forage intake or digestibility, whereas positive associative effects are considered when forage intake or digestibility is improved (Moore et al., 1999). However, producers may want to feed a supplement that reduces forage intake when forage availability is limited or in order to increase stocking rates (Leupp et al., 2009).

A decrease in forage intake due to supplementation is considered substitution, in which the animal substituted a certain amount of forage per unit of supplement consumed (Moore et al., 1999). In a meta-analysis comparing loose DDG supplementation rates for cattle consuming forage-based diets, Griffin et al. (2009) observed a quadratic decrease in forage intake with increased rate of supplemental loose DDG. When steers grazing summer Sandhill range were supplemented loose DDG at rates ranging from 0 to 1.03 % of BW, there was a 0.53 kg decrease in forage intake for every 1 kg increase in loose DDG supplemented (Morris et al., 2006). Furthermore, Leupp et al. (2009) concluded that protein supplementation may allow producers to increase cattle stocking rates due to decreased intake of smooth brome hay when loose DDG were supplemented up to 1.2% of BW. Therefore, DDG supplementation may be beneficial in the case that forage availability is limited or to increase stocking rates by reducing forage intake.

Supplementation and Forage Quality

Supplementation of protein and energy to cattle to meet animal performance goals is more common when low-quality forages are utilized, as the energy consumed from the forage alone is often inadequate (Moore et al., 1999). However, supplementation of protein and energy to growing cattle can also be employed as a management strategy when forage availability is limited, to improve the utilization of forage, or to increase production and profitability (Kunkle et al., 2000), all of which are associated with medium- to high-quality forages. The effects of supplemental concentrate on forage intake vary, which may be related to the quality of forage and the characteristics of the supplement being evaluated. Morris et al. (2005) determined that consumption of both low- and high-quality forage was decreased in heifers in response to increased supplementation rate of loose DDG; however, the response was greater for higher quality forages. In contrast, Winterholler et al. (2012) reported supplementation of loose DDG increased intake of low-quality tall-grass prairie hay by 18 to 31% compared with unsupplemented cows. Overall, supplementation of protein and energy can be beneficial for cattle regardless of forage quality, but the benefits may differ.

Forage Intake and Digestibility

Forage dry matter intake **(DMI)** is an essential component of grazing ruminant production; however, the applicability is dependent on the accuracy of measurement (Detmann et al., 2001). Several techniques for the measurement of forage intake have been adopted, including the use of internal and external markers. Internal markers have been defined as intrinsic, or indigestible, components of feedstuffs that may be recovered, while external markers are inactive compounds that must be supplemented to the animal (Owens and Hanson, 1992). Although total fecal collection has typically resulted in more accurate digestibility estimates, total collection may not be feasible and the use of markers for estimation of fecal excretion may be required (Sampaio et al., 2011). While there are advantages to using each method, complete fecal recovery is imperative for a marker to be considered adequate (Owens and Hanson, 1992). The marker system has limitations when used in grazing systems due to the disruption in normal grazing behavior. Nevertheless, the use of both an internal and external marker is a commonly utilized practice that allows for the estimation of both intake and digestibility.

External Markers

Chromium oxide (**Cr_2O_3**), and more recently titanium dioxide (**TiO_2**), are two of the most commonly used external markers for intake and digestibility estimation (Myers et al., 2004; Ferret et al., 1999). Additionally, TiO_2 has gained more attention for use as an external marker over Cr_2O_3 because it can be supplemented legally and without the potential carcinogenic effects (Titgemeyer et al., 2001).

Regardless, the use of external markers to estimate intake and digestibility relies on the recovery of the marker in the feces. External markers, such as TiO_2 or Cr_2O_3, can either be top-dressed on animal feed or administered via bolus. However, it is difficult to ensure the proper dose is received by each animal when the marker is mixed with the feed. Marker administration via oral bolus twice daily has been reported to reduce variation in fecal marker concentration (Brisson et al., 1956). In cattle, marker concentration typically begins to plateau after 5 to 7d of dose administration (Owens and Hanson, 1992), after which rectal grab fecal sampling is required for at least 4d at the time of dosing to estimate fecal output. Additionally, passage rate can be determined by intensive time point fecal sampling following the last dose of the external marker in order to determine marker concentration over time (Lippke, 2002). Fecal samples must then be analyzed for marker concentration, via wet lab analysis or more recently x-ray fluorescence, to estimate fecal output and passage rate (Van Soest, 1994).

Internal Markers

When evaluating digestion parameters, such as rumen kinetics and digestibility estimates, indigestible components of feedstuffs are ideal internal digestibility markers (Adams et al., 2020). The use of internal digestibility markers can be advantageous as preparation is not required (Huhtanen et al., 1994), however, rumen cannulated animals are necessary for ruminal incubation and may result in a costlier analysis. Indigestible DM (**iDM**) and indigestible neutral detergent fiber (**iNDF**) are two of the more common internal markers used to estimate digestibility due to their intrinsic nature. A known quantity of feedstuff is typically allocated into porous fiber bags prior to lengthy *in situ* ruminal incubation. Improved digestibility predictions have been reported when internal markers were ruminally incubated for 576-h (Norris et al., 2019). Following ruminal incubation and analytical procedures, digestibility can be calculated. Although requiring increased analytics, reduced variability, thus improved precision, in estimations have been reported when iNDF was used as an internal digestibility marker compared to iDM (Adams et al., 2020; Norris et al., 2019; Sampaio et al., 2011; Valente et al., 2011).

Equations

Following the analytical procedures associated with internal and external markers, intake and digestibility can be calculated. In addition, equations reported by Kartchner (1980) allow for the separation of forage and total diet intake and digestibility when supplements are fed (Appendix 1).

Summary of Literature

The beef industry continues to rely on forage as the primary feedstuff, whether it be pasture or hay. Bermudagrass and tall fescue are the common moderate- to high-quality introduced forages in mixed-species pastures for stocker cattle in the southern United States. However, hay-fed cattle typically consume forages of low- to moderate-quality quality.

Regardless of the source of the forage consumed, proper nutritional management is pertinent to ensure growing cattle achieve optimal animal performance. On pasture, N fertilization has long been accepted as a management strategy to increase forage production and quality. Supplemental concentrate as a source of protein and energy can provided to growing cattle consuming pasture or hay to improve performance and allow for more efficient forage utilization. Supplementation can ultimately allow producers to increase stocking rates and conserve forage by reducing forage intake, while meeting performance goals due to the increased protein and energy provided by the supplement.

Overall, appropriate nutritional management strategies and attention to the effects of those strategies on animal performance and forage utilization can support optimal system productivity.

CHAPTER II

EFFECTS OF SUPPLEMENTATION RATE OF AN EXTRUDED DRIED DISTILLERS' GRAINS CUBE FOR CATTLE ON VOLUNTARY INTAKE AND DIGESTIBILITY OF BERMUDAGRASS HAY

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ABSTRACT: Our objectives were to 1) investigate the change in chemical composition and difference in disappearance kinetics between loose dried distillers' grains **(DDG)** and extruded DDG cubes and 2) evaluate the effects of supplementation rate of extruded DDG cubes on voluntary dry matter intake (**DMI**), rate and extent of digestibility, and blood parameters of growing beef heifers offered ad libitum bermudagrass (*Cynodon dactylon*) hay. To characterize the changes in chemical composition during the extrusion process, loose and extruded DDG were evaluated via near-infrared reflectance spectroscopy, and dry matter **(DM)** disappearance kinetics were evaluated via time point in situ incubations. Extruded DDG cubes had greater ($P \leq 0.01$) contents of fat, neutral detergent insoluble crude protein, and total digestible nutrients, but lower ($P \leq 0.01$) neutral and acid detergent fiber than loose DDG. Additionally, the DM of extruded DDG cubes was more immediately soluble ($P < 0.01$), had greater ($P < 0.01$) effective degradability and lag time, and tended ($P = 0.07$) to have a greater disappearance rate than loose DDG. In the 29-d supplementation rate study, 23 Charolais-cross heifers were randomly assigned to one of four supplemental treatments: 1) Control, no supplement; 2) Low, 0.90 kg DDG cubes/d; 3) Intermediate, 1.81 kg DDG cubes/d; or 4) High, 3.62 kg DDG cubes/d. Titanium dioxide was used as an external marker to estimate fecal output and particulate passage rate (**K_p**). Blood was collected from each animal to determine supplementation effects on blood metabolites. Indigestible neutral detergent fiber was used as an internal marker to assess the rate and extent of hay and diet DM digestibility **(DMD)**. Increasing supplementation rate increased K_p and total diet DMI linearly ($P < 0.01$), yet linearly decreased ($P < 0.01$) hay DMI. Hay DMD was reduced quadratically ($P < 0.01$), while total diet DMD increased linearly ($P < 0.01$) with increased inclusion of DDG cubes. Supplemented heifers had greater ($P = 0.07$) blood urea nitrogen concentrations 4 h following supplementation than control animals. Intermediate and high rates of supplementation resulted in lower ($P < 0.01$) serum non-esterified fatty acid concentrations post-supplementation than animals in the control group. Concentrations of serum glucose and lactate were greatest ($P \leq 0.06$) 8 h post-supplementation. Our results suggest that extruded DDG cubes may be an adequate supplement for cattle consuming moderate-quality forage.

Keywords: digestibility, disappearance, extruded dried distillers' grains cube, intake, supplementation rate

INTRODUCTION

Supplemental concentrate as a source of protein and energy is typically required for grazing growing cattle to meet performance goals. This management strategy is more common for low-quality forages as energy consumed from the forage alone is often inadequate to meet production goals (Moore et al., 1999). Consequently, relatively few studies have evaluated supplementation regimens' effects for cattle consuming medium- to high-quality forage. However, supplementation of protein and energy to growing cattle can also be employed as a management strategy when forage availability is limited, to improve the utilization of forage, or to increase production and profitability (Kunkle et al., 2000), all of which are associated with medium- to high-quality forages. The effects of supplemental concentrate on forage intake vary, which may be related to the quality of forage and the characteristics of the supplement being evaluated. Morris et al. (2005) determined that consumption of both low- and high-quality forage was decreased in heifers in response to increased supplementation rate of loose dried distillers' grains (**DDG**); however, the response was greater for higher quality forages. In contrast, Winterholler et al. (2012) reported supplementation of loose DDG increased intake of low-quality tall-grass prairie hay by 18 to 31% compared with unsupplemented cows.

Traditional sources of supplemental concentrate tend to be high in starch content, which negatively affects forage digestibility, but by-products of grain milling and distilling industries are often moderate in protein with lower starch content (Morris et al., 2005). Dried distillers' grains are a by-product of ethanol production and have become a commonly utilized supplement for growing cattle due to the high energy and rumen undegradable protein (**RUP**) content. In addition, starch is removed from the DDG during the ethanol production process, resulting in a significant increase in the concentration of nutrients (Spiehs et al., 2002; Stock et al., 1999). A novel extrusion process has enabled the production of a stable DDG cube that provides advantages for supplementing cattle on pasture, such as reduced loss of product to wind and soil mixing, which is common when feeding loose DDG on pasture.

Although research evaluating supplementation rates of traditional protein and energy sources is abundant, research investigating the effects of supplementation rates of extruded DDG cubes is almost nonexistent. Therefore, the objectives of these studies were to 1) investigate the change in chemical composition and difference in disappearance kinetics between loose DDG and the extruded DDG cube obtained from a production plant (MasterHand Milling, Lexington, NE) and 2) evaluate the effects of supplementation rate of DDG cubes on voluntary intake (**DMI**), rate and extent of digestibility, and blood parameters of growing beef heifers offered ad libitum bermudagrass (*Cynodon dactylon*) hay.

MATERIALS AND METHODS

All animals and procedures used in this experiment were approved by the Institutional Care and Use Committee (protocol AG-14-13) of Oklahoma State University.

Chemical composition of loose and extruded DDG.

Twice daily from 12 August to 14 August 2019, one sample of each DDG before entering the extrusion process and DDG following the extrusion process at the MasterHand Milling production facility (Lexington, NE) were collected (n = 12 samples). Data logs from processing machines were obtained for comparison of the extrusion process between the collection days. Data logs contained the setpoints and actual measurements at the time of collection for temperatures throughout processing, as well as rotations per minute (**RPM**), pressure, and thrust of the machine. On collection dates, all five extruder temperatures were set at 82°C with a set point of 33 RPM. The actual measurements of extruder temperatures differed slightly between collection dates, with temperatures ranging from 81 to 92°C. Water temperature in the extruder ranged from 32 to 35°C, with an average temperature of 33°C. The melt temperature, or the last temperature measurement before entering the drying process, ranged from 87 to 94°C and averaged 91°C. The setpoint and actual measurements for RPM of the extruder ranged from 31.1 to 33 RPM, but the average for the exact measurement over the collection period was 32.6 RPM. Extruder pressure varied over the collection period, with an average of 3019 psi, whereas the screw thrust averaged 50% with minimal variation.

Loose DDG samples were ground to pass through a 2-mm screen using a cutting mill (Pulverisette 19, Fritsch Milling and Sizing Inc., Pittsboro, NC), while extruded DDG cube samples were crushed with a mortar and pestle prior to being ground in the same manner. Following the grinding process, chemical composition of all samples were estimated via near-infrared reflectance spectroscopy (**NIRS**; NIRS DS2500 F, Foss Analytics, Eden Prairie, MN; da Paz et al., 2019). The total mixed ration and high moisture corn calibration was used for NIRS analyses, and all global and neighbourhood

H values were below 2.0 and 0.5, respectively. Total digestible nutrients **(TDN)** were calculated based on equations from Tedeschi and Fox (2020). Crude protein **(CP)**, fat, neutral detergent fiber **(NDF)**, acid detergent fiber **(ADF)**, ash, NDF digestibility **(NDFD)**, ND insoluble CP **(NDICP)**, AD insoluble CP **(ADICP)**, and calculated TDN were compared for paired loose and extruded DDG collected at the same time.

Based upon the values from NIRS analysis, the average TDN calculated for both the loose and extruded DDG was used as selection criteria for further evaluation. Paired samples of DDG from pre-extrusion and post-extrusion, one collected on 12 August 2019 at 1500 h and the other on 13 August 2019 at 0800 h, were closest to the average TDN and therefore selected for the evaluation of in situ disappearance kinetics.

Supplementation Rate and Intake

Charolais-cross heifers (n = 23; BW = 286 ± 38.9 kg) were used to evaluate the effects of DDG cube supplementation rate on voluntary intake of ad libitum bermudagrass (*Cynodon dactylon*) hay during a 29-d study. Animals were randomly assigned to one of four supplementation treatments: 1) Control (**CON**), no supplement offered (n = 6); 2) Low (**DGL**), DDG cubes offered at 0.90 kg/d (n = 6); 3) Intermediate (**DGI**), DDG cubes offered at 1.81 kg/d (n = 5); or 4) High (**DGH**), DDG cubes offered at 3.62 kg/d (n = 6). Supplementation rates were selected to achieve approximately 0, 0.25, 0.50, and 1.0 % of BW intake (As-Fed Basis) for CON, DGL, DGI, and DGH, respectively. All heifers were maintained in a dry lot with ad libitum access to round bales of bermudagrass hay fed in a ring-type feeder. The chemical composition of the hay and supplemental DDG cubes are presented in Table 2.1. Heifers were separated into individual feeding stalls each morning and offered supplemental DDG cubes for 1 h. After 1 h, animals were returned to the dry lot, and orts were collected and weighed to determine actual supplement intake as a % of BW for use in the analysis. This was especially necessary for DGH heifers due to variable intake between animals and a pattern of fluctuating intake of supplemental DDG cubes from day to day, which may have been caused by jaw fatigue from extensive chewing (Forbes, 1986) in the short time span of exposure.

Following a 14-d adaptation to supplement and feeding stalls, heifers were orally dosed twice daily with 5 g of titanium dioxide (**TiO_2**), at 0800 h and 1700 h, in porcine gelatin capsules (10 g/d; Torpac #10: Torpac Inc., Fairfield, NJ) from d 15 to d 25 (Brisson et al., 1956). After the concentration of TiO_2 was assumed to have reached a plateau (Owens and Hanson, 1992), fecal samples were collected from the rectum from d 22 to d 25 at the time of each dosing to estimate fecal output (**FO**). Fecal sampling continued from d 25 to d 29 at 3, 15, 19, 23, 27, 39, 51, 63, 72, 87, and 96 h after the last dose of TiO_2 to determine passage rate (**K_p**). Following collection, all fecal samples were dried in a forced-air oven at 55° C for 72 h, or until weight loss ceased. After drying, daily fecal samples were composited by animals and ground to pass through a 2-mm screen using a cutting mill and stored for future analysis. In addition, subsamples of hay and supplemental DDG cubes offered were collected throughout the trial and dried and ground in the same manner before being stored for future analysis. On d 26, blood was collected from each animal via jugular venipuncture (9 mL neutral Sarstedt Monovette, Starstedt AG & Co. KG, Nümbrecht, Germany) immediately before supplementation and

4 and 8 h post-supplementation for analysis of blood urea N (**BUN**), non-esterified fatty acid **(NEFA)**, glucose, and lactate concentrations.

Digestibility parameters were evaluated using indigestible NDF (**iNDF**) as an internal digestibility marker based on Adams et al. (2020), while disappearance kinetics and rate and extent of the disappearance of dry matter (**DM**) and NDF were determined via time point in situ incubations.

Digestibility and in situ disappearance kinetics. Four Holstein steers (BW = 281 ± 29.5 kg) fitted with rumen cannulas were used as in situ incubation animals. All incubation animals were maintained in a dry lot with ad libitum access to round bales of bermudagrass (*Cynodon dactylon*) hay similar to that used in the supplementation rate experiment. Two steers received 0.90 kg/d of supplemental DDG cubes throughout the incubation period to evaluate the effects of supplementation on the rate and extent of digestion of the incubated forage samples. Supplemented animals were adapted to the DDG cubes for 14 d before the onset of the trial. Steers receiving DDG cubes were separated into individual stalls at 0700 each morning and provided DDG cubes daily throughout the incubation period.

The measurement of iNDF was performed using F57 fiber bags (ANKOM Technology, Macedon, NY) filled with a sample size-to-surface area ratio of 20 mg/cm^2 and a 576 h ruminal incubation (Norris et al., 2019; Adams et al., 2020). Hay and supplemental DDG cubes, as well as the fecal samples composited by animal (n = 23) were prepared in duplicate for each cannulated animal, and all bags were incubated for 576 h within a commercial laundry bag placed in the rumen.

Disappearance kinetics were evaluated using the same bag type and sample size-to-surface area ratio. In addition to hay and supplemental DDG cubes fed throughout the trial, the paired samples of loose DDG and extruded DDG cubes selected from the production plant were included to determine differences in the extent of digestion. For each incubation animal (n = 4) and incubation length (n = 9), three replicates of hay samples and four replicates of supplemental DDG cubes fed in the supplementation trial, as well as four replicates of both production plant loose and extruded DDG were ruminally incubated for 0, 6, 12, 24, 36, 48, 72, 96, and 120 h within a second commercial laundry bag. All bags were inserted in reverse order for ease of removal, with internal marker samples being inserted at h-0 and the addition of disappearance kinetics samples beginning at h-456. Upon completion of incubation, all bags were simultaneously removed from the rumen and immediately soaked in ice water to terminate fermentation (Dewhurst et al., 1995). After fermentation ceased, all bags were rinsed on the delicate cycle of a household washing machine with cold water (Krizsan and Huhtanen, 2013) until the water was clear. Although the 0 h bags were not ruminally incubated, they underwent the same soaking and rinsing processes as the incubated bags to estimate the immediately soluble fraction of each feedstuff (Warner et al., 2020). All bags were dried in a forced-air oven at 55°C for 48 h and subsequently dried at 105°C for 24 h.

Laboratory Analysis

Concentrations of TiO_2 in each hay, supplement, and all fecal samples were measured in duplicate using a handheld X-ray fluorescence (**XRF**) analyzer (Delta Premium with Rh anode, Olympus Scientific Solutions, Waltham, MA; Thompson et al., 2019). Marker concentrations in fecal composite samples were used to estimate FO, while K_p was determined from the disappearance of TiO_2 in fecal samples collected over 96 h.

Blood samples were agitated and stored on ice for transportation back to the laboratory, where serum was separated via centrifugation at 3000 × g for 20 minutes and held at -20°C for future analysis (Zebeli et al., 2010). Serum glucose and lactate concentrations were determined using an immobilized enzyme analyzer (YSI Model 2900D; YSI Inc., Yellow Springs, OH). Serum urea nitrogen concentrations were measured via automated colorimetric procedures (Marsh et al., 1965), and serum concentrations of NEFA were determined using an enzymatic colorimetric method (NEFA-C Kit; WAKO Chemicals USA, Richmond, VA).

Following drying procedures, all in situ bags were transferred into a desiccator to equilibrate and weighed to determine DM remaining (**DMR**). Following Van Soest et al. (1991), all bags were subsequently washed in neutral detergent (**ND**) solution with a ratio of 100 ml/g DM and 4 mL of heat-stable amylase using the ANKOM^{2000} automated fiber analyzer (ANKOM Technology, Macedon, NY) with the omission of sodium sulfite (Van Soest, 1994). Afterward, bags were soaked in acetone and air-dried before being dried at 105°C for 24 h. Upon removing from the dryer, bags were placed in a desiccator to equilibrate and weighed to obtain NDF remaining (**NDFR**) and iNDF. Fecal composite samples collected from each heifer during the supplementation rate study were washed in duplicate using the ND washing procedure mentioned above to determine NDF content for the calculation of NDFD.

Calculations

Determination of DMR post-incubation was calculated using the following equations, and as iNDF and NDFR were calculated in the same manner, both will be referred to as NDFR within the following equations:

$$\text{DMR, \% DM} = \frac{\text{W3 - (W1} \times \text{C1)}}{\text{W2}} \times 100 \qquad (1)$$

$$\text{NDFR, \% DM} = \frac{\text{W4 - (W1} \times \text{C2)}}{\text{W2}} \times 100 \qquad (2)$$

Where W1 is the initial weight of the empty bag (g), W2 is the initial sample weight (g), W3 is the weight of the dried bag and sample remaining after the initial post-incubation water rinse (g), W4 is the weight of the dried bag and sample remaining following the ND wash (g), C1 is the blank correction factor following the initial post-incubation water rinse (average weight of the dry bag following the cold water rinse divided by the initial weight of the empty bag, for each incubation length), and C2 is the blank correction factor following the ND wash (average weight of the dry bag following the ND wash divided by the initial weight of the empty bag, for each incubation length).

Fecal output was calculated according to Van Soest (1994) using the equation:

$$\text{FO, kg/d} = \frac{\text{TiO}_2 \text{ dosed } (\frac{\text{kg}}{\text{d}})}{[\text{TiO}_2] \text{ in feces } (\frac{\text{kg}}{\text{kg}})} \qquad (3)$$

Furthermore, equations reported by Kartchner (1980) were used to estimate hay and total diet DMI and DM digestibility (**DMD**) for heifers during the intake experiment, with TiO_2 as the external marker and iNDF as the internal digestibility marker (Appendix 1).

The degradation fractions of DM and NDF were defined according to Ørskov and McDonald (1979), with the A fraction being the immediately soluble fraction of the feedstuff that rapidly disappears upon ruminal incubation, the B fraction defined as the amount of the specific nutrient that disappears at a fractional rate over time, and the C fraction being the undegradable portion that did not disappear throughout incubation.

Disappearance curves for incubation animal and sample type were analyzed using PROC NLIN, with the fraction parameters being B: 20 to 50 by 2, C: 10 to 40 by 2, K: 0 to 0.2 by 0.01, and L: 0 to 10 by 1 and bounds for the model being specified as B: 0 to 100, C: 0 to 100, K: 0 to 0.3, and L: 0 to 48. The undegradable C fraction was considered the percent of nutrient remaining after 120 h for each sample type due to the initial violation of the C fraction's bound (Warner et al., 2020). While the B and C fractions, as well as the lag time and rate of disappearance (**K_d**), were determined via nonlinear regression, the A fraction and effective degradability of each of the nutrients were calculated according to Ørskov and McDonald (1979) using the following equations.

$$\text{A Fraction} = 100 - (\text{B Fraction} + \text{C Fraction}) \qquad (4)$$

$$\text{Effective Degradability} = \text{A} + \left\{\text{B} \times \left[\frac{K_d}{(K_d + K_p)}\right]\right\} \qquad (5)$$

The K_p determined for CON and DGL heifers in the supplementation rate and intake trial were used in the calculation of effective degradability for in situ samples incubated in non-supplemented and supplemented incubation animals, respectively.

Statistical Analysis

All statistical analyses were performed using SAS software (SAS Institute Inc., Cary, NC). The comparison of the NIRS analysis of paired samples of loose and extruded DDG was conducted using the mixed procedures of SAS, with the shift within collection date acting as the random variable. Effects of extrusion on in situ A, B, and C fractions, effective degradability, K_d, and the lag time of DM were analyzed using PROC MIXED with incubation animal within replicate as the random variable.

Effects of incubation animal diet on in situ A, B, and C fractions, effective degradability, K_d, and lag time of hay and DDG cube DM and NDF were analyzed using PROC MIXED with incubation animal within incubation animal diet acting as the random variable.

The particle K_p for the supplementation rate study was determined for each animal by regressing the natural logarithm of TiO_2 concentration in feces over sampling time using the regression procedure of SAS (Martínez-Pérez et al., 2013). The parameters for forage and total diet intake and digestibility were analyzed via PROC REG to determine the relationship between actual extruded DDG cube intake and forage intake and digestibility.

All blood parameters were analyzed using PROC MIXED with hour of the collection as the repeated measure and animal within treatment as the subject. Based upon Akaike Information Criterion values, compound symmetry covariance structure for repeated measures best fit the data for blood parameters and was used within the model (Littell et al., 1998).

Interactions were considered significant at $P < 0.10$, while main effect differences were deemed significant at $P \leq 0.05$, and main effect differences at $0.10 \geq P > 0.05$ were assumed to be tendencies. The LSMEANS statement was used to determine the least-squares means, and the largest standard error is reported.

RESULTS AND DISCUSSION

Characterization of the Effects of Extrusion on Chemical Composition of DDG

The chemical composition of loose and extruded DDG is presented in Table 2.2. No differences in CP, ash, NDFD, or ADICP ($P \geq 0.17$) were detected between the loose and extruded DDG. The fat content of the extruded DDG was greater ($P < 0.01$) than that of the loose DDG. Solanas et al. (2008) evaluated the effects of feedstuff extrusion, and the differences in chemical composition in soybean meal before and after extrusion were minimal. However, loose DDG had greater NDF and ADF ($P \leq 0.01$) concentrations than extruded DDG cubes. More specifically, concentrations of NDF and ADF were decreased in extruded DDG by approximately 7 and 13%, respectively. As acid and neutral detergent fiber concentrations are directly related to each other, the similar trend in NDF and ADF would be expected. Similar to our study, fiber concentrations were greater in ground corn than in extruded corn based upon the reported chemical composition (Alvarado et al., 2009). Although lower in fiber content, extruded DDG cubes had greater NDICP ($P = 0.01$) than loose DDG. As NDICP represents a fraction of RUP (Sniffen et al., 1992), the higher content observed for extruded DDG suggests their protein are more resistant to ruminal breakdown and more protein is likely to bypass the rumen intact to the lower digestive tract. In addition, the calculated TDN was greater ($P < 0.01$) for extruded DDG cubes by approximately 3 percentage units. Overall, the increased NDICP and estimated energy content of the extruded DDG indicate they may be nutritionally advantageous over loose DDG.

Dry matter disappearance data for loose and extruded DDG are presented in Table 2.3. When comparing disappearance kinetics of loose and extruded DDG, the extruded DDG cubes displayed a greater A fraction ($P < 0.01$) than the loose DDG for DM. More specifically, extruded DDG cubes had a 2.0 percentage unit greater A fraction of DM than loose DDG. The A fractions observed in the current study were approximately 25.3 and 23.4% greater for extruded and loose DDG, respectively, compared to that observed by Winterholler et al. (2009) for loose DDG. A greater B fraction ($P = 0.04$) was observed for loose DDG compared to extruded DDG, with 40.9 and 39.0% of DM disappearing at a fractional rate, respectively. There was no difference ($P = 0.87$) in the C fraction, or ruminally undegradable fraction, of DM. Effective degradability of DM was approximately 2.2 percentage units greater ($P < 0.01$) for the extruded DDG than the loose DDG, which was likely associated with the greater A fraction of extruded DDG cubes. There was a tendency ($P = 0.07$) for the K_d of DM to be faster for extruded DDG than for loose DDG (2.1 and 2.0 %/h, respectively). In a study comparing grain processing methods, the DM K_d of extruded grains was faster than that of dry-rolled grains (Gaebe et al., 1998). The lag time of DM disappearance was significantly greater ($P < 0.01$) for extruded DDG cubes when compared to loose DDG, with 7.3 and 2.9 h lag times, respectively. Although the A fraction of DM was much greater than that observed by Winterholler et al. (2009), both the K_d and effective degradability in the current study were similar to that observed by their lab regardless of the supplement form.

Effect of Supplementation Rate on Intake and Digestibility.

Intake and Digestibility of Hay and Diet. There was no relationship ($P = 0.41$; $r^2 = 0.03$) between supplementation rate and FO (Figure 2.1). However, particulate K_p increased linearly ($P < 0.01$; $r^2 = 0.50$), ranging from 2.46 to 3.34 %/h, with increased inclusion of supplemental DDG cubes (Figure 2.2). This agrees with McCollum and Galyean (1985a), who reported increased K_p of prairie hay with an increased supplementation rate. In general agreeance with our results, Guthrie and Wagner (1988) observed a linear increase in forage K_p with increased inclusion of supplemental protein; however, they found the increase in K_p to be highly correlated with increases in forage intake. As forage intake was reduced with supplemental DDG cubes in our study, the increase in K_p is likely related to the greater total DMI and greater protein content of the total diet (Guthrie and Wagner, 1988; McCollum and Galyean, 1985b).

Forage DMI decreased linearly with increasing supplementation rate ($P < 0.01$; $r^2 = 0.51$), whereas total diet DMI increased linearly ($P = 0.01$; $r^2 = 0.29$) with increased supplemental DDG cubes (Figure 2.3a and 2.3b, respectively). Positive associative effects of increased forage digestibility and intake are most commonly associated with providing rumen degradable protein (**RDP**) to protein-deficient forage diets with low CP and TDN: CP ratio > 7:1 (Moore et al., 1999). However, the hay used in the current experiment was not deficient in RDP (Table 2.1) and the TDN:CP ratio would be considered balanced (5.7:1) based on Moore et al. (1999). Decreased forage DMI due to supplementation has been attributed to a forage TDN:CP ratio < 7, and is typically observed when cattle consume forages adequate in RDP (Moore et al., 1999). Thus, the reduction in hay DMI with supplementation of DDG cubes in our study may be due to the

TDN:CP ratio of 5.7 for the bermudagrass hay. In a meta-analysis, Griffin et al. (2012) reported a similar quadratic decrease in forage intake with an increased loose DDG supplementation rate. Additionally, Morris et al. (2005) observed decreased forage DMI and a forage replacement rate of -0.32 when loose supplemental DDG were fed to cattle consuming smooth bromegrass. In other studies that related forage intake to intake of supplemental concentrate, forage replacement ranged from approximately -0.33 to -0.50 (Garcés-Yépez et al., 1997; MacDonald et al., 2007). Overall, the forage replacement rate of -1.78 observed in the current study is greater than that reported in similar studies and is related to the quality of both the forage and supplemental DDG cubes.

Forage DMD was strongly associated with DDG cube intake ($r^2 = 0.90$), and a quadratic decrease ($P < 0.01$) was observed with a greater supplementation rate (Figure 2.3c). However, increased inclusion of supplemental DDG cubes resulted in a linear increase ($P < 0.01$; $r^2 = 0.91$) in total diet DMD, with DGH having 17.42% greater diet digestibility than CON (Figure 2.3d). It has been noted that increased diet digestibility, with consumed energy in excess of nutritive energy required by the animal, would result in decreased DMI (Ellis, 1978). As indicated by the reduced forage DMI with increased supplemental DDG cubes, the supplemented animals required less energy from the forage due to supplemental energy and increased diet digestibility. Total diet NDFD increased linearly ($P = 0.01$; $r^2 = 0.27$) with increased rate of supplementation (Figure 2.3e). When DelCurto et al. (1990) evaluated the effects of supplemental protein concentration on NDFD for steers consuming low-quality hay, a quadratic response was observed with moderate (24.7% CP) and high (41.3% CP) supplements improving NDFD by 30% compared to the low (12.4% CP) supplement. Although Chase and Hibberd (1987) detected a cubic decrease in NDFD with an increased rate of corn supplementation for beef cows consuming native hay, the greatest reduction occurred as corn inclusion was increased from 1 to 2 kg/d and could be attributed to the increase in starch content. As corn grain is generally higher in starch content than DDG cubes, the positive linear relationship between total diet NDFD and DDG cube supplementation rate in the current study was likely a result of generally lower supplementation rates and starch content.

In Situ DM and NDF disappearance of hay and supplement. The disappearance of DM and NDF of hay and extruded DDG cubes fed during the supplementation rate experiment is displayed in Tables 2.4 and 2.5, respectively. There was no effect of incubation animal supplementation ($P \geq 0.25$) on any variable of DM disappearance of the hay (Table 2.4) or DDG cubes (Table 2.5) fed throughout the trial. As the hay and DDG cube samples were comingled within the rumen during incubation, it was not unexpected to observe those lack of differences in DM disappearance due to the diet of the incubation animal.

However, there was a tendency for the A fraction ($P = 0.07$) of hay NDF to be greater when the incubation animal received supplemental DDG cubes. Similar to DM disappearance, the remaining variables of NDF disappearance for hay were not affected ($P \geq 0.17$) by incubation animal diet. Furthermore, no effect of incubation animal treatment ($P = 0.44$) was observed for any variable of NDF disappearance of the DDG cubes.

Blood metabolites. A treatment × hour interaction ($P = 0.07$) was present for BUN concentration, with supplemented animals having greater concentrations 4 h following supplementation compared to CON (Figure 2.4). More specifically, supplemented heifers had approximately 2.7 mg/dL greater BUN concentrations 4 h after consuming supplemental DDG cubes than those not supplemented. Similar to our results, Cappellozza et al. (2014a) observed increased plasma urea nitrogen concentrations in beef heifers following protein supplementation compared to control animals. As rumen ammonia and BUN concentrations are generally related, our results indicated that increased BUN concentration in supplemented animals may be due to rumen ammonia concentration reaching a peak level approximately 4 h postprandial (Lewis, 1957). Additionally, intake of dietary CP and RDP have been reported to be positively associated with BUN concentration (Broderick and Clayton, 1997). Although our observed BUN concentrations followed the same trend as seen in similar studies, the relatively low concentrations in the current study may be due to the short supplementation period (Hammond, 1997).

Serum NEFA concentrations displayed a treatment × hour interaction ($P < 0.01$), with DGH and DGI having significantly lower concentrations 4 and 8 h post-supplementation compared to CON at the same time points (Figure 2.5). Cappellozza et al. (2014b) also observed lower NEFA concentrations in beef heifers that were provided supplemental protein or energy compared to those not supplemented. In further agreeance with our study, cows consuming prairie hay and provided supplemental RUP had lower plasma NEFA concentrations than cows only consuming the low-quality hay (Sletmoen-Olson et al., 2000). When the energy requirements of animals are not met by the diet, adipose tissue is mobilized to meet the energy requirements and can be indicated by increased concentrations of NEFA in the blood (Bowden, 1971). Thus, CON heifers having approximately 230 and 80% greater concentrations of NEFA 4 and 8 h following supplementation, respectively, compared to DGI and DGH suggests that the hay alone did not supply enough energy to meet animal requirements and that the additional energy provided by the extruded DDG cubes was adequate to do so.

Regardless of treatment, serum glucose concentrations were greatest ($P < 0.01$) and serum lactate concentrations tended to be greater ($P = 0.06$) immediately before supplementation and 8 h post-supplementation (Table 2.6). The similar trends in glucose and lactate concentrations in respect to time are likely due to lactate being a product of glucose metabolism, which has also been observed in feedlot steers (Warner et al., 2020). Reilly and Chandrasena (1978) further supported our results as they determined an interrelationship between glucose and lactate concentrations by evaluating their kinetic parameters in sheep.

CONCLUSION

In conclusion, increasing DDG cube supplementation to calves consuming bermudagrass hay may reduce forage intake and increase diet digestibility. In addition, our results suggest that extruded DDG cubes are an adequate supplement for calves consuming moderate-quality hay due to the increased supply of energy, and may be helpful in grazing systems. Future research is warranted to evaluate the ability of DDG cubes to allow for increased stocking rates in grazing systems and overall increased productivity.

Table 2.1 Chemical composition of bermudagrass hay and supplemental extruded dried distillers' grains (DDG) cubes fed

Item[1]	Bermudagrass hay	DDG cube
Chemical composition[2]		
DM, %	89.3	90.6
CP, % DM	10.5	34.9
aNDF, % DM	68.8	33.5
ADF, % DM	36.3	10.6
Fat, % DM	3.0	8.9
NFC, % DM	9.8	12.6
TDN, % DM	59.9	86.1

[1] Items are chemical composition of hay and supplement fed evaluated via near-infrared reflectance spectroscopy.

[2] aNDF, neutral detergent fiber with the addition of alpha-amylase and sodium sulfite; ADF, acid detergent fiber; NFC, non-fiber carbohydrates; TDN, total digestible nutrients calculated according to Tedeschi and Fox (2020).

Table 2.2 Effect of extrusion on the chemical composition of dried distillers' grains (DDG) determined by near-infrared reflectance spectroscopy

Items[1]	Loose	Extruded	SEM	*P*-value
Chemical composition[2], %DM				
CP	33.27	34.89	0.807	0.17
Fat	7.92^{a}	8.94^{b}	0.141	<0.01
NDF	36.03^{b}	33.51^{a}	0.482	<0.01
ADF	12.22^{b}	10.55^{a}	0.361	0.01
Ash	9.93	10.26	0.546	0.65
NDFD	77.89	79.40	1.693	0.55
NDICP	7.31^{a}	8.12^{b}	0.158	0.01
ADICP	0.65	0.64	0.024	0.84
TDN	84.97^{a}	87.35^{b}	0.346	<0.01

[1] Items are chemical composition of loose and extruded DDG evaluated via near-infrared reflectance spectroscopy.

[2] NDF, neutral detergent fiber; ADF, acid detergent fiber; NDFD, NDF digestibility; NDICP, ND insoluble CP; ADICP, AD insoluble CP; TDN, total digestible nutrients calculated according to Tedeschi and Fox (2020).

$^{a-b}$ Least-squares means followed by different superscripts differ within rows ($P < 0.05$).

Table 2.3 In situ DM disappearance of loose and extruded dried distillers' grains (DDG)

Item[1]	Loose	Extruded	SEM	*P*-value
DM disappearance, %DM				
A fraction	40.36^{a}	42.33^{b}	0.555	<0.01
B fraction	40.93^{b}	39.08^{a}	0.833	0.04
C fraction	18.70	18.58	0.784	0.87
ED	57.98^{a}	59.77^{b}	0.879	<0.01
K_d, %/h	2.01^{a}	2.14^{b}	0.108	0.07
Lag time, h	2.97^{a}	7.39^{b}	1.611	<0.01

[1] Disappearance kinetics: A fraction, immediately soluble; B fraction, fractional disappearance rate; C fraction, undegradable; ED, effective degradability; K_d, disappearance rate (Orskov and McDonald, 1979).

[a-b] Least-squares means followed by different superscripts differ within rows ($P < 0.05$).

Table 2.4 Effects of incubation animal diet on in situ DM and NDF disappearance of bermudagrass hay

	Diet[1]			
Items[2]	Non-supplemented	Supplemented	SEM	*P*-value
DM disappearance, %DM				
A fraction	19.18	18.78	1.321	0.85
B fraction	29.58	28.83	1.499	0.75
C fraction	51.23	52.38	0.927	0.47
ED	34.10	32.51	0.935	0.35
K_d, %/h	2.55	2.58	0.272	0.94
Lag time, h	4.37	2.39	2.289	0.60
NDF disappearance, %DM				
A fraction	29.46^a	31.10^b	0.345	0.07
B fraction	26.29	24.28	0.688	0.17
C fraction	44.23	44.61	0.359	0.53
ED	43.25	44.02	0.631	0.47
K_d, %/h	2.76	3.22	0.312	0.41
Lag time, h	7.97	13.28	2.340	0.24

[1] Incubation animal diet: Non-supplemented, received no supplemental DDG cubes during in situ incubation period; Supplemented, received 0.90 kg DDG cubes/d during in situ incubation period.

[2] Disappearance kinetics: A fraction, immediately soluble; B fraction, fractional disappearance rate; C fraction, undegradable; ED, effective degradability; K_d, disappearance rate (Orskov and McDonald, 1979).

[a-b] Least-squares means followed by different superscripts differ within rows ($P < 0.05$).

Table 2.5 Effects of incubation animal diet on in situ DM and NDF disappearance of supplemental extruded dried distillers' grains (DDG) cubes

	Diet[1]			
Items[2]	Non-supplemented	Supplemented	SEM	*P*-value
DM disappearance, %DM				
A fraction	39.13	39.63	0.940	0.74
B fraction	40.01	36.27	1.891	0.29
C fraction	20.85	24.09	1.456	0.25
ED	57.61	55.71	1.604	0.49
K_d, %/h	2.15	2.23	0.188	0.79
Lag time, h	5.42	13.43	3.670	0.26
NDF disappearance, %DM				
A fraction	57.39	57.08	0.234	0.44
B fraction	35.08	35.38	1.408	0.89
C fraction	7.51	7.53	1.203	0.99
ED	77.33	74.85	1.899	0.45
K_d, %/h	3.36	2.83	0.552	0.57
Lag time, h	12.63	15.91	3.193	0.54

[1] Incubation animal diet: Non-supplemented, received no supplemental DDG cubes during in situ incubation period; Supplemented, received 0.90 kg DDG cubes/d during in situ incubation period.

[2] Disappearance kinetics: A fraction, immediately soluble; B fraction, fractional disappearance rate; C fraction, undegradable; ED, effective degradability; K_d, disappearance rate (Orskov and McDonald, 1979).

Table 2.6 Effect of dried distillers' grains (DDG) cube supplementation rate on blood glucose and lactate concentrations

	Treatment[1]						Hour[2]				
Item	CON	DGL	DGI	DGH	SEM[3]	*P*-value	0	4	8	SEM	*P*-value
Glucose, mg/dL	60.35	67.31	68.82	69.62	3.709	0.23	67.46^{b}	61.83^{a}	70.28^{b}	2.129	<0.01
Lactate, mg/dL	18.43	26.11	33.94	31.85	6.429	0.29	27.59^{ab}	22.75^{a}	32.40^{b}	3.793	0.06

[1] Supplemental treatment: CON = no supplement, DGL = DDG cubes at 0.90 kg/d, DGI = DDG cubes at 1.81 kg/d, DGH = DDG cubes at 3.62 kg/d.

[2] Hour of blood collection: 0 = before supplementation, 4 = 4 h post-supplementation, 8 = 8 h post-supplementation.

[3] Group variances are estimated separately, the largest SEM is reported.

[a-b] Least-squares means followed by different superscripts differ within rows ($P < 0.05$).

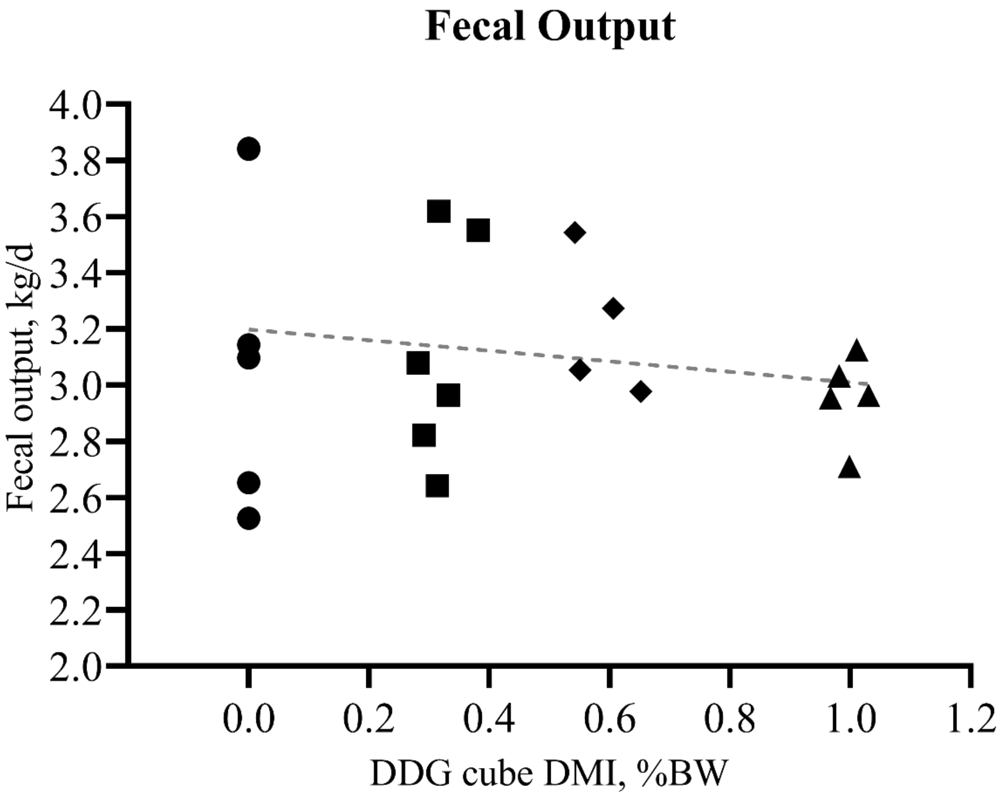

Figure 2.1 Linear effect of supplemental dried distillers' grains (DDG) cube intake on fecal output (*P* = 0.41; y = -0.1880x + 3.1983; $r^2 = 0.03$). Circle = no supplementation, square = 0.90 kg DDG cubes/d, diamond = 1.81 kg DDG cubes/d, triangle = 3.62 kg DDG cubes/d.

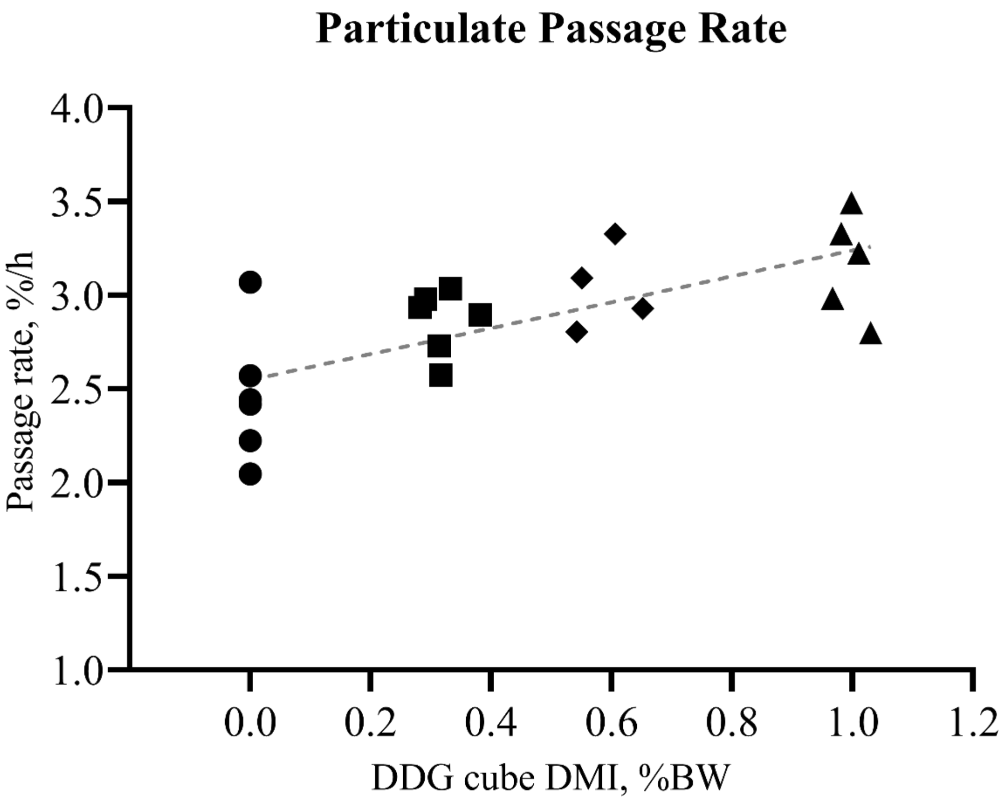

Figure 2.2 Linear effect of supplemental dried distillers' grains (DDG) cube intake on particle passage rate ($P < 0.01$; $y = 0.6913x + 2.5480$; $r^2 = 0.50$). Circle = no supplementation, square = 0.90 kg DDG cubes/d, diamond = 1.81 kg DDG cubes/d, triangle = 3.62 kg DDG cubes/d.

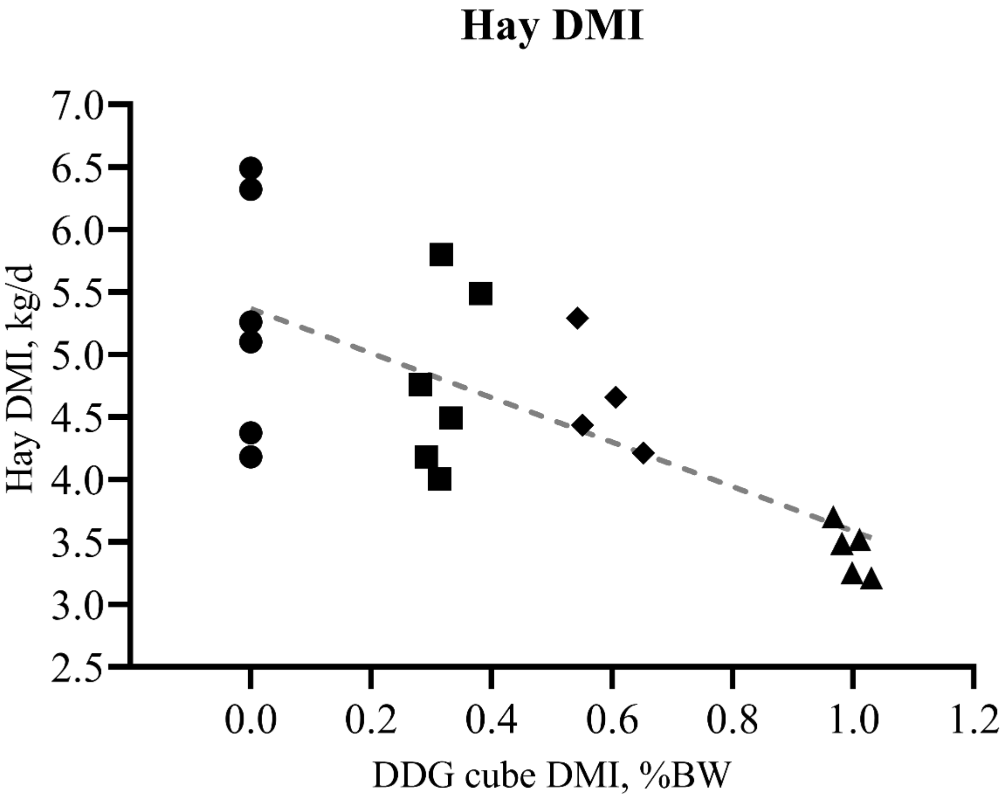

Figure 2.3a Effects of supplemental dried distillers' grains (DDG) cube intake on hay DMI (linear: $P < 0.01$; $y = -1.7800x + 5.3679$; $r^2 = 0.51$). Circle = no supplementation, square = 0.90 kg DDG cubes/d, diamond = 1.81 kg DDG cubes/d, triangle = 3.62 kg DDG cubes/d.

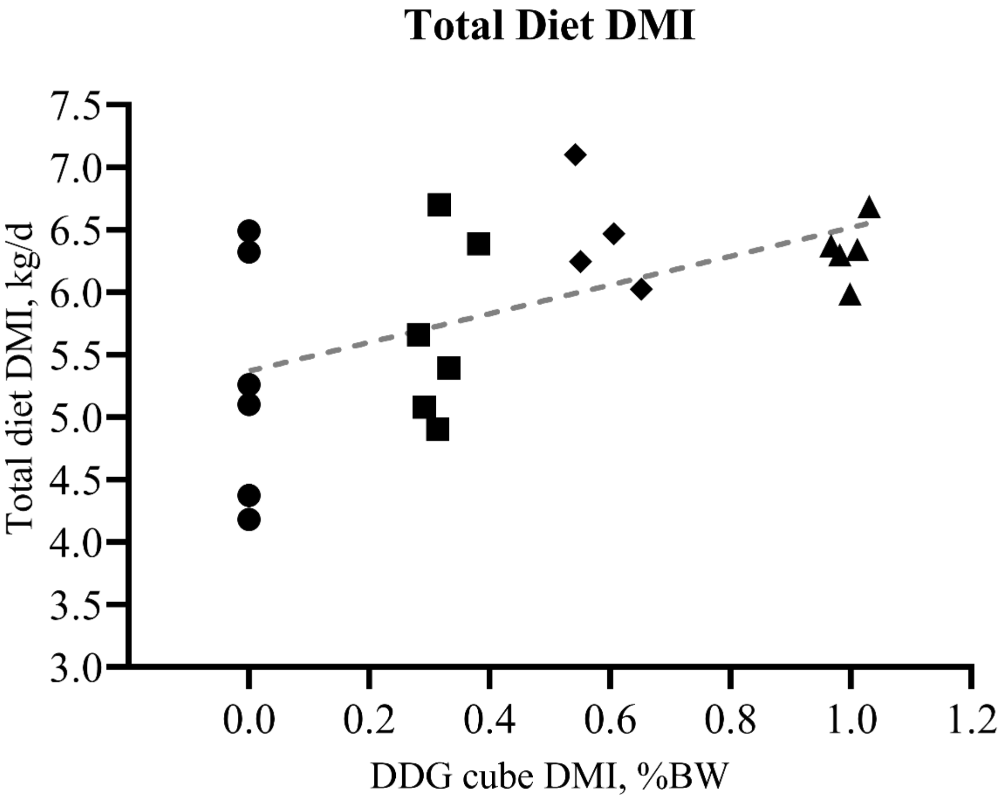

Figure 2.3b Effects of supplemental dried distillers' grains (DDG) cube intake on total diet DMI (linear: $P = 0.01$; $y = 1.1484x + 5.3699$; $r^2 = 0.29$). Circle = no supplementation, square = 0.90 kg DDG cubes/d, diamond = 1.81 kg DDG cubes/d, triangle = 3.62 kg DDG cubes/d.

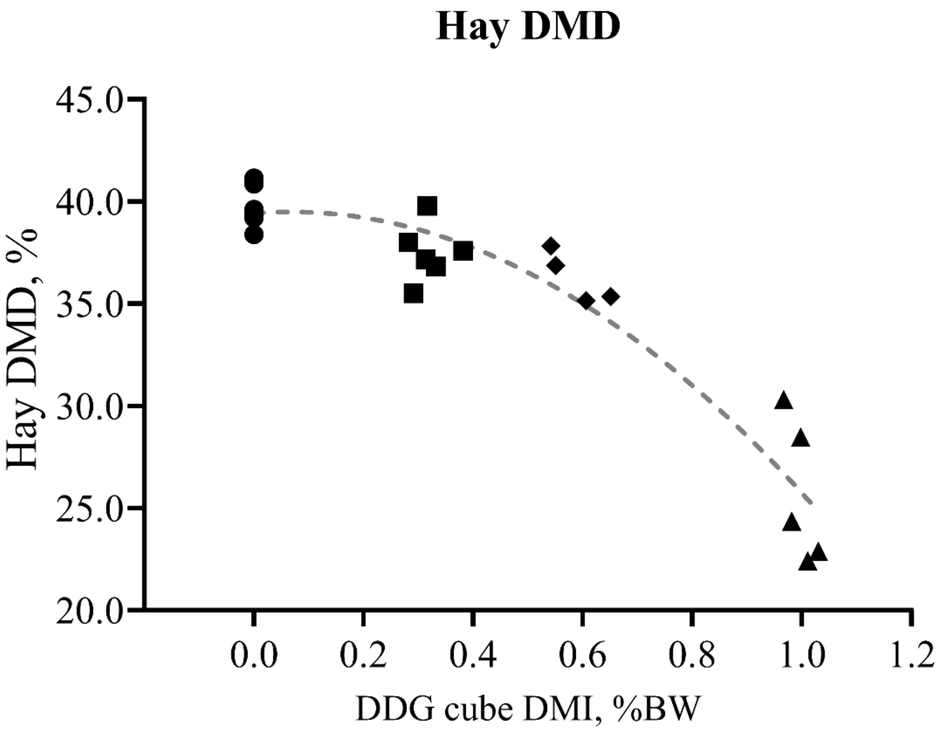

Figure 2.3c Effects of supplemental dried distillers' grains (DDG) cube intake on hay DMD (quadratic: $P < 0.01$; $y = -15.8044x^2 + 2.1320x + 39.4136$; $r^2 = 0.90$). Circle = no supplementation, square = 0.90 kg DDG cubes/d, diamond = 1.81 kg DDG cubes/d, triangle = 3.62 kg DDG cubes/d.

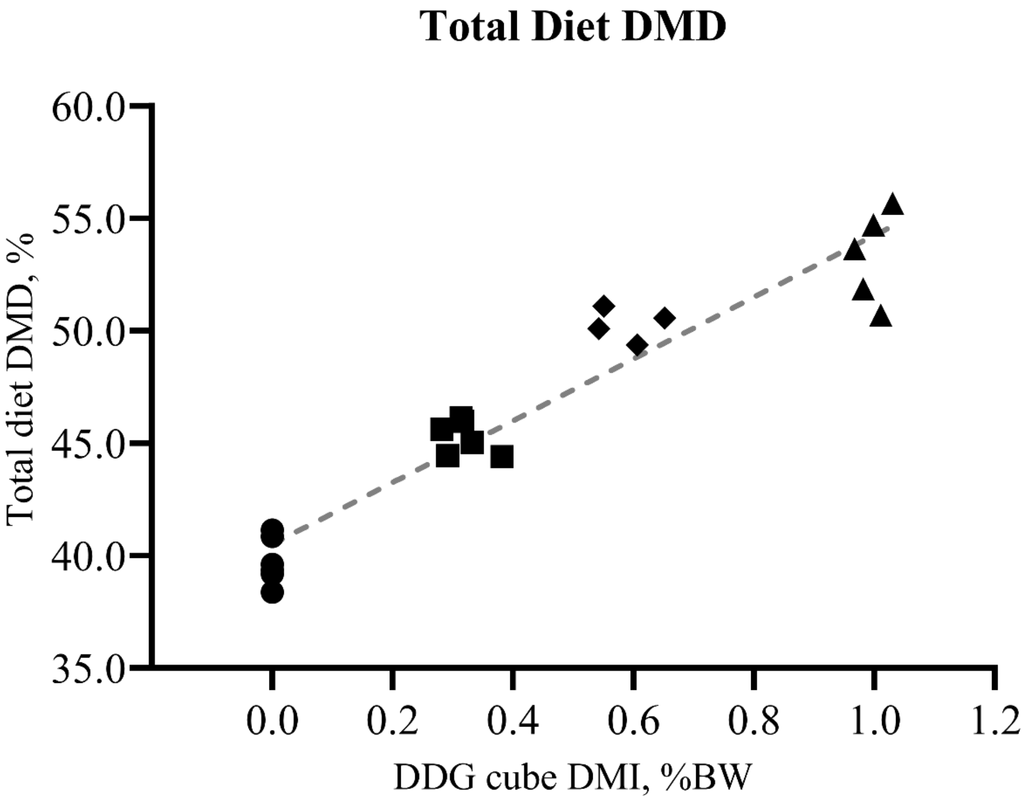

Figure 2.3d Effects of supplemental dried distillers' grains (DDG) cube intake on total diet DMD (linear: $P < 0.01$; $y = 13.7304x + 40.5147$; $r^2 = 0.91$). Circle = no supplementation, square = 0.90 kg DDG cubes/d, diamond = 1.81 kg DDG cubes/d, triangle = 3.62 kg DDG cubes/d.

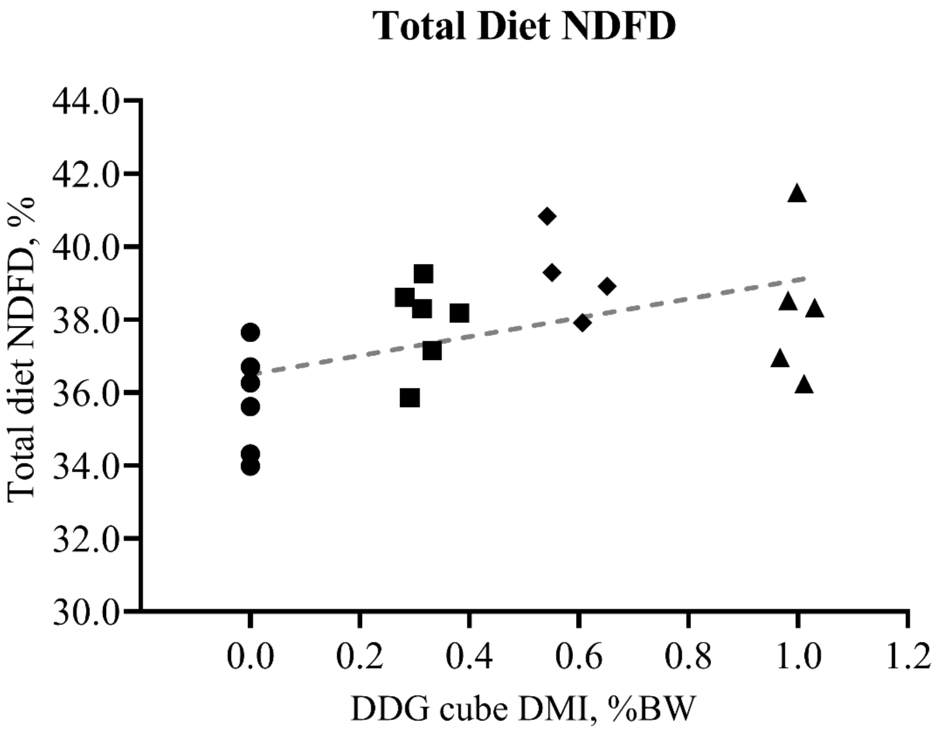

Figure 2.3e Effects of supplemental dried distillers' grains (DDG) cube intake on total diet NDFD (linear: $P = 0.01$; $y = 2.5911x + 36.4947$; $r^2 = 0.27$). Circle = no supplementation, square = 0.90 kg DDG cubes/d, diamond = 1.81 kg DDG cubes/d, triangle = 3.62 kg DDG cubes/d.

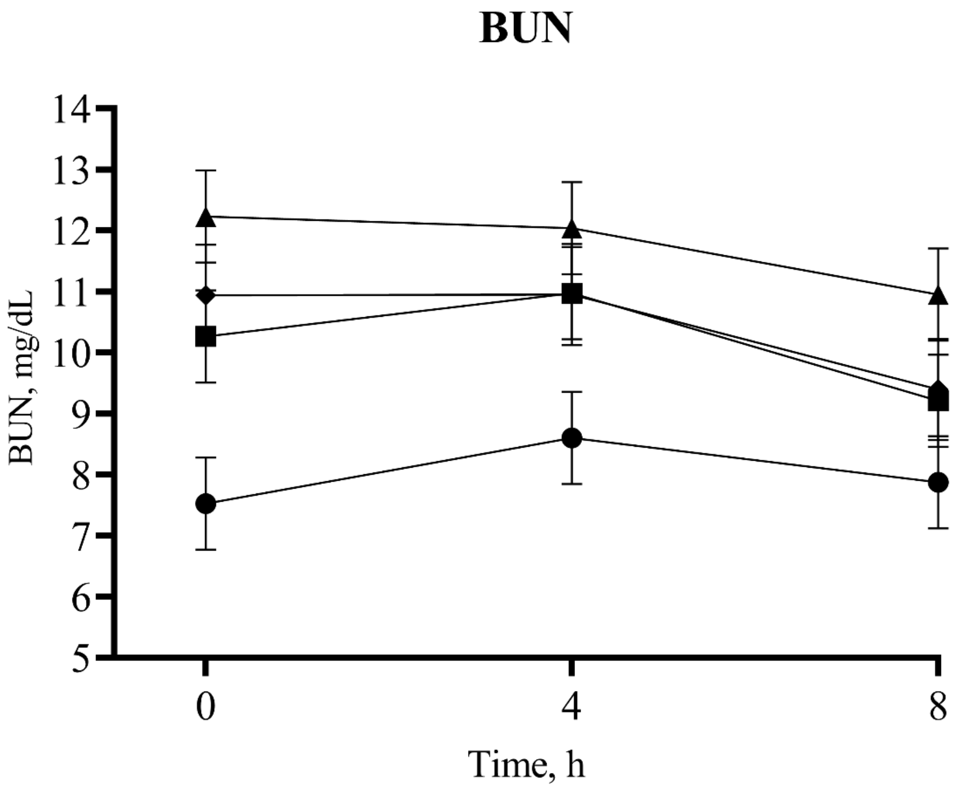

Figure 2.4 Effects of dried distillers' grain (DDG) cube supplementation rate on blood urea nitrogen (BUN) concentration in heifers consuming bermudagrass hay (circle = no supplementation, square = 0.90 kg DDG cubes/d, diamond = 1.81 kg DDG cubes/d, triangle = 3.62 kg DDG cubes/d; Time = hour of blood collection in relation to time of supplementation). Treatment × time interaction, $P = 0.07$. Treatment effect, $P = 0.01$. Time effect, $P < 0.01$.

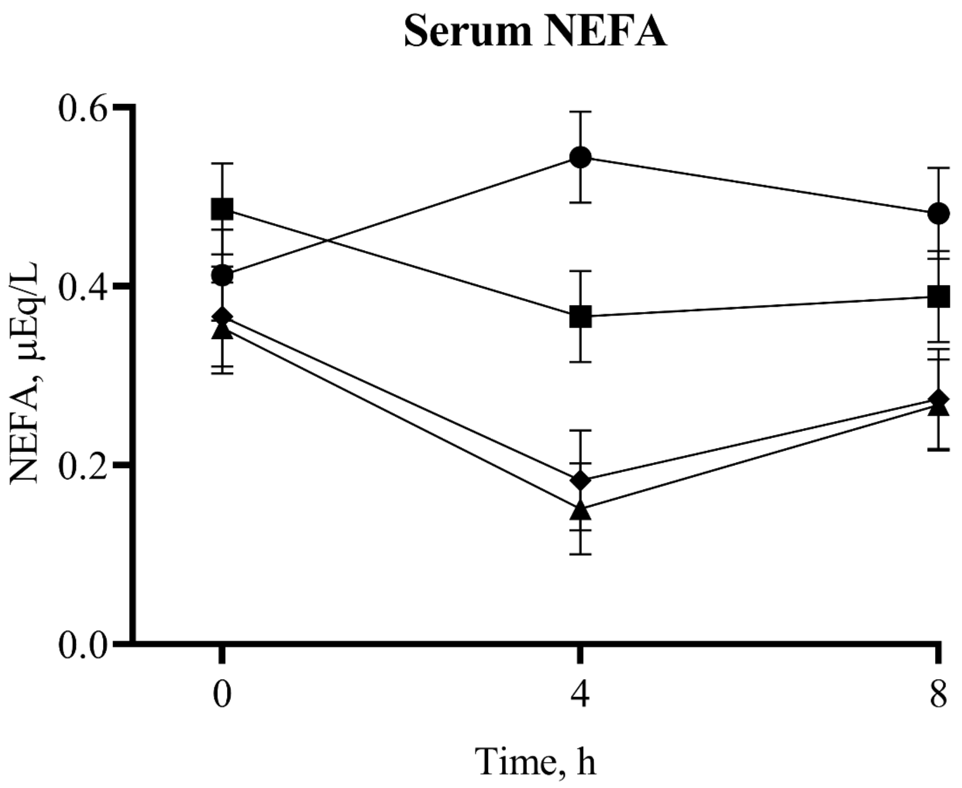

Figure 2.5 Effects of dried distillers' grain (DDG) cube supplementation rate on serum non-esterified fatty acid (NEFA) concentration in heifers consuming bermudagrass hay (circle = no supplementation, square = 0.90 kg DDG cubes/d, diamond = 1.81 kg DDG cubes/d, triangle = 3.62 kg DDG cubes/d; Time = hour of blood collection in relation to time of supplementation). Treatment × time interaction, $P < 0.01$. Treatment effect, $P < 0.01$. Time effect, $P < 0.01$.

CHAPTER III

EFFECTS AND ECONOMIC FEASIBILITY OF EXTRUDED DRIED DISTILLERS' GRAINS CUBE SUPPLEMENTATION FOR STEERS GRAZING INTRODUCED PASTURES ON ANIMAL PERFORMANCE AND FORAGE PRODUCTION

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ABSTRACT: The objectives of this study were to evaluate the effects of dried distillers' grains (**DDG**) cubes on performance and economics of steers grazing mixed tall fescue (*Festuca arundinacea*) and bermudagrass (*Cynodon dactylon*) pastures (n = 9 pastures; 7.2 ± 2.90 ha) in summer 2020 (n = 155d) and 2021 (n = 182d). Each year, crossbred steers (n = 140) were randomly assigned to one of nine pastures, and each pasture was assigned to one of three supplemental treatments (n = 3 pastures/treatment); receiving either 1) Fertilized Control (**FC**) - no supplement to steers on N fertilized pastures (112 kg N/ha); 2) Fertilized Supplement (**FS**) – steers were supplemented with DDG cubes at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; or 3) Supplement (**S**) – steers were supplemented DDG cubes at 0.75% of BW/d prorated for 5-d/wk feeding on unfertilized pastures. Economic feasibility was determined each year using an enterprise budget analysis. Forage biomass was greater ($P < 0.01$) in year 1 than in year 2 due to extreme climate conditions prior to grazing in year 2. Pooled between years, forage biomass increased throughout summer and was greatest in September ($P < 0.01$). Pasture fertilization resulted in increased CP ($P < 0.01$) in April and May, and decreased acid and neutral detergent fiber ($P \leq 0.02$) from April to July relative to S pastures, but did not differ in August and September. Supplemented animals had greater ($P \leq 0.01$) mid-summer and final BW than FC steers. Steers in S had greater gains ($P < 0.01$) in the late summer and total season compared to FC and FS. However, FS steers had greater total season supplemental efficiency ($P = 0.03$) than S. Cost of gain was the least ($P < 0.01$) for FC animals and the greatest for S ($P < 0.01$). Supplementation resulted in greater gross returns ($P < 0.01$), but FC had the greatest net returns ($P < 0.01$). Our results suggest that DDG cubes are a suitable supplement and can replace N fertilizer for steers grazing introduced pastures, but the producer must determine the management strategy most profitable to meet their production goals.

Keywords: animal performance, extruded dried distillers' grains cube, forage production, profitability, stocker cattle

INTRODUCTION

Backgrounding, or grazing cattle on pasture after weaning is a common management strategy in the United States beef industry in order to provide growth and maturation prior to entrance into the feedlot. Although both the stocker and finishing sectors target maximal animal growth, the stocker industry is primarily focused on enhancement of muscle and frame growth, while growth in the finishing phase is aimed more towards fattening of the cattle (Peel, 2003). Furthermore, backgrounding calves on high-quality pastures has often been associated with improved profitability in the beef industry (Hoveland, 1986) due to the improvement of the overall quality of the cattle and preparedness for feedlot production (Peel, 2003).

In the southern United States, warm-season bermudagrass (*Cynodon dactylon*) and cool-season tall fescue (*Festuca arundinacea*) are the predominant introduced forage species and are commonly used for stocker cattle on pasture (Franzluebbers et al., 2013a). Improved and consistent forage quality throughout the grazing season has been reported when the combination of warm- and cool-season grasses are used in grazing systems (Kallenbach et al., 2012). Additionally, the utilization of mixed-species introduced pastures have the capability to promote greater stocking rates, although increased input costs for management may be required (Phillips and Coleman, 1995). Routine application of nitrogen (**N**) fertilizer on introduced pastures has been a common management strategy resulting in increased forage biomass and crude protein (**CP**) content (Gadberry et al., 2009). However, with N fertilization constituting a significant cost in direct association with the production of introduced forages, offering grazing cattle a supplement high in rumen undegradable protein (**RUP**) may be viable alternative and allow for N fertilizer use to be reduced or replaced (Phillips and Coleman, 1995). Furthermore, supplemental RUP may correct a metabolizable protein (**MP**) deficiency commonly observed in growing cattle due to the rapid rumen degradability of protein in high-quality, actively growing forages (Creighton et al., 2003). Regardless, the management strategy employed for the improvement of animal performance and forage production must be economically feasible.

During the summer grazing season, steers grazing introduced forages are oftentimes provided supplemental concentrate as a source of protein and energy to improve animal performance. Supplemental cereal grains typically have negative effects on forage digestibility, as they tend to be higher in starch content compared to by-products of grain milling and distilling that often contain less starch (Morris et al., 2005). Dried distillers' grains **(DDG)** are a by-product of ethanol production and a commonly utilized supplement for growing cattle due to the high energy and RUP content, along with minimal starch. However, extruded DDG cubes, made using a novel extrusion process, are rarely studied and may be a more adequate supplement for grazing cattle. A stable extruded DDG cube provides advantages for pasture supplementation due to wind and soil mixing not posing a significant risk for loss of product, as seen with loose DDG. Therefore, the objectives of this study were to evaluate the effects of supplementing extruded DDG cubes and growth promoting implants for steers grazing introduced pastures on steer performance and forage production, as well as the profitability of DDG cube supplementation using an enterprise budget analysis.

MATERIALS AND METHODS

All animals and procedures used in this experiment were approved by the Institutional Care and Use Committee of Oklahoma State University.

Experiment site and design

This experiment was conducted during two consecutive years at the Oklahoma State University Eastern Research Station located near Haskell, Oklahoma (35°44' N, 95°38’ W). The most prominent soil types are Choteau loam, as well as Dennis and Parsons silt loam (USDA-NRCS, 2020).

A split-plot design was used in year 1 to determine the effects of supplemental DDG cubes and growth promoting implants for steers grazing mixed tall fescue (*Festuca arundinacea*) and bermudagrass (*Cynodon dactylon*) pastures on animal performance and forage production. The trial was replicated in year 2 as a completely randomized design and only the effects of supplemental DDG cubes were evaluated.

Effect of supplementation on animal performance and forage production.

Animal management and treatments. In year 1, crossbred steers (n = 140; 238 ± 13.8 kg) were sourced from sale barns in Oklahoma and Arkansas, while in year 2, crossbred steers (n = 140; 247 ± 22.6 kg) were sourced from Oklahoma and Texas via video auction (Superior Livestock, Fort Worth, TX). All animals were randomly assigned to graze one of nine mixed tall fescue (*Festuca arundinacea*) and bermudagrass (*Cynodon dactylon*) pastures (7.2 ± 2.90 ha) from 14 April to 17 September 2020 (n = 155 d; year 1) and 2 April to 1 October 2021 (n = 182 d; year 2). Each pasture was randomly assigned to one of three supplemental treatments (n = 3 pastures/treatment): 1) Fertilized Control (**FC**) - no supplementation on N fertilized pastures (112 kg N/ha); 2) Fertilized Supplement (**FS**) – steers fed supplemental DDG cubes at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures throughout the summer; or 3) Supplement (**S**) – steers supplemented DDG cubes at 0.75% of BW/d on unfertilized pastures prorated for 5-d/wk feeding. In year 1 pastures were randomly assigned to supplemental treatments, and pastures were assigned to the same treatments in year 2.

In year 1, steers in each pasture were randomly assigned to one of three growth promoting re-implant treatments on d 84 of grazing for evaluation of effects on animal performance, receiving either: 1) No re-implant; 2) 40 mg trenbolone acetate and 8 mg estradiol (**REV-G**, Revalor G, Merck Animal Health, Omaha, NE); or 3) 200 mg progesterone and 20 mg estradiol (**SYN-S**; Synovex S, Zoetis Animal Health, Kalamazoo, MI) at the mid-summer collection of weights.

Prior to turnout in year 1, all animals were treated with an anti-parasitic (LongRange, Merial Limited, Duluth, GA) for internal and external parasites, an insecticide (Permectrin CDS, Bayer HealthCare LLC., Shawnee Mission, KS), and an insecticide ear tag (Tri-Zap, Y-Tex, Cody, WY). All steers were previously implanted during receiving with REV-G in year 1. Whereas in year 2, all steers were vaccinated for bovine rhinotracheitis-virus diarrhea (Pyramid 3 + Presponse SQ, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO) and pinkeye (Piliguard Pinkeye + 7, Merck Animal Health, Omaha, NE), treated with an anti-parasitic (Cydectin, Bayer HealthCare LLC., Shawnee Mission, KS), and an insecticide ear tag (Corathon, Bayer HeathCare LLC., Shawnee Mission, KS). Due to not receiving growth promoting implants during receiving, all steers were implanted with 40 mg trenbolone acetate, 8 mg estradiol, and 29 mg of tylosin (Component TE-G with Tylan, Elanco Animal Health, Greenfield, IN) at processing and were not re-implanted during the trial.

Steers were weighed full, without previous shrink, for two consecutive days, for both initial and final BW, in order to reduce variability. Additionally, BW was recorded mid-summer and supplement rates were adjusted accordingly for S pastures. All calves were allowed ad libitum access to a complete mineral containing 6.5% Ca, 1.5% P, 18%

NaCl, 13.5% Mg, 0.5% K, 1,300 ppm Zn, 450 ppm Mn, 425 ppm Cu, 75 ppm I, and 12 ppm Se (Ranch Pro, Enid, OK).

Pasture management and data collection. The FC and FS pastures were fertilized with 56 kg of N from urea per hectare prior to stocking and after approximately 60 days of grazing each year, for total season fertilization of 112 kg N/ha. No fertilizer was applied to S pastures in order to determine the fertilizer replacement effects of DDG cube supplementation.

Forage availability was determined monthly using a calibrated rising plate meter. In each pasture, forage height was measured in a 0.10-m^2 quadrat using a rising plate meter before being hand clipped to ground level (Dougherty et al., 2011). Twenty rising plate meter readings were recorded from random locations in each pasture for the estimation of average forage biomass. Calibration of the rising plate meter was determined by the dry matter (**DM**) yield (kg DM/ha) of the forage clipped regressed on the sampled forage height (Rayburn and Rayburn, 1998). Forage samples were collected by hand at random locations within each pasture, representative of animal diet, for determination of forage quality. Furthermore, subsamples of supplemental DDG cubes were obtained from each pallet of supplement fed for the evaluation of nutritive value (Table 3.1), and total digestible nutrients **(TDN)** were calculated based on equations from Tedeschi and Fox, 2020. Forage and DDG cube samples were dried in a forced-air oven at 55°C for 72 h and subsequently weighed to obtain DM. Forage was ground to pass a 2-mm screen and stored for future analysis.

Profitability of supplementation

An enterprise budget analysis was used to evaluate the profitability of DDG cube supplementation to improve animal performance or replace the use of N fertilizer for steers grazing introduced pastures. The assumptions used in this analysis were based on actual costs of inputs for pasture management and the supplemental DDG cubes, as well as the 5-year average Oklahoma auction market prices for 227 and 250 kg steers in April and 386 and 432 kg steers in October for year 1 and 2, respectively. A $0.22/kg slide adjustment was used for cattle prices in both years (USDA-AMS, 2020a). A breakdown of pasture and fixed costs that were considered in the enterprise budget are displayed in Tables 3.2 and 3.3 for year 1 and year 2, respectively. Pasture costs included the variable prices of yardage and rent, mineral, herbicide, insecticide, health supplies, implants, N fertilizer, and supplemental DDG cubes, as well as the operation costs of machinery and equipment. Actual cost of supplemental DDG cubes used in the study was $335/ton in year 1 and $440/ton in year 2, which was approximately twice the average cost of loose DDG reported by USDA-AMS (2020b) between April and September. The actual fertilizer costs were $355/ ton in year 1 and $530/ton in year 2. Additionally, actual cost of pasture rent was $37.05/ha in year 1 and $48.18/ha in year 2 (USDA-NASS, 2021). The fixed costs included those associated with the ownership of machinery and equipment and were calculated using a spreadsheet program developed by Johnson (2020). Breakeven costs were calculated to determine the price per kg BW needed to cover all costs. Additionally, costs of supplemental DDG cubes and fertilizer required for FC and S pastures to have equivalent returns were determined.

Laboratory Analysis

All supplement and forage diet samples were analyzed for quality using the 2020 near-infrared reflectance spectroscopy (**NIRS**) consortium equations (NIRS DS2500 F, Foss Analytics, Eden Prairie, MN) for the determination of CP, acid detergent fiber (**ADF**), and neutral detergent fiber with the addition of alpha amylase and sodium sulfite (**aNDF**) content. All global and neighbourhood H values were below 3.0 and 2.0, respectively.

Statistical Analysis

All statistical analyses were performed using SAS software (SAS Institute Inc., Cary, NC). Using PROC REG, the DM yield (kg DM/ha) of the forage clipped was regressed on the calibration forage height to obtain prediction equations for the determination of forage biomass (Rayburn and Rayburn, 1998). Forage biomass and quality were analyzed using PROC MIXED with date as the repeated measure and pasture as the subject. Effect of trial year on forage biomass and quality attributes were analyzed using PROC MIXED, with month within trial year as the repeated measure and pasture as the subject.

The comparison of animal performance data in individual years was conducted using PROC MIXED. Pasture within supplemental and implant treatments was the random variable within the model for year 1 and pasture within supplemental treatment was the random variable for year 2. As supplemental efficiency was calculated from pasture average data, no random statement was included in the analysis.

Effect of trial year on animal performance data were analyzed using PROC MIXED, with pasture within year and supplemental treatment as the random variable.

Based upon Akaike Information Criterion values, compound symmetry covariance structure best fit the data for year comparisons of animal performance and was included in the model. Supplemental efficiency data were analyzed using PROC MIXED, with year as the random variable.

The enterprise budget analysis was evaluated using PROC MIXED for the determination of treatment effects on costs and returns. The model included trial year, supplemental treatment, and their 2-way interaction.

The LSMEANS statement was used to determine the least-squares means, and the largest standard error of the means is reported. Significance was considered at $P \leq 0.05$ and tendencies were assumed at $0.10 \geq P > 0.05$.

RESULTS AND DISCUSSION

Weather Conditions

Precipitation and temperature data during the grazing seasons were obtained and compared to the 30-year average (Oklahoma Climatology Survey, 2021). Precipitation fluctuated in 2020 with increased rainfall in May, July, and August and decreased rainfall in April, June, and September relative to the 30-year average (Figure 3.1a). Whereas in the 2021 grazing season, precipitation was only below the 30-year average in May and September (Figure 3.2a). Temperatures generally followed the same trend as the average, ranging from approximately 14 to 27°C during both the 2020 and 2021 grazing seasons (Figures 3.1b and 3.2b, respectively). However, precipitation was well below the mean in the January, February, and March prior to the 2021 grazing season. Additionally, temperatures in February 2021 were below 0°C and approximately 7°C below the normal temperature.

Forage Production and Quality

Year effects. An effect of trial year was detected for forage data (Table 3.4). Forage biomass was approximately 2252 kg DM/ha greater ($P < 0.01$) in year 1 than in year 2. However, the lower forage biomass in year 2 was likely a result of the below average precipitation and extreme temperatures prior to the onset of the trial. Forage quality did not follow the same trend, as forage CP was increased ($P = 0.01$) and forage ADF and aNDF were decreased ($P < 0.01$) in year 2 compared to in year 1. Although the weather conditions prior to the trial in year 2 were not beneficial for forage production, the more consistent precipitation and favorable temperatures during the 2021 grazing season may have allowed for improved forage nutritive quality relative to the 2020 grazing season.

Forage production. In year 1, fertilization of FC and FS pastures had no effect on forage biomass ($P = 0.39$) throughout the grazing season compared with S pastures. The lack of differences in forage biomass between treatments may be the result of a substitution effect exhibited by steers in S pastures or excess N excreted by steers being recycled back to the soil (Lomas and Moyer, 2015). In a meta-analysis of grazing trials with supplemental DDG, Griffin et al. (2009) reported that loose DDG replaced at least 0.34 kg of forage per kg of supplemental DDG. Although forage intake was not measured in the current study, reduced forage intake is commonly observed due to supplementation on improved cool- and warm-season pastures (Moore at al., 1999; Adams et al., 2022).

There was a main effect of month (*P* < 0.01), with forage biomass being greatest in June and September (Figure 3.3). In addition, forage biomass increased by approximately 2,000 kg DM/ha from April to September, which could be the result of the favorable temperatures and above average rainfall (Gadberry et al., 2010).

Similar to the results in year 1, forage biomass was not affected by pasture fertilization (*P* = 0.30) in year 2 and averaged 3665 kg DM/ha across supplemental treatments. A main effect of month (*P* < 0.01) was observed for forage biomass, with biomass being the greatest in September (Figure 3.4). More specifically, forage biomass increased by approximately 1784 kg DM/ha from April to September, which is similar to that observed in year 1.

An interaction of treatment × year was not detected for forage biomass (*P* = 0.22) or for any forage quality attributes ($P \geq 0.46$); thus, data was pooled between years and evaluated on a monthly basis. There was no treatment × month interaction for forage biomass (*P* = 0.42); however, forage biomass was affected by month of the trial (Figure 3.5; *P* < 0.01). When pooled between years, forage biomass increased throughout the trial and was greatest in September. This is reflective of the responses observed for forage biomass during the individual years, in which forage biomass increased in the late summer.

Forage quality. Fertilization of FC and FS pastures did have an effect on forage quality in year 1 with increased CP (Figure 3.6a; *P* = 0.01) and a tendency to decrease acid and neutral detergent fibers (Figures 3.6b and 3.6c, respectively; *P* = 0.06) relative to S pastures in the early summer (April, May, June, and July), but did not differ in the late summer (August and September). On average, FC and FS pastures had 28% greater CP ($P \leq 0.03$), 10% less ADF ($P \leq 0.10$), and 10% less aNDF ($P \leq 0.07$) than S pastures in the early summer. Although forage CP was lower for S in the early summer, CP content steadily declined in FC and FS throughout the summer while steadily increasing in S from June to September; with the increased CP likely being associated with increased N excretion in S pastures (Rivera et al., 2017). Forage aNDF and ADF content followed a trend similar to CP as fiber concentrations steadily increased throughout the grazing season for FS and FC pastures, but steadily decreased in S pastures from June to September. As decreased CP and increased fiber concentrations are associated with forage maturity in the late summer, the opposite effect observed in S pastures implied the beneficial response to increased N excretion and recycling from supplemental RUP (Beck et al., 2014; Rivera et al., 2017).

Similarly, in year 2, fertilization of FC and FS pastures had an effect on forage quality with increased CP (Figure 3.7a; $P < 0.01$) and decreased ADF (Figure 3.7b; $P < 0.01$) and aNDF (Figure 3.7c; $P = 0.05$) relative to S pastures in April. Furthermore, FS pastures tended ($P = 0.06$) to have greater CP in May and FC pastures tended ($P = 0.09$) to have greater CP in July compared to S pastures. These results are in contrast to that observed in year 1 in which fertilization affected forage quality from April to July.

When pooled between trial years, fertilization of pastures in FC and FS resulted in greater CP content ($P < 0.01$) than S pastures in April and May, but minimal differences were observed in June, July, August, and September (Figure 3.8a). Forage ADF and aNDF content was decreased (Figures 3.8b and 3.8c; $P \leq 0.02$) in fertilized pastures relative to S pastures in the early summer months (April, May, June, and July), but did not differ in the late summer months (August and September). Overall, there was minimal variability in the effects of supplemental treatment on forage biomass and forage quality between the two years of the study. There was an increase in forage biomass as the season progressed, which can be attributed to the growth of the warm-season bermudagrass and the favorable climate conditions throughout the trial. Our results suggest that late season supplementation of extruded DDG cubes is beneficial as fertilization only had an effect on forage quality attributes in the early summer months.

Animal Performance

Year effects. There was no effect of trial year on steer average daily gains (**ADG**; $P \geq 0.25$) or late and total season supplemental efficiency ($P \geq 0.38$). However, early summer supplemental efficiency was approximately 52% greater ($P < 0.01$) in year 2 than in year 1.

Treatment effects. Animal performance results as affected by supplemental treatment during the two grazing seasons are displayed in Table 3.5. In year 1, initial BW did not differ between treatments ($P = 0.78$) and was approximately 238 ± 13.8 kg. However, FS and S steers were heavier ($P < 0.01$) at the end of the trial and tended to weigh more ($P = 0.07$) in mid-summer compared to FC animals. Steers in FS and S gained more per day than FC in the early ($P = 0.03$) and late summer ($P < 0.01$), with 0.23 and 0.26 kg/d greater ADG ($P < 0.01$), respectively, in the total season compared to FC animals. These results are similar to those reported by Gadberry et al. (2010) who supplemented loose DDG to steers grazing bermudagrass and observed 0.24 kg/d greater ADG in supplemented steers compared to control animals. Although not expected, re-implanting had no effect on ADG (*P* = 0.57) or BW (*P* = 0.34), but statistical power may have been lacking. Supplemental efficiency did not differ between FS and S ($P \geq 0.23$) throughout the trial. However, supplemental efficiency in the current study was low, with 0.17 and 0.11 kg added BW gain per kg of supplement during the total season for FS and S, respectively. In other words, animals in FS required 5.9 kg of DDG cubes per kg of BW gain and those in S required 9.1 kg of DDG cubes per kg of BW gain. In a similar study, Gadberry et al. (2010) reported that decreased supplemental efficiency was associated with a supplementation rate of 0.75% of BW or higher, which is in agreeance with our results of numerically lower supplemental efficiency for S steers. Supplemental conversions of approximately 9 to 10 kg of supplemental concentrate per kg of added BW gain have commonly been reported for grazing cattle (Horn et al., 2005). Comparable results were observed by Watson et al. (2012) when steers were supplemented loose DDG on smooth bromegrass and accredited the increased BW gain to the RUP and energy content of the supplement. Although the low supplemental efficiency observed resulted in negative effects economically, the supplemental conversion remained relatively lower than that typical of stocker cattle supplementation programs.

Similar to the previous year, no differences were observed between treatments for initial BW (*P* = 0.99) in year 2, with the average being 247 ± 22.6 kg (Table 3.5). Steers in FS and S were an average of 33 kg heavier (*P* = 0.01) in mid-summer than those in FC. Final BW was greater for S steers ($P < 0.01$) than FC steers and tended to be heavier (*P* = 0.06) than steers in FS. In addition, supplemented animals had greater gains ($P < 0.01$) in the early summer compared to those in FC. More specifically, FS and S animals had approximately 0.32 and 0.38 kg increased gains per day, respectively, over FC steers. However, S steers had greater gains ($P < 0.01$) in the late summer and throughout the total season than FC and FS steers. There was no effect of supplemental treatment on early or late summer supplemental efficiency ($P \geq 0.41$). However, total season supplemental efficiency was greater ($P < 0.01$) for FS, gaining approximately 0.50 kg BW more per kg of supplement than S steers.

A treatment × year interaction was not present for any animal performance data ($P \geq 0.16$); therefore, main effects of supplemental treatment were pooled between years and are reported in Table 3.6. There was no difference ($P = 0.88$) in initial BW between treatments, which was expected due to weights being recorded before animals were provided the respective supplemental treatments. Steer BW in the mid-summer followed the same trend observed for individual years, with pooled mid-summer BW being greater ($P = 0.01$) for FS and S steers compared to those in FC. Supplemented animals had greater final BW ($P < 0.01$) than FC animals, with S steers tending ($P = 0.07$) to be heavier than FS steers. Similar to our study, Greenquist et al. (2009) reported greater final BW when steers were provided loose DDG on unfertilized pastures compared to those grazing fertilized pastures without supplementation, and attributed the improvement to the increased supplemental energy supplied after meeting protein requirements. As energy tends to be a limiting factor in warm-season pastures, animal performance was improved for supplemented cattle in the current trial as a result of increased energy supplied by DDG cubes (Beck et al., 2014; Rivera et al., 2017). Early summer ADG was affected by supplemental treatment ($P = 0.02$), with increased gains for FS and S cattle over those in FC, similar to results for individual years. However, steers in S had greater gains ($P < 0.01$) than FC and FS steers in the late summer and total season. Pooled between the two years, S animals gained approximately 0.31 and 0.07 kg per day more ($P \leq 0.04$) than FC and FS animals, respectively, in the total grazing season. Although there were no differences ($P \geq 0.18$) in early or late summer supplemental efficiency, animals in FS displayed greater ($P = 0.03$) supplemental efficiency in the total season compared to animals in S. Overall, there was little variability in the effects of supplementation on animal performance over the two years. Thus, extruded DDG cubes may be an adequate supplement for stocker cattle on introduced pastures with reliability and consistency in the improvement of animal performance.

Profitability of Supplementation

Results for enterprise budget analyses in individual years are shown in Table 3.7.

Costs. In year 1, net cost at turnout was similar between all treatments as those costs included steer purchase and receiving costs (Table 3.2). Total pasture costs were \$291.92, \$467.96, and \$533.66/ha for FC, FS, and S, respectively. Supplemental DDG cubes and N fertilization were responsible for a majority of the pasture costs for FS and S, with the cost of DDG cubes being \$176.03 and \$341.99/ha for FS and S, respectively, and N fertilizer costing \$95.14/ha for FS. Watson et al. (2012) conducted a similar economic analysis and reported N fertilization costs of \$35.48/hd, which is comparable to the \$38.52/hd observed in the current study. However, the DDG cubes we supplemented were priced at \$335/ton, which was more than double the price of loose DDG used in their study. Therefore, our cost of supplementation on a per head and per hectare basis was also much greater. Furthermore, Loken et al. (2009) backgrounded steers at high and low rates of gain and determined that the cost of feed represented 75% of the total costs in their study. Comparably, when both cost of DDG cubes and fertilization in the current study were considered, they accounted for 33, 57, and 62% of the total costs for FC, FS, and S, respectively. Although supplementation and fertilization greatly increased costs, there must be a balance between profit and performance when managing stocker cattle on introduced pastures. Fixed costs included those associated with ownership of machinery and equipment, thus FS and FC had greater fixed costs than S due to equipment required for fertilization. Total cost per hectare ranged from \$312.80 to \$549.15/ha with FC being the least ($P < 0.01$) and S being the greatest ($P < 0.01$; Table 3.7). Similarly, FC cost less per kg of gain ($P < 0.01$) than FS and S.

Similar to year 1, net cost at turnout was the same for all treatments in year 2 due to the lack of difference in initial BW and all animals following the same receiving procedures (Table 3.3). Total pasture costs were \$339.11, \$614.15, and \$770.87/ha for FC, FS, and S, respectively. However, fertilization of pastures resulted in greater fixed costs relative to S. Total cost per hectare followed the same trend as in year 1 and ranged from \$356.71 to \$786.66/ha, with FC being the least ($P < 0.01$) and S being the greatest ($P < 0.01$; Table 3.7). Additionally, cost of gain was least for FC ($P < 0.01$), intermediate for FS ($P < 0.01$), and the greatest for S ($P < 0.01$). More specifically, it cost \$0.35 and \$0.52 per kg of BW gain less for FC compared to FS and S, respectively.

Returns. In year 1, gross return per hectare for S tended ($P = 0.06$) to be \$19.40 and \$90.64 greater than FS and FC, respectively (Table 3.7). However, FC had the greatest net return per hectare ($P = 0.01$) compared to FS and S, which were in deficit. When evaluating the profitability of calves grazing warm-season pastures with or without supplementation, Beck et al. (2013) also reported increased costs due to supplementation, but overall profitability was observed when calves were supplemented in their study. The lower net returns for supplemented steers in the current study can be accredited to the higher cost of supplemental DDG cubes and low supplemental efficiency.

Similar to year 1, gross returns were greatest for supplemented cattle ($P < 0.01$), with FS and S having \$107.93 and \$148.51/ha greater gross returns than FC animals, respectively in year 2. However, net returns were greatest for FC animals ($P < 0.01$), while FS and S were both in deficit. Steers in S had the lowest net return ($P < 0.01$), with a return of \$-194.18/ha.

As input costs, such as those for fertilizer and supplement, inevitably vary between years, costs and returns were pooled between years to evaluate treatment effects (Table 3.8). The variable pasture costs are an important aspect to consider when comparing profitability between years. For instance, increased management inputs in the first year may result in reduced costs the following year. This was observed in the current study as herbicide costs were reduced from \$27.07/ha in 2020 to \$2.64/ha in 2021. However, costs of N fertilizer and supplemental DDG cubes increased in year 2. When pooled between years, cost of gain was least ($P < 0.01$) for FC, intermediate ($P < 0.01$) for FS, and greatest ($P < 0.01$) for S animals. More specifically, it cost approximately \$0.32 and \$0.46 less per kg of BW gain for FC steers than for FS and S animals, respectively. Supplementing cattle resulted in the greatest ($P < 0.01$) gross returns, with FS and S having \$89.47 and \$119.57 greater gross returns per ha than FC, respectively. Net returns were greatest ($P < 0.01$) for FC, intermediate for FS ($P < 0.01$), and the least for S steers ($P < 0.01$). However, both supplemented treatments resulted in a net loss.

Equivalents and breakeven. In order for S cattle to be equivalent in profitability to FC in year 1, a $94.38/ha reduction in supplemental DDG cube cost would be required, which would be $89.50 less per ton of supplement (Table 3.7). Whereas for FC to result in equivalent deficit as S, a $94.53/ha or $352.46/ton increase in fertilizer cost would be required. The breakeven prices in year 1 were calculated to be $3.30, $3.19, and $3.21 per kg of BW for FC, FS, and S, respectively (Table 3.7). Therefore, in order for FS and S animals to breakeven, they would need to be sold when cattle prices were increased by $0.06 and $0.08 per kg of BW, respectively. Otherwise, FS and S cattle would need to be 8 and 12 kg heavier, respectively, at the end of the grazing season to cover all costs when sold at the prices used in the study.

In year 2, the equivalent cost of DDG cubes required for S to be as profitable as FC was $283.62/ha (Table 3.7). Therefore, a $220.52/ton reduction in DDG cube prices would be required. However, fertilizer prices would have to increase from $530/ton to $1685/ton for FC to have a similar net loss in profit to S pastures. Calculated breakeven prices were $3.10, $3.05, and $3.05 per kg of BW for FC, FS, and S, respectively (Table 3.7). For FC animals, that means they could have weighed approximately 12 kg less at the end of the grazing season and still cover all costs. Whereas FS and S steers would have to be 8 and 25 kg lighter, respectively, or be sold when cattle prices were $0.05 and $0.14 per kg of BW more than the current prices used in the study, respectively.

Several studies that reported greater profitability when grazing cattle were supplemented with loose DDG used supplement costs between $116.80/ton and $241.50/ton (Watson et al., 2012; Gadberry et al., 2010). Therefore, reduced costs of supplemental DDG cubes or increased costs of fertilization in the current study could have increased the profitability of supplementation.

CONCLUSION

In terms of forage production and quality, as well as animal performance, our results imply that extruded DDG cube supplementation for stocker cattle is an adequate alternative to N fertilization. Changes in forage biomass in the current study can be attributed to climatic conditions over the two grazing seasons. Additionally, fertilization of pastures only had a beneficial impact on forage quality in the early months of the summer grazing season.

Regardless of pasture fertilization, supplementation of extruded DDG cubes resulted in improved animal performance with minimal variation between the two grazing seasons. Similarly, Greenquist et al. (2009) observed increased performance of steers grazing smooth bromegrass and supplemented with loose DDG compared to steers on N fertilized pastures. In addition, Watson et al. (2012) determined that pasture fertilization was beneficial to increase stocking rates, but had no benefit for steer performance when grazing smooth bromegrass pastures. Therefore, supplemental extruded DDG cubes for stocker cattle can replace the use of N fertilizer on introduced pastures during the summer grazing season with reliable and consistent improvement in animal performance.

With feed representing the second greatest cost for stocker cattle production (Peel, 2003), it is important to ensure that the supplementation regimen is economically feasible. Although costs were reduced when animals were not supplemented, minimizing the cost of production could be detrimental to animal performance (Beck et al., 2013), which was observed in the current study. Nevertheless, the profitability of stocker cattle production is predominantly reliant on gross returns to determine the value of gain in backgrounding systems (Peel, 2003). Furthermore, input prices such as those for fertilization and supplementation, as well as cattle prices, inevitably vary over time. Therefore, the producer must determine the management strategy most viable and profitable to meet the production goals of their grazing system.

Table 3.1 Chemical composition of supplemental dried distillers' grains (DDG) cubes determined via near-infrared reflectance spectroscopy

Items	DDG cubes
Chemical composition[1], %DM	
DM	93.21
CP	34.68
aNDF	34.01
ADF	12.64
Fat	10.36
NFC	6.58
TDN	85.50

[1] aNDF, neutral detergent fiber with the addition of alpha amylase and sodium sulfite; ADF, acid detergent fiber; NFC, non-fiber carbohydrates; TDN, total digestible nutrients (Tedeschi and Fox, 2020).

Table 3.2 Year 1 cost breakdown used in enterprise budget analysis based on pasture and fixed costs of supplemental treatments for steers grazing introduced pastures

	Treatments[1]		
Item	Fertilized Control $/ha	Fertilized Supplement $/ha	Supplement $/ha
Steer purchase	2544.34	2544.34	2528.83
Receiving	187.72	187.72	187.72
Net cost at turnout	2732.06	2732.06	2716.55
Pasture costs			
Mineral	31.56	31.56	31.56
Yardage	38.28	38.28	38.28
Rent	37.05	37.05	37.05
DDG cubes	-	176.03	341.99
Vet supplies/medicine	23.19	23.19	23.19
Implants	3.33	3.33	3.33
Fertilizer	95.14	95.14	-
Herbicide	27.07	27.07	27.07
Insecticide	4.86	4.86	4.86
Machinery/equipment			
Repairs	7.53	7.53	6.99
Fuel	7.16	7.16	5.80
Lubrication/filters	1.08	1.08	0.86
Labor	15.63	15.63	12.64
Total pasture costs	291.92	467.96	533.66
Fixed costs			
Machinery/equipment			
Interest	7.63	7.63	6.76
Taxes, insurance, housing	2.29	2.29	2.02
Depreciation	10.81	10.81	6.47
Total fixed costs	20.74	20.74	15.26
Total costs (pasture + fixed)	312.80	488.91	549.15

[1] Fertilized Control, no supplement on N fertilized pastures; Fertilized Supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

Table 3.3 Year 2 cost breakdown used in enterprise budget analysis based on pasture and fixed costs of supplemental treatments for steers grazing introduced pastures

	Treatments[1]		
Item	Fertilized Control $/ha	Fertilized Supplement $/ha	Supplement $/ha
Steer purchase	2559.80	2559.80	2559.80
Receiving	191.07	191.07	191.07
Net cost at turnout	2750.87	2750.87	2750.87
Pasture costs			
Mineral	37.10	37.10	37.10
Yardage	44.97	44.97	44.97
Rent	48.18	48.18	48.18
DDG cubes	-	275.04	568.64
Vet supplies/medicine	24.78	24.78	24.78
Fertilizer	131.11	131.11	-
Herbicide	2.64	2.64	2.64
Insecticide	21.01	21.01	21.01
Machinery/equipment			
Repairs	6.76	6.76	6.21
Fuel	8.44	8.44	6.49
Lubrication/filters	1.27	1.27	0.97
Labor	12.85	12.85	9.88
Total pasture costs	339.11	614.15	770.87
Fixed costs			
Machinery/equipment			
Interest	6.47	6.47	5.60
Taxes, insurance, housing	1.94	1.94	1.68
Depreciation	9.35	9.35	8.61
Total fixed costs	17.76	17.76	15.89
Total costs (pasture + fixed)	356.71	631.76	786.66

[1] Fertilized Control, no supplement on N fertilized pastures; Fertilized Supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

Table 3.4 Forage production and quality of introduced pastures grazed by summer stocker cattle as affected by year of trial

	Year[1]			
Item	1	2	SEM	*P*-value
Biomass, kg DM/ha	5917^b	3665^a	68.5	<0.01
Quality[2], %DM				
CP	14.42^a	15.47^b	0.201	0.01
ADF	33.40^b	31.10^a	0.204	<0.01
aNDF	55.93^b	53.27^a	0.341	<0.01

[1] Year of trial, 1 = 2020 and 2 = 2021.

[2] CP, crude protein; ADF, acid detergent fiber; aNDF, neutral detergent fiber with the addition of alpha amylase and sodium sulfite.

[a-b] Least-squares means followed by different superscripts within rows differ ($P < 0.05$).

Table 3.5 Effects of dried distillers' grains (DDG) cube supplementation on performance of steers grazing introduced pastures

	Treatment[1]				
Item	Fertilized Control	Fertilized Supplement	Supplement	SEM[2]	*P*-value
Year 1					
BW, kg					
Initial (4/10 and 4/14)	238	238	236	2.0	0.78
July 7	334^{a}	354^{b}	348^{ab}	5.9	0.07
Final (9/16 and 9/17)	373^{a}	408^{b}	412^{b}	5.0	<0.01
ADG, kg/d					
Early summer	1.13^{a}	1.37^{b}	1.32^{ab}	0.064	0.03
Late summer	0.55^{a}	0.75^{b}	0.89^{b}	0.043	<0.01
Total season	0.86^{a}	1.09^{b}	1.12^{b}	0.027	<0.01
Supplemental efficiency[3]					
Early summer	-	0.18	0.09	0.064	0.36
Late summer	-	0.16	0.12	0.021	0.23
Total season	-	0.17	0.11	0.036	0.25
Year 2					
BW, kg					
Initial (3/31 and 4/1)	247	247	247	3.4	0.99
July 7	353^{a}	384^{b}	390^{b}	6.1	0.01
Final (9/30 and 10/1)	405^{a}	449^{b}	468^{b}	5.9	<0.01
ADG, kg/d					
Early summer	1.10^{a}	1.42^{b}	1.48^{b}	0.055	<0.01
Late summer	0.59^{a}	0.75^{b}	0.90^{c}	0.045	<0.01
Total season	0.86^{a}	1.10^{b}	1.21^{c}	0.025	<0.01
Supplemental efficiency					
Early summer	-	0.23	0.18	0.044	0.41
Late summer	-	0.13	0.09	0.038	0.54
Total season	-	0.18^{b}	0.13^{a}	0.007	<0.01

[1] Fertilized Control, no supplementation on N fertilized pastures; Fertilized Supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

[2] Group variances estimated separately, the largest SEM is reported.

[3] Calculated as kg of added gain per kg of supplement (as-fed basis).

[a-c] Least-squares means followed by different superscripts within rows differ ($P < 0.05$).

Table 3.6 Effects of dried distillers' grains (DDG) cube supplementation on performance of stocker cattle grazing introduced pastures pooled between two years

	Treatment[1]				
Item	Fertilized Control	Fertilized Supplement	Supplement	SEM[2]	*P*-value
BW, kg					
Initial	243	243	242	1.8	0.88
Mid	343^a	369^b	368^b	5.8	0.01
Final	389^a	429^b	439^b	3.7	<0.01
ADG, kg/d					
Early summer	1.12^a	1.39^b	1.40^b	0.068	0.02
Late summer	0.57^a	0.75^b	0.90^c	0.048	<0.01
Total season	0.86^a	1.10^b	1.17^c	0.021	<0.01
Supplemental efficiency[3]					
Early summer	-	0.21	0.13	0.044	0.18
Late summer	-	0.14	0.10	0.020	0.21
Total season	-	0.18^b	0.11^a	0.017	0.03

[1] Fertilized Control, no supplementation on N fertilized pastures; Fertilized Supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

[2] Group variances estimated separately, the largest SEM is reported.

[3] Calculated as kg of added gain per kg of supplement (as-fed basis).

[a-c] Least-squares means followed by different superscripts within rows differ ($P < 0.05$).

Table 3.7 Overall profitability of dried distillers' grains (DDG) cube supplementation for stocker steers grazing introduced pastures over two years

	Treatment[1]				
Item	Fertilized Control	Fertilized Supplement	Supplement	SEM	*P*-value
Year 1					
Cost					
$/ha	312.80^{a}	488.91^{b}	549.15^{c}	-	<0.01
$/kg gain	0.88^{a}	1.17^{b}	1.28^{b}	0.045	<0.01
Gross return, $/ha	350.16^{a}	421.40^{ab}	440.80^{b}	22.851	0.06
Net return, $/ha	37.37^{b}	-67.50^{a}	-108.35^{a}	22.851	0.01
Breakeven sales[2], $/kg BW	3.30	3.19	3.21	-	-
DDG cube equivalent[3], $/ha	-	-	247.61	-	-
Fertilizer equivalent[4], $/ha	189.67	-	-	-	-
Year 2					
Cost					
$/ha	356.71^{a}	631.76^{b}	786.66^{c}	-	<0.01
$/kg gain	0.92^{a}	1.27^{b}	1.44^{c}	0.019	<0.01
Gross return, $/ha	443.96^{a}	551.89^{b}	592.47^{b}	16.856	<0.01
Net return, $/ha	87.25^{c}	-80.11^{b}	-194.18^{a}	16.856	<0.01
Breakeven sales, $/kg BW	3.10	3.05	3.05	-	-
DDG cube equivalent, $/ha	-	-	283.62	-	-
Fertilizer equivalent, $/ha	416.39	-	-	-	-

[1] Fertilized Control, no supplement on N fertilized pastures; Fertilized Supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

[2] Cattle sales price per kg final BW needed to breakeven and cover all costs during grazing.

[3] Cost of supplemental DDG cubes required for FC and S to have equivalent returns.

[4] Cost of fertilizer required for FC and S to have equivalent returns.

[a-c] Least-squares means followed by different superscripts within rows differ ($P < 0.05$).

Table 3.8 Overall profitability of dried distillers' grains (DDG) cube supplementation for stocker steers grazing introduced pastures pooled between two years

	Treatment[1]				
Item	Fertilized Control	Fertilized Supplement	Supplement	SEM	*P*-value
Cost					
$/kg gain	0.90^{a}	1.22^{b}	1.36^{c}	0.024	<0.01
Gross return, $/ha	397.06^{a}	486.53^{b}	516.63^{b}	14.197	<0.01
Net return, $/ha	62.31^{c}	-73.80^{b}	-151.27^{a}	14.197	<0.01

[1] Fertilized Control, no supplement on N fertilized pastures; Fertilized Supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

$^{a\text{-}c}$ Least-squares means followed by different superscripts within rows differ ($P < 0.05$).

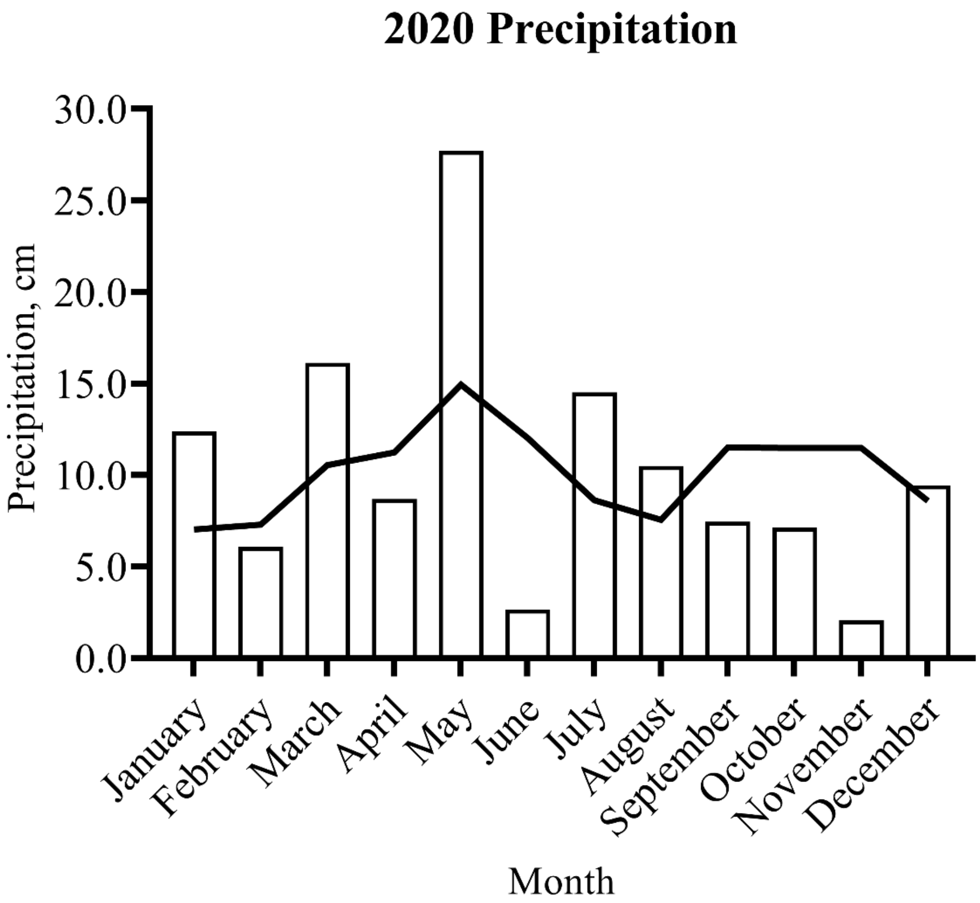

Figure 3.1a Precipitation data from 2020 (empty bars) compared to the 30-yr average (black line; Oklahoma Climatology Survey, 2021).

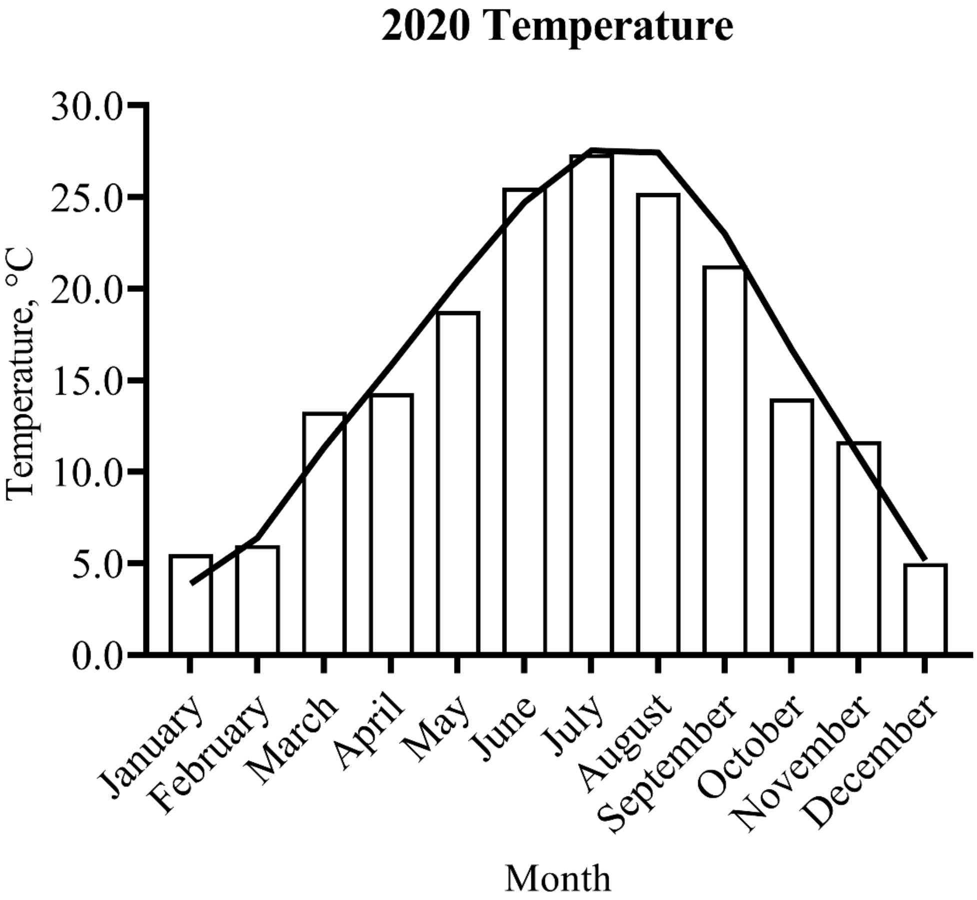

Figure 3.1b Temperature data from 2020 (empty bars) compared to the 30-yr average (black line; Oklahoma Climatology Survey, 2021).

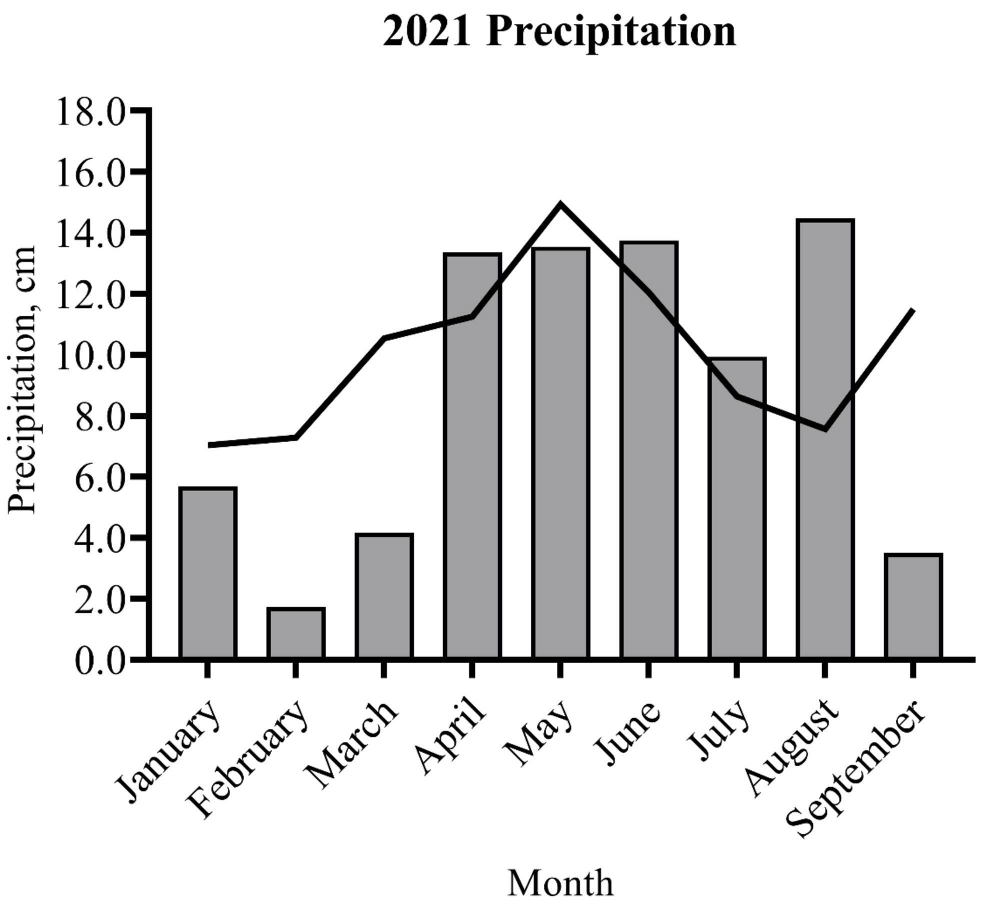

Figure 3.2a Precipitation data from 2021 (solid bars) compared to the 30-yr average (black line; Oklahoma Climatology Survey, 2021).

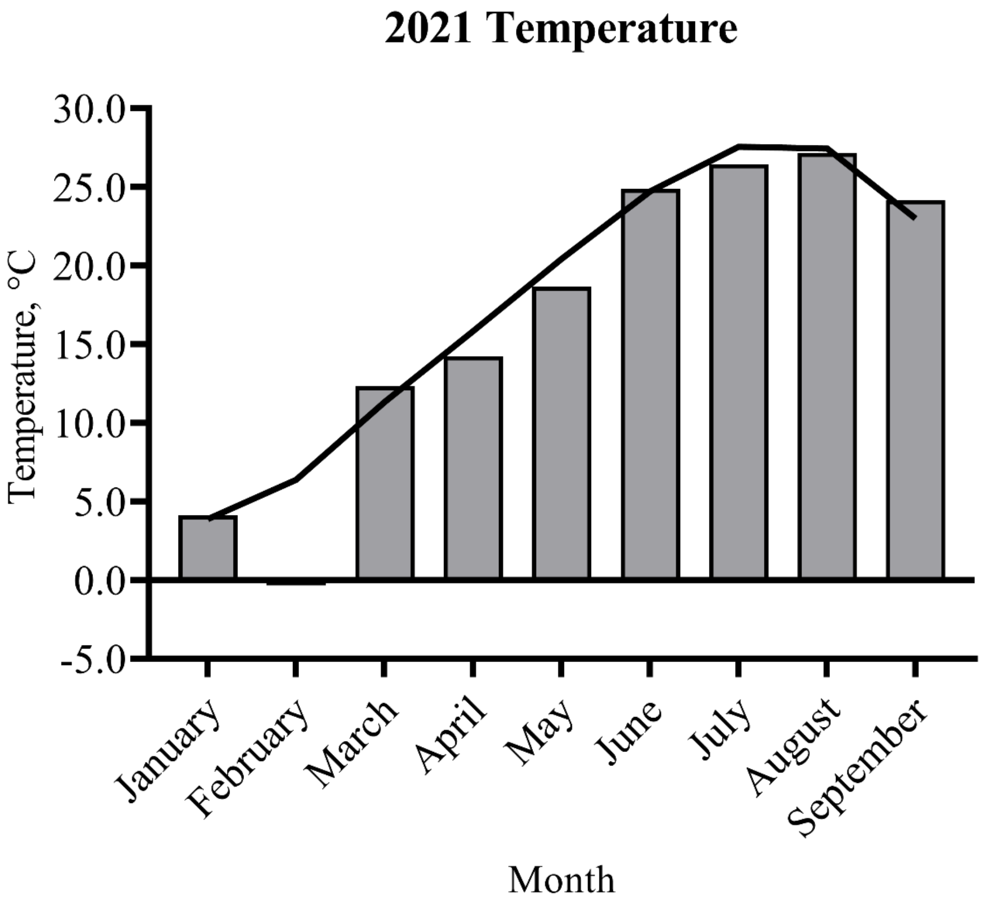

Figure 3.2b Temperature data from 2021 (solid bars) compared to the 30-yr average (black line; Oklahoma Climatology Survey, 2021).

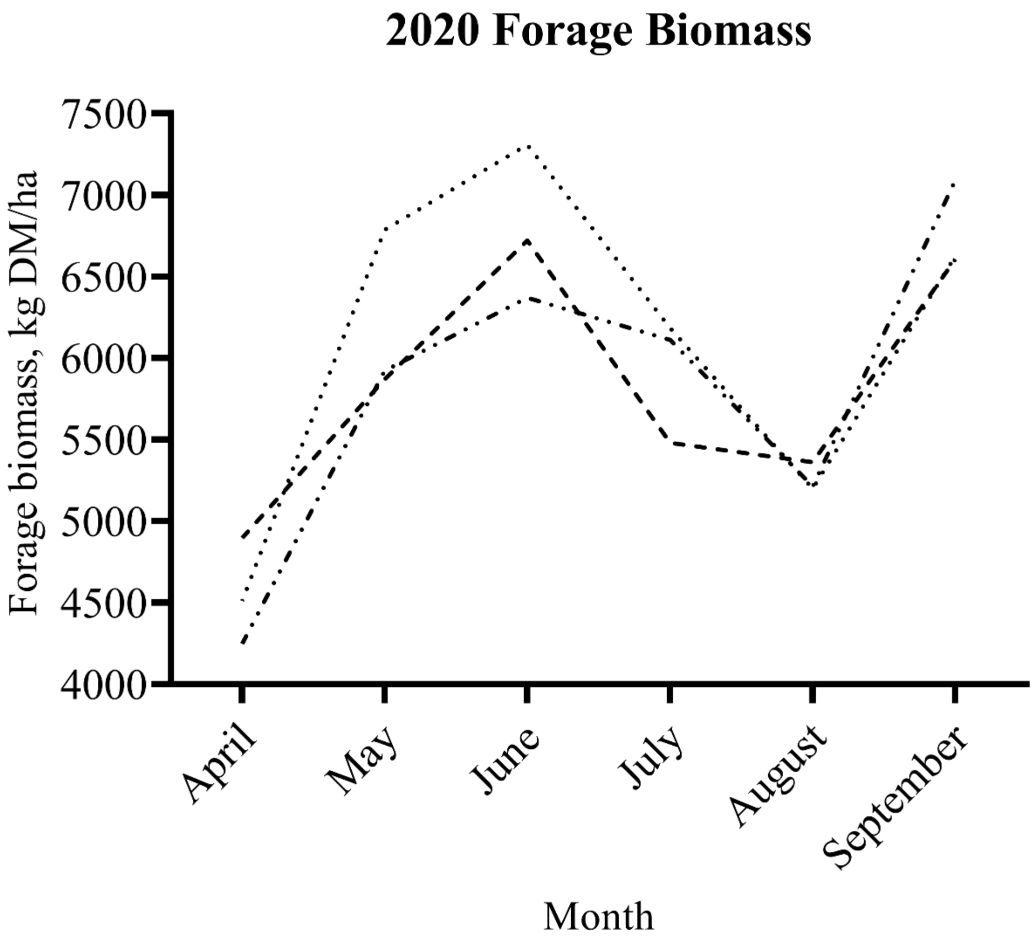

Figure 3.3 Effect of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures on forage biomass in year 1. Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures. Treatment × month interaction, *P* = 0.49, SEM = 375.2. Treatment effect, *P* = 0.39, SEM = 153.1. Month effect, *P* < 0.01, SEM = 216.6.

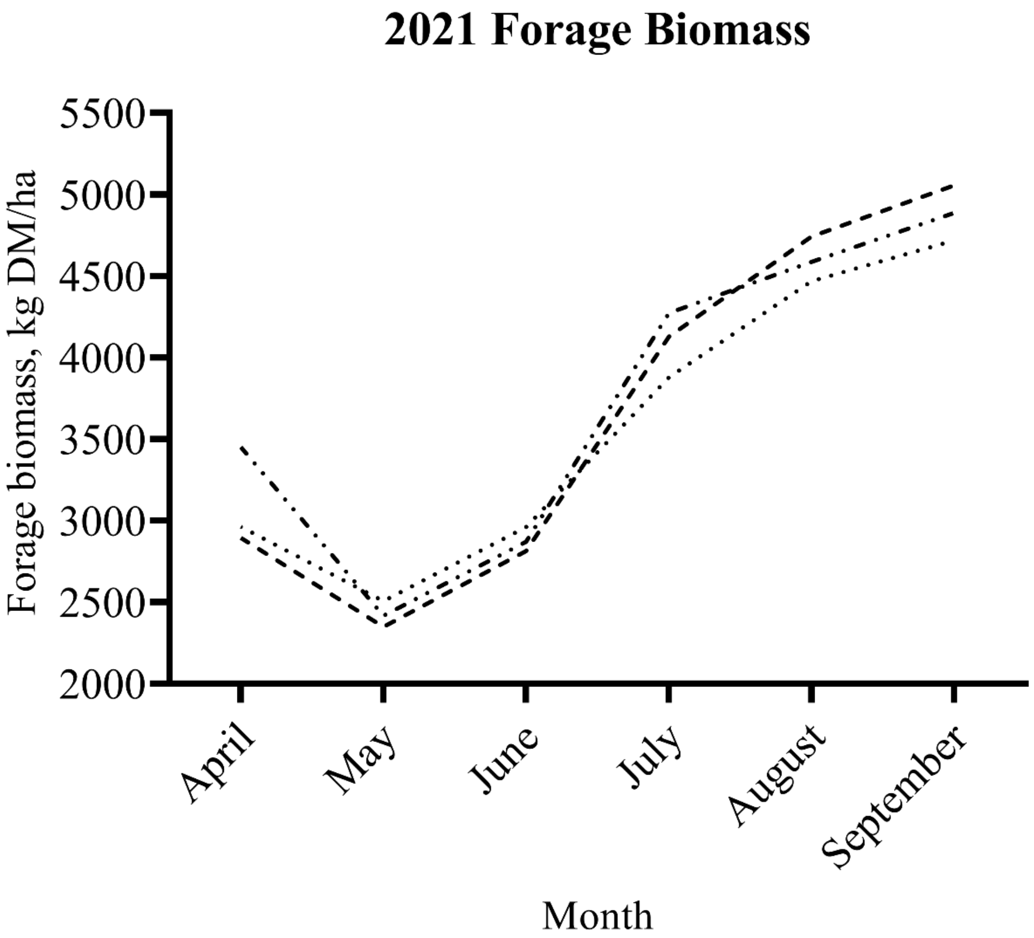

Figure 3.4 Effect of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures on forage biomass in year 2. Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures. Treatment × month interaction, *P* = 0.42, SEM = 168.3. Treatment effect, *P* = 0.30, SEM = 68.7. Month effect, *P* < 0.01, SEM = 97.1.

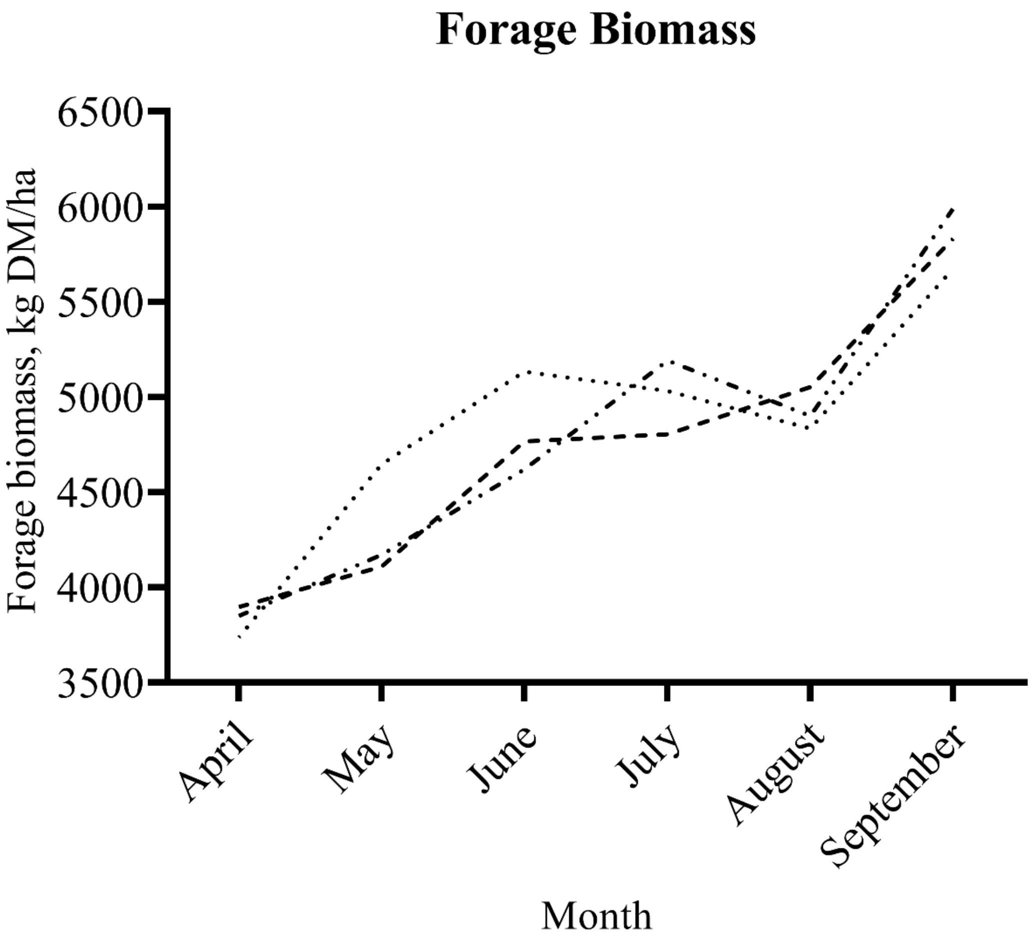

Figure 3.5 Effect of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures on forage biomass pooled between years. Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures. Treatment × month interaction, *P* = 0.42, SEM = 205.6. Treatment effect, *P* = 0.71, SEM = 83.9. Month effect, *P* < 0.01, SEM = 118.7.

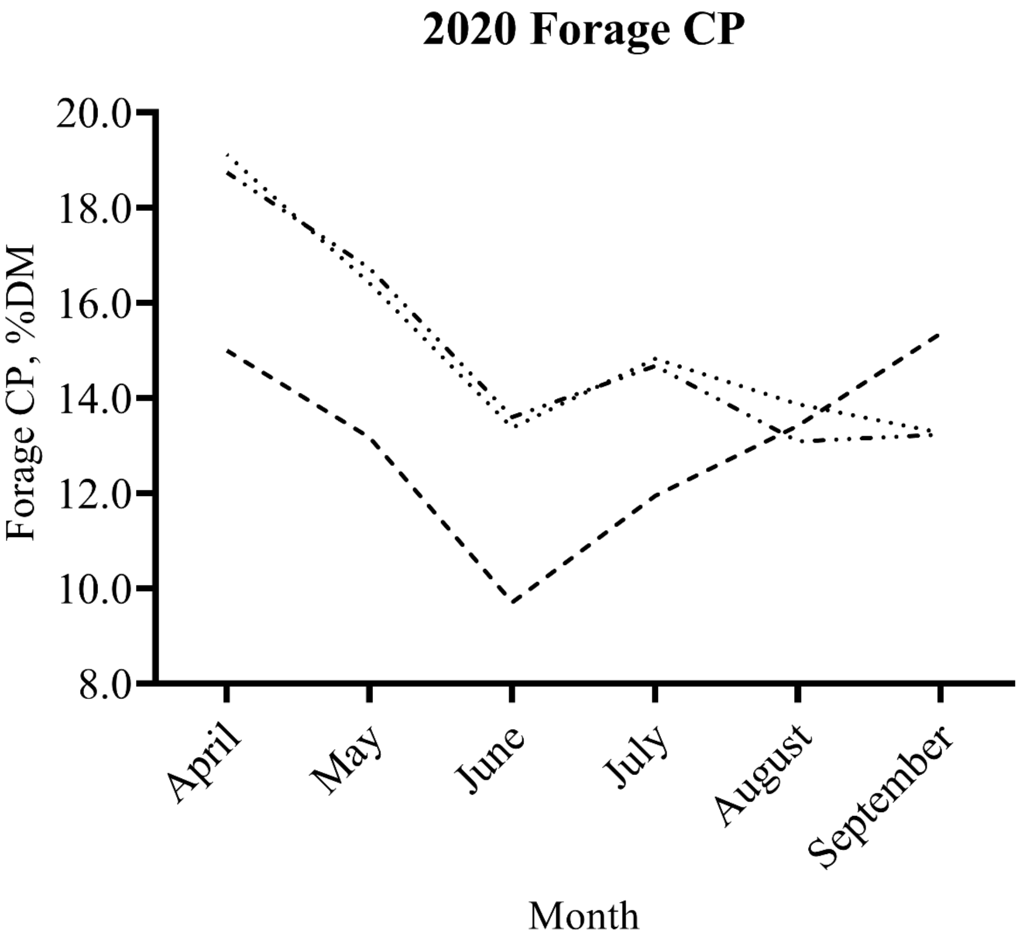

Figure 3.6a Effects of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures in year 1 on forage crude protein (CP) content (treatment × month interaction, *P* = 0.01). Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

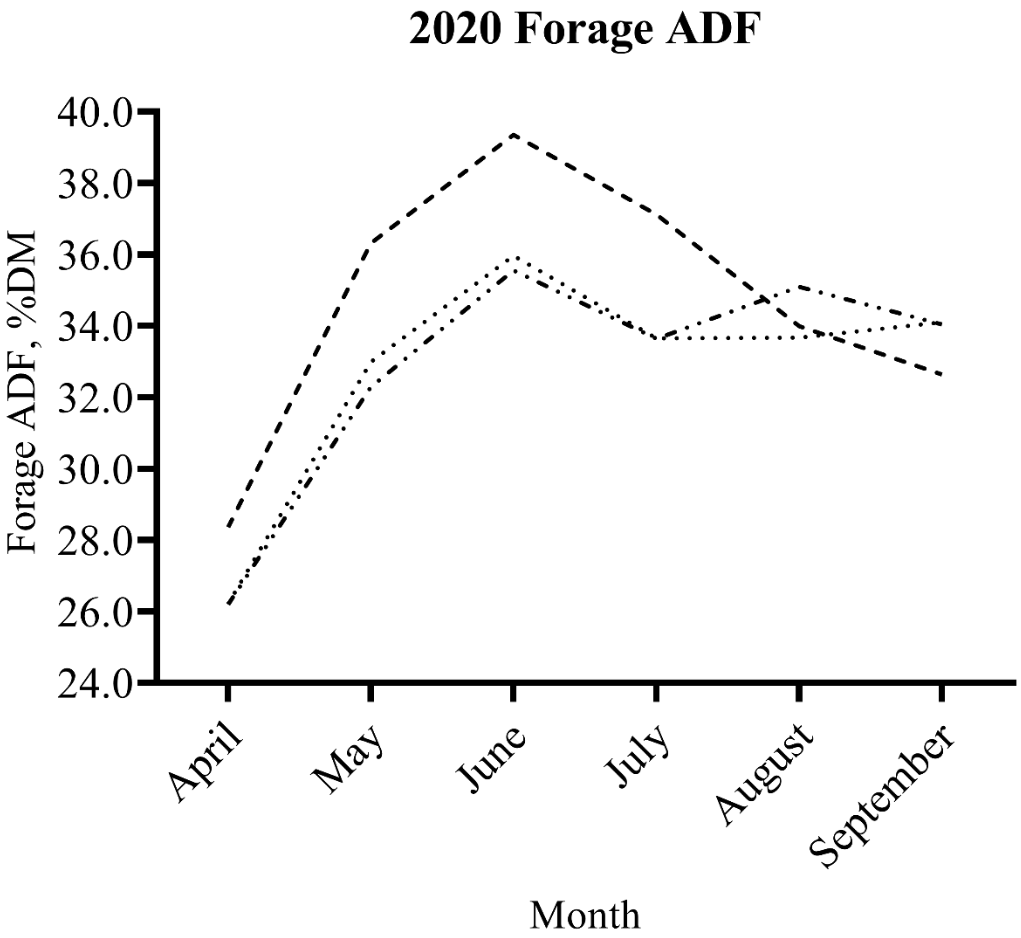

Figure 3.6b Effects of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures in year 1 on forage acid detergent fiber (ADF) content (treatment × month interaction, *P* = 0.06). Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

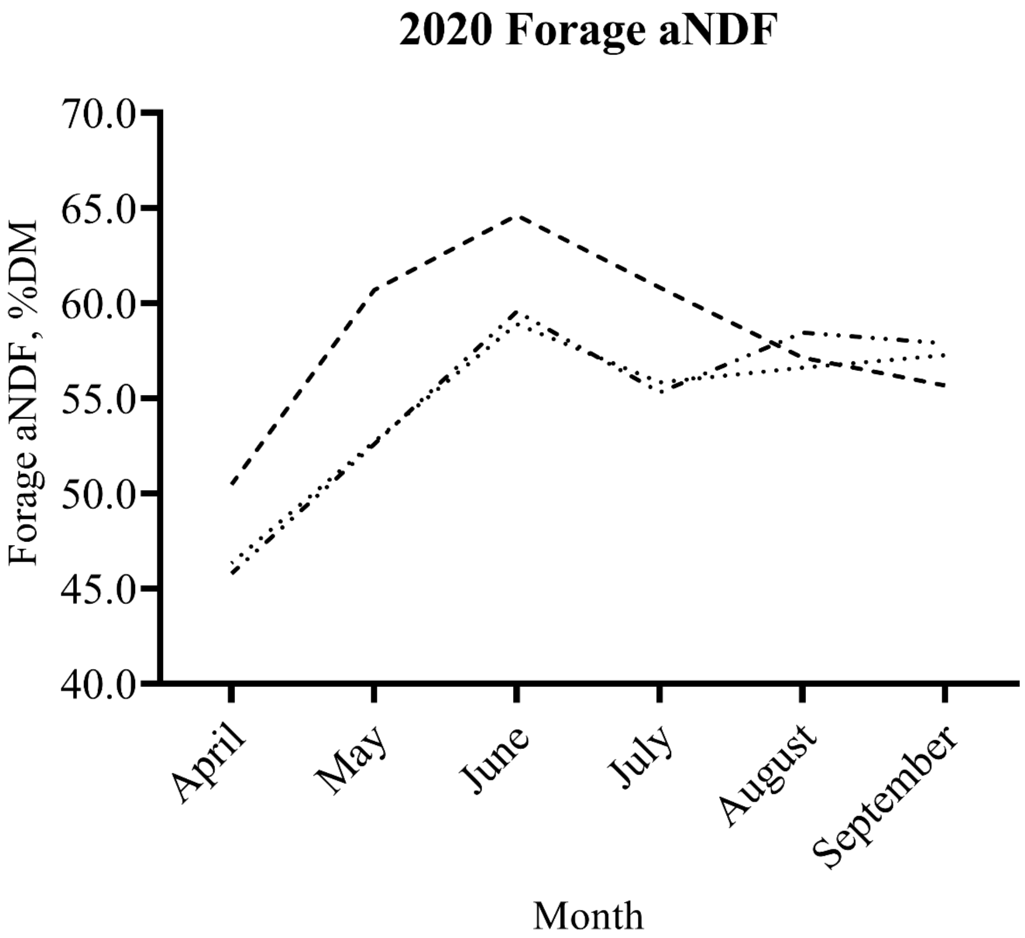

Figure 3.6c Effects of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures in year 1 on forage neutral detergent fiber (aNDF) content (treatment × month interaction, *P* = 0.06). Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

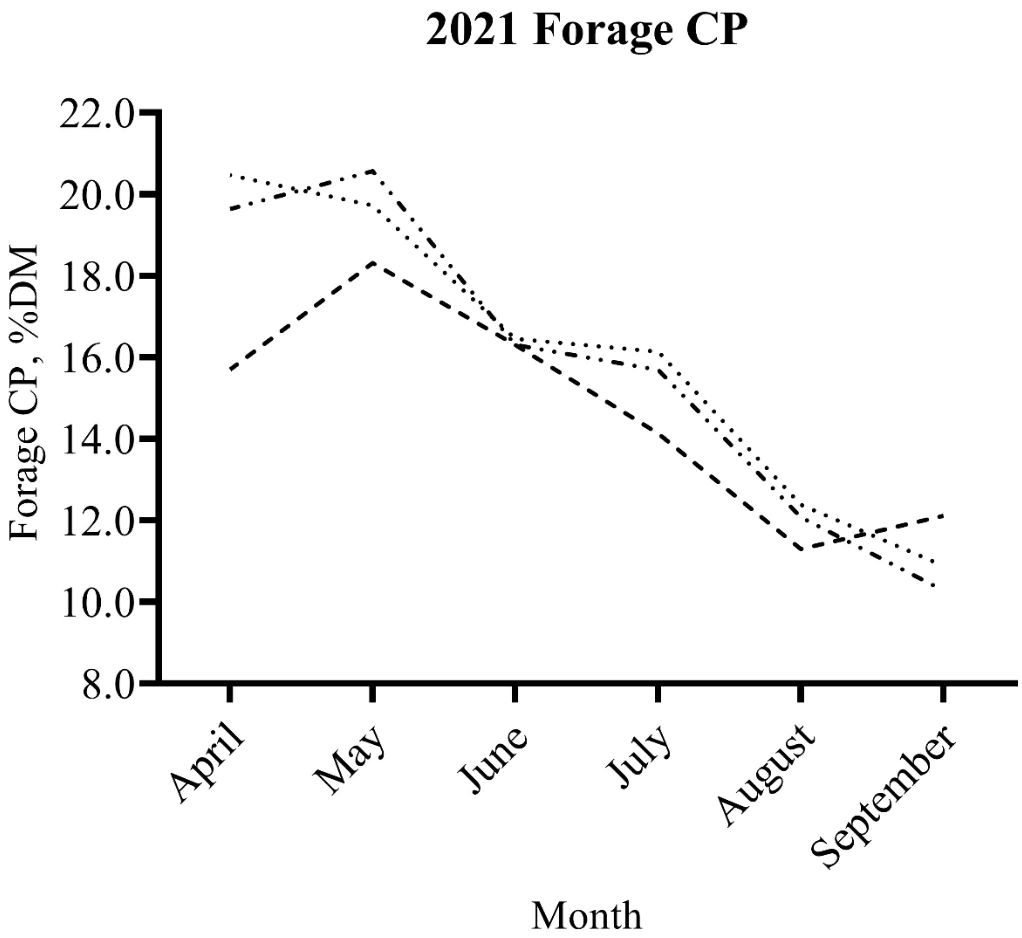

Figure 3.7a Effects of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures in year 2 on forage crude protein (CP) content (treatment × month interaction, $P < 0.01$). Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

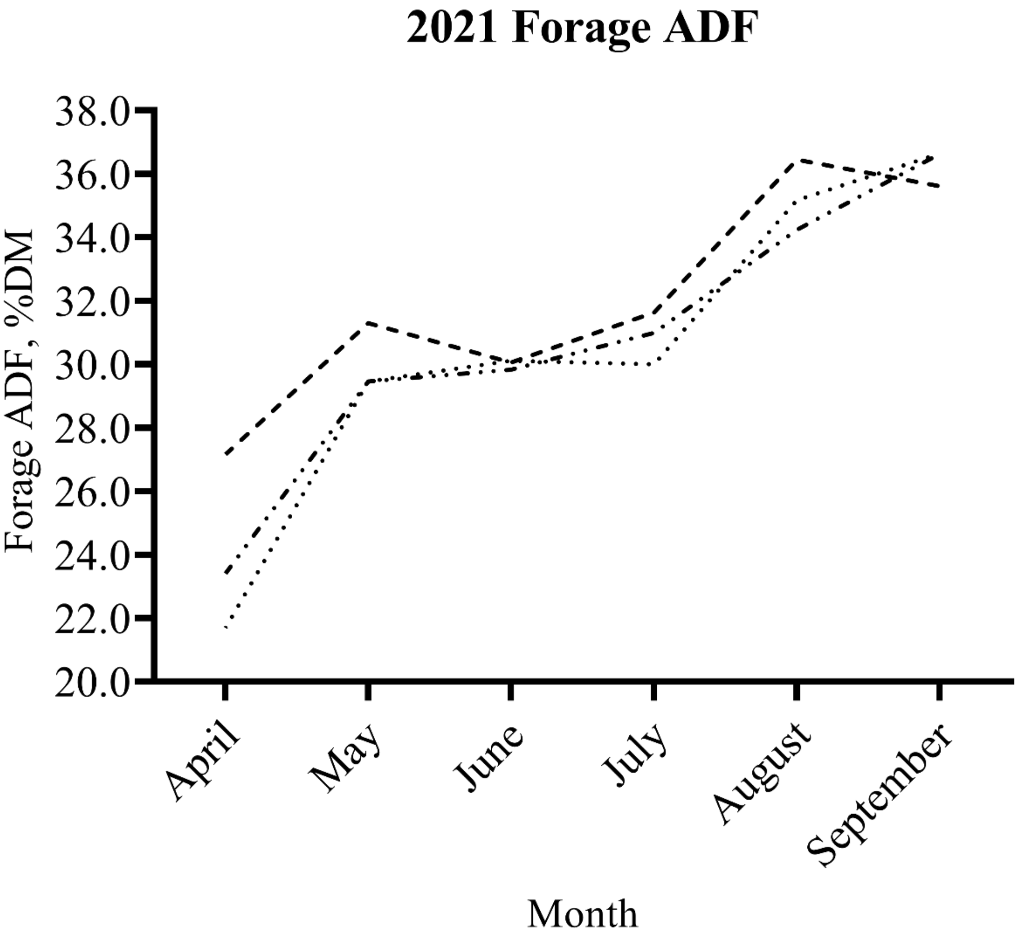

Figure 3.7b Effects of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures in year 2 on forage acid detergent fiber (ADF) content (treatment × month interaction, $P < 0.01$). Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

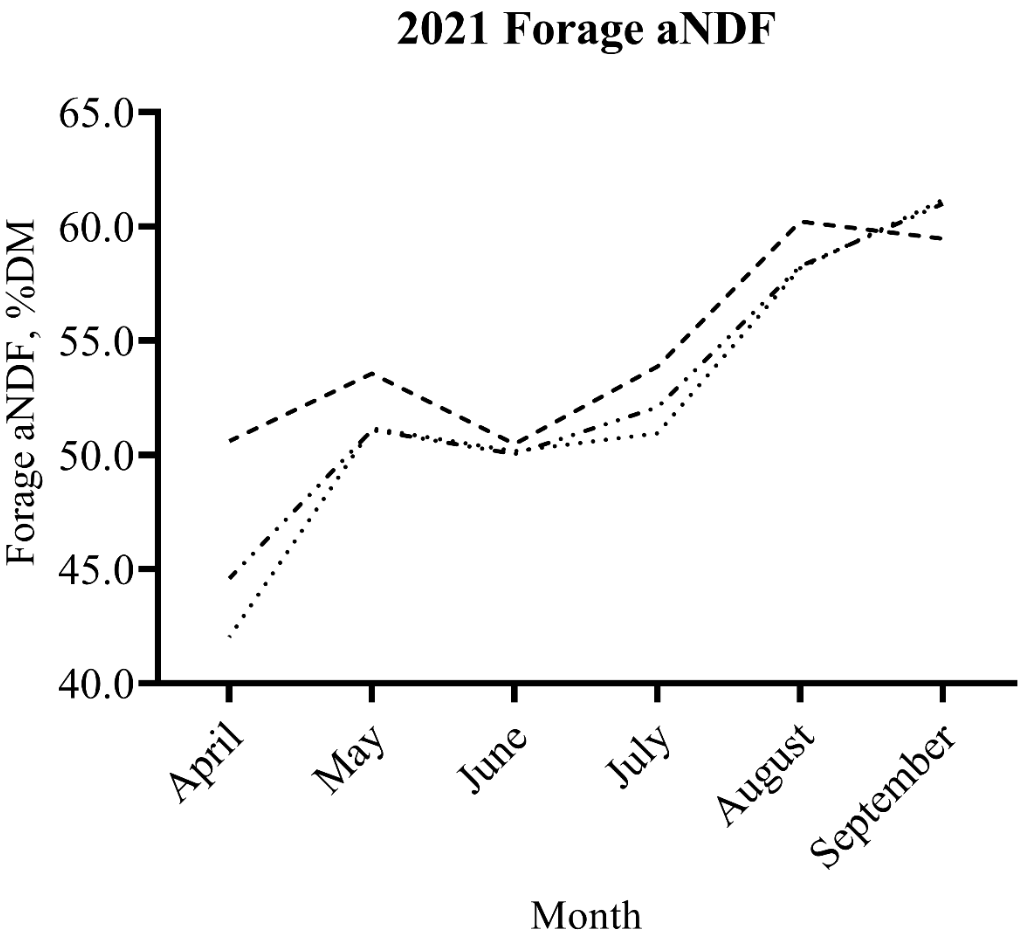

Figure 3.7c Effects of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures in year 2 on forage neutral detergent fiber (aNDF) content (treatment × month interaction, $P = 0.05$). Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

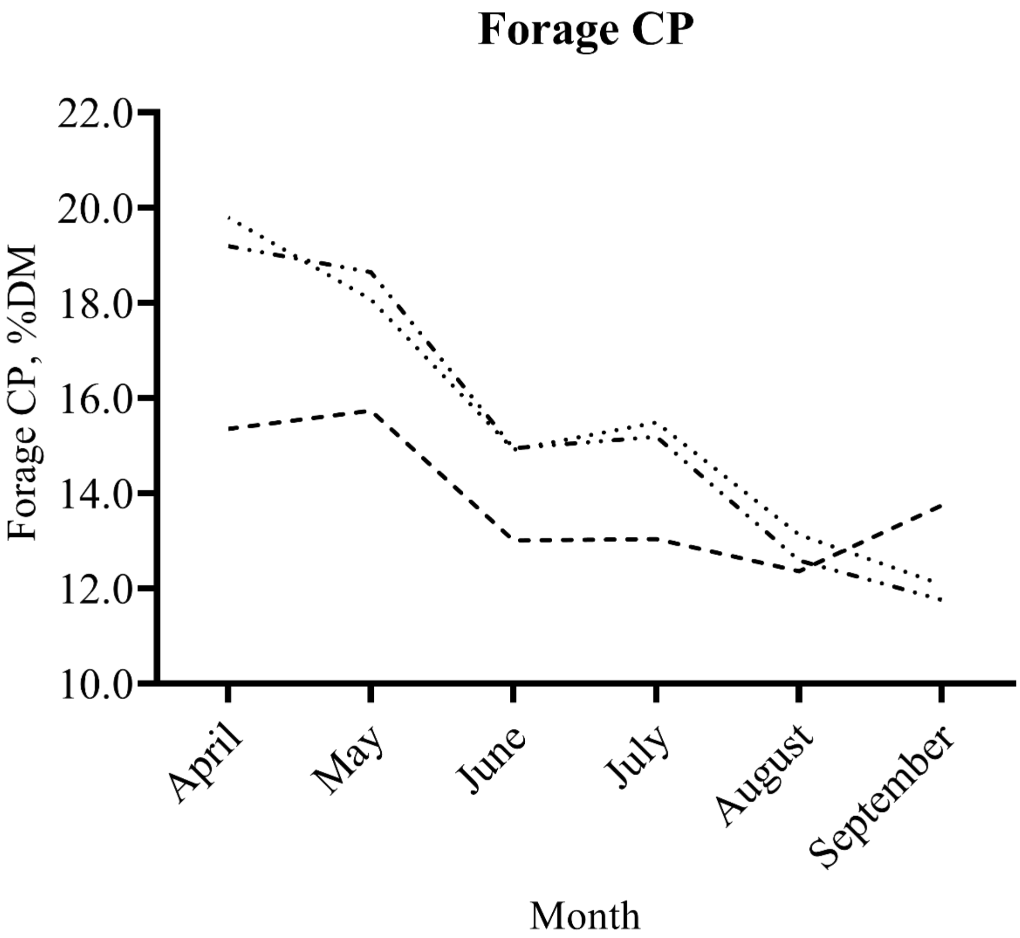

Figure 3.8a Effects of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures pooled between years on forage crude protein (CP) content (treatment × month interaction, *P* < 0.01). Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

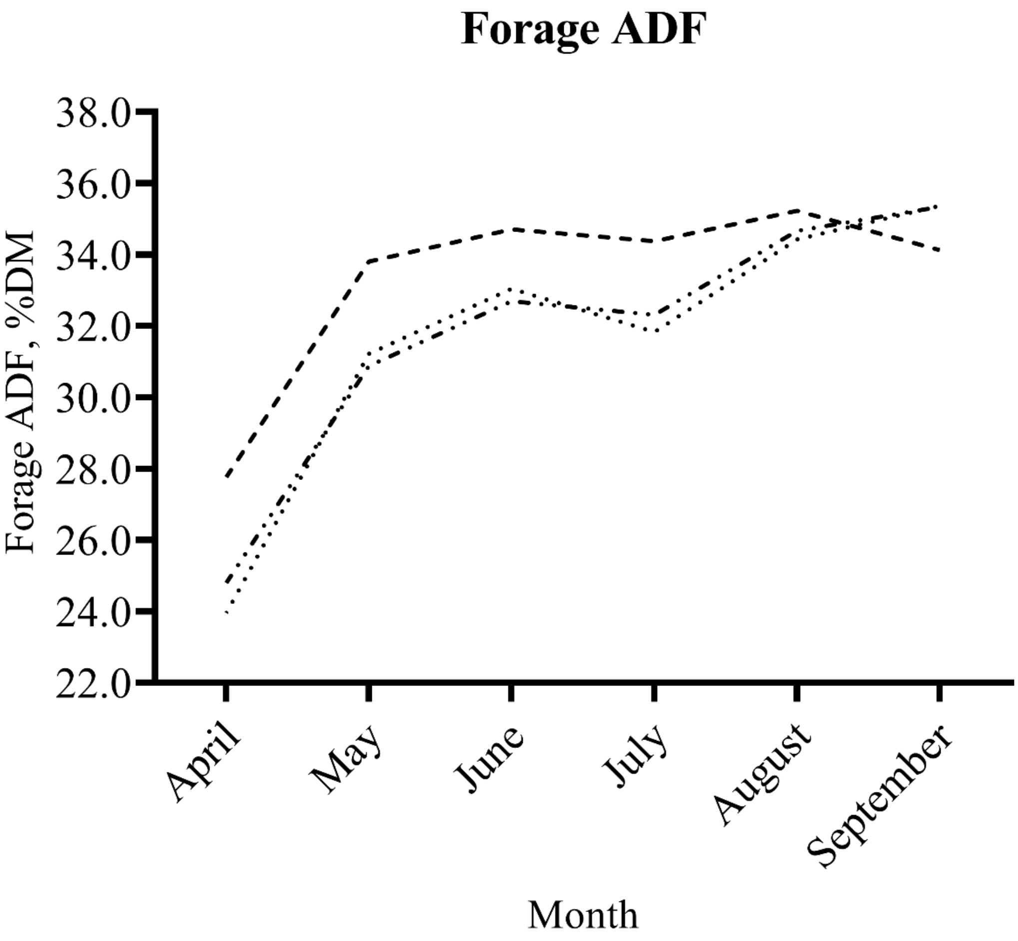

Figure 3.8b Effects of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures pooled between years on forage acid detergent fiber (ADF) content (treatment × month interaction, *P* = 0.02). Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

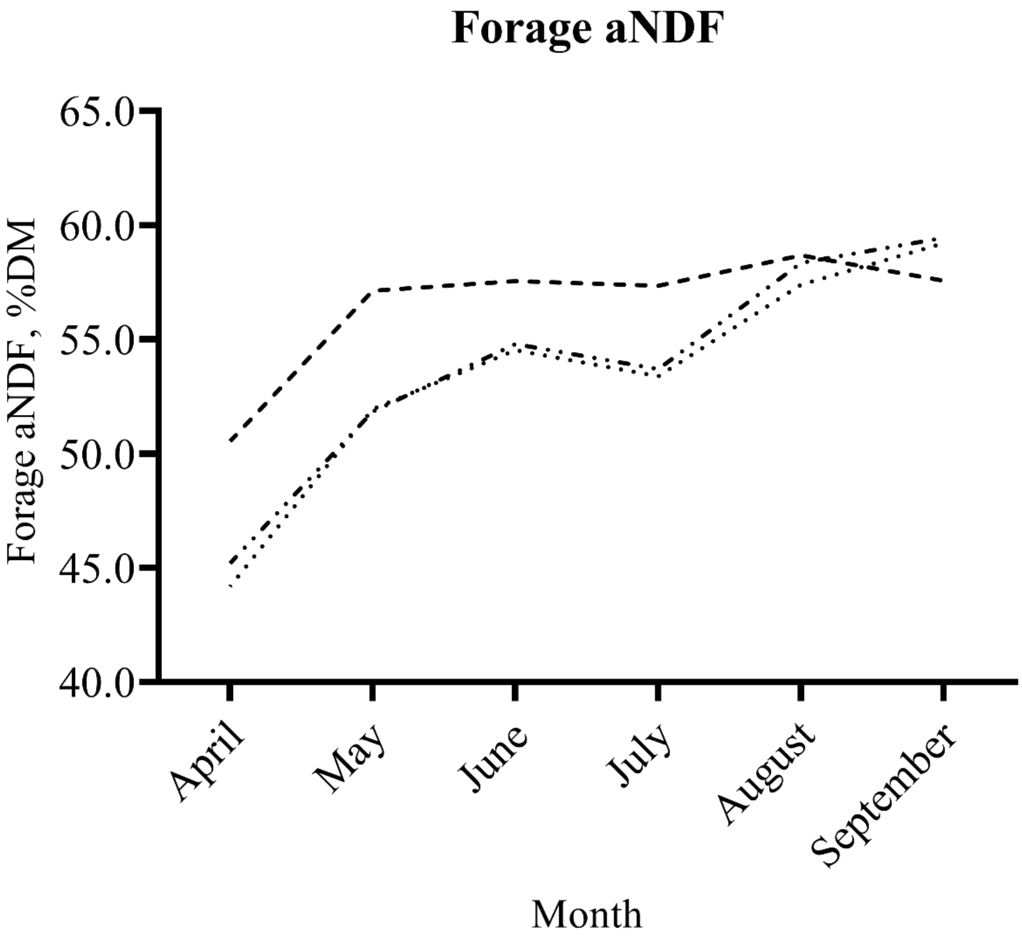

Figure 3.8c Effects of dried distillers' grains (DDG) cube supplemental treatment for steers grazing introduced pastures pooled between years on forage neutral detergent fiber (aNDF) content (treatment × month interaction, *P* = 0.01). Dot = fertilized control, no supplementation on N fertilized pastures; Dash dot dot = fertilized supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Dash = supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

CHAPTER IV

EFFECTS OF SUPPLEMENTING EXTRUDED DRIED DISTILLERS' GRAINS CUBES TO STOCKER CATTLE GRAZING INTRODUCED PASTURES ON SUBSEQUENT FEEDLOT PERFORMANCE AND CARCASS CHARACTERISTICS

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ABSTRACT: The objective of this study was to evaluate the effects of supplementing extruded dried distillers' grains (**DDG**) cubes to stocker steers grazing introduced pastures on subsequent feedlot performance and carcass characteristics. Crossbred steers (n = 140) grazed mixed tall fescue (*Festuca arundinacea*) and bermudagrass (*Cynodon dactylon*) pastures (n = 9 pastures; 7.2 ± 2.90 ha) from 14 April to 17 September 2020 (n = 155 d) to evaluate the effects of supplemental DDG cubes and growth promoting implants on animal performance. Supplemental treatments (n = 3 pastures/treatment) included: 1) Fertilized Control (**FC**), no supplementation on N fertilized pastures (112 kg N/ha); 2) Fertilized Supplement (**FS**), supplemented DDG cubes at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; and 3) Supplement (**S**), supplemented DDG cubes at 0.75% of BW/d prorated for 5-d/wk feeding on unfertilized pastures. Following grazing, animals were followed through the finishing phase in a commercial feedyard on a common feedlot diet to evaluate carryover effects on performance and feed intake. Additionally, ultrasounds were performed upon entering the feedlot and at re-implantation, and carcass data were obtained at harvest, to determine differences in carcass characteristics. Supplemented animals were heavier ($P < 0.01$) at feedlot entry than FC, but harvest BW did not differ ($P = 0.23$). However, supplemented steers required an average of 37 fewer days on feed ($P = 0.01$) than FC. Overall, FS and S animals consumed less feed ($P = 0.02$) and had lower feed costs ($P = 0.01$) relative to FC steers. Gains were greater for FC and FS from d0 to d84 ($P = 0.02$), but did not differ otherwise ($P \geq 0.15$) from S. At harvest, FC had lower yielding carcasses than FS ($P = 0.01$), but did not differ ($P = 0.11$) from S. Carcass dressing percent was greatest ($P < 0.01$) for FC, but there were no differences in any other carcass characteristics ($P \geq 0.17$), empty body composition and gain ($P \geq 0.15$), and carcass value ($P = 0.52$). Overall, our results implied that extruded DDG cube supplementation during grazing did not negatively affect subsequent feedlot performance or carcass characteristics.

Keywords: carcass characteristics, carryover effects, extruded dried distillers' grains cubes, feedlot performance

INTRODUCTION

Backgrounding cattle on pasture after weaning has become a common management strategy in the United States beef industry in order to maximize skeletal and muscular growth prior to entrance into the feedlot. Although both the stocker and finishing sectors target maximal animal growth, the stocker industry is primarily focused on enhancement of muscle and skeletal growth, while growth in the finishing phase is aimed more towards fattening of the cattle (Peel, 2003). Furthermore, backgrounding calves on high-quality pastures has often been associated with improved profitability in the beef industry (Hoveland, 1986) due to the improvement of the overall quality of the cattle and preparedness for feedlot production (Peel, 2003).

Supplementation programs for stocker cattle on pasture as a management strategy to improve animal performance and overall productivity have been extensively researched. However, research examining subsequent feedlot performance and carcass quality as affected by stocker supplementation programs continues to be limited and generally inconsistent. Dried distillers' grains (**DDG**) are a by-product of ethanol production and have been widely studied as a supplement for stocker cattle on pasture, but subsequent effects in the finishing phase are not as well documented. A stable DDG cube produced via a novel extrusion process provides improvements to pasture supplementation, including the reduction of wind and soil mixing common when supplementing loose DDG in pasture settings. However, research evaluating the effects of extruded DDG cube supplementation is almost nonexistent for both stocker cattle and the subsequent effects in the finishing phase. Therefore, the objective of this study was to evaluate the effects of supplementing extruded DDG cubes to stocker cattle during the summer grazing season on subsequent feedlot performance and carcass characteristics.

MATERIALS AND METHODS

Stocker phase

From 14 April to 17 September 2020 (n = 155 d), crossbred steers (n = 140) grazed mixed tall fescue (*Festuca arundinacea*) and bermudagrass (*Cynodon dactylon*) pastures to evaluate the effects of supplemental DDG cubes and growth promoting implants on animal performance. At the initiation of the trial, steers were randomly assigned to one of nine pastures (7.2 ± 2.90 ha) located at the Oklahoma State University Eastern Research Station near Haskell, Oklahoma (35°44’ N, 95°38’ W). Each pasture was randomly assigned to one of three supplemental treatments (n = 3 pastures/treatment): 1) Fertilized Control (**FC**) - no supplementation on N fertilized pastures (112 kg N/ha); 2) Fertilized Supplement (**FS**) - supplemental DDG cubes fed at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; or 3) Supplement (**S**) - supplemented DDG cubes at 0.75% of BW/d on unfertilized pastures prorated for 5-d/wk feeding. In addition, steers in each pasture were randomly assigned to one of three growth promoting re-implant treatments on d 84 of grazing, receiving either: 1) No re-implant; 2) 40 mg trenbolone acetate and 8 mg estradiol (**REV-G**; Revalor G, Merck Animal Health, Omaha, NE); or 3) 200 mg progesterone and 20 mg estradiol (**SYN-S**; Synovex S, Zoetis Animal Health, Kalamazoo, MI).

Feedlot phase

Following the grazing period, animals were transported approximately 500 km to Buffalo Feeders, LLC in Buffalo, Oklahoma to be followed through the finishing phase for the evaluation of carryover effects on feedlot animal performance and carcass characteristics. Upon arrival at the feedlot on 22 September 2020, all animals were vaccinated for infectious bovine rhinotracheitis and bovine virus diarrhea (Bovi-Shield Gold IBR-BVD, Zoetis Animal Health, Kalamazoo, MI), and implanted with 20 mg estradiol benzoate, 200 mg progesterone, and 29 mg tylosin tartrate (Component E-S with Tylan, Elanco US Inc., Greenfield, IN). All steers were re-implanted on 15 December

2020 (d84) with 20 mg estradiol, 200 mg trenbolone acetate, and 29 mg tylosin tartrate (Component TE-200 with Tylan, Elanco US Inc., Greenfield, IN). Due to limited pen availability, steers were split into two pens with the FS and S animals commingled in one pen and the FC animals in a separate pen. The finishing rations fed in the feedlot are displayed in Table 4.1. Rations 1, 2, and 3 were step up diets and were fed for 5d each with a 2d transition period between them, and ration 4 was the finishing diet fed until harvest. At processing and re-implant, animal BW was recorded and ultrasounds were performed using an Aloka 500V system equipped with a 17 cm-3.5 MHz transducer probe (Aloka Co. Ltd., Wallingford, CT) by trained personnel for the measurement of ribeye area (**REA**) and backfat thickness (**BF**).

Carcass characteristics

Upon being deemed finished at mature BW in the feedlot phase, animals were transported to a commercial abattoir for slaughter. Due to differences in BW, steers were slaughtered in three groups between March and April 2021. At harvest, hot carcass weight (**HCW**), USDA quality (**QG**) and yield grade (**YG**), marbling score (200 = Standard$^+$, 300 = Select$^+$, 400 = Choice$^-$, 500 = Choice°, 600 = Choice$^+$, 700 = Prime$^-$, 800 = Prime°, 900 = Prime$^+$; USDA-AMS, 2017), REA, and BF were recorded, and dressing percent **(DP)** as a percent of BW was calculated for the evaluation of differences among grazing supplemental treatments. As animals were commingled throughout the finishing period, equations from Guiroy et al. (2001) and Tedeschi et al. (2004) were used to estimate days on feed (**DOF**) in the feedlot, adjusted final shrunk BW (**AFSBW**), shrunk weight gain (**SWG**), empty body weight (**EBW**), empty body weight gain (**EWG**), empty body composition of fat (**EBF**), individual DM intake (**DMI**), and feed efficiency (**G:F**). Additionally, carcass value was calculated using a base grid to account for changes in cattle prices between slaughter dates.

Statistical Analysis

All statistical analyses were performed using SAS software (SAS Institute Inc., Cary, NC). All animal performance and carcass data were analyzed using PROC MIXED, with supplemental treatment as the fixed effect and pasture within supplemental treatment during the grazing phase as the random variable. Differences were considered significant at $P \leq 0.05$, and tendencies were assumed at $0.10 \geq P > 0.05$.

RESULTS AND DISCUSSION

Animal Performance

Grazing. A summary of grazing animal performance is presented in Table 4.2. Supplemented animals were heavier ($P < 0.01$) than FC animals at the end of the grazing period. As energy tends to be a limiting factor in warm-season pastures, it was speculated that animal performance was improved for supplemented cattle during grazing as a result of increased energy supplied by DDG cubes (Beck et al., 2014; Rivera et al., 2017). Total season gains were greater ($P < 0.01$) for FS and S steers than for those in FC. More specifically, FS and S animals gained approximately 0.23 and 0.26 kg/d more, respectively, than FC steers throughout the grazing season. Although not expected, re-implanting did not affect ADG ($P = 0.57$) or steer BW ($P = 0.34$), which may have been due to a lack of statistical power. Additionally, supplemental efficiency did not differ ($P = 0.25$) between FS and S, with 0.17 and 0.11 kg of added BW gain per kg of supplement, respectively, during the total season. Although supplemental efficiency was low, conversions of approximately 0.10 to 0.11 kg of added BW gain per kg of supplemental concentrate have commonly been reported for grazing cattle (Horn et al., 2005).

Finishing. Feedlot animal performance data are displayed in Table 4.3. As expected due to final grazing BW, FS and S steers were heavier (*P* < 0.01) than FC animals upon entering the feedlot. Although FS and S animals were also heavier (*P* = 0.04) at re-implantation compared to FC, there was no difference in harvest BW (*P* = 0.23) between supplemental treatments, weighing an average of 671 ± 9.4 kg. In a similar study, Smith et al. (2020) observed no differences in harvest BW of steers due to supplementation of loose DDG during grazing. Nevertheless, it was calculated that animals that received supplemental DDG cubes during the grazing period required an average of 37 fewer days on feed (*P* = 0.01) than steers not supplemented on pasture. Although final feedlot BW did not differ between treatments, this can be attributed to the FC animals having greater days on feed, which in in agreement with that observed by Gadberry et al. (2021). Similar to our study, steers that grazed tall fescue and received supplemental loose DDG required 14 fewer days on feed in the subsequent feedlot phase than steers not supplemented during grazing (Lomas and Moyer, 2015).

Between d0 and d84, steers in FS and FC had greater gains (*P* = 0.02) than S animals. More specifically, FS and FC steers gained an average of 0.24 and 0.25 kg/d more than S steers during the first 84 d in the feedlot. However, ADG did not differ from d84 to harvest (*P* = 0.84) or during the total feeding period (*P* = 0.15). Likewise, greater ADG for heifers supplemented on rangeland did not carryover to feedlot performance, with total feedlot gains of 1.90 and 1.92 kg/d for supplemented and non-supplemented animals, respectively (Larson et al., 2019). In contrast, greater gains on pasture for steers supplemented loose DDG resulted in approximately 8 to 18% lower ADG during the finishing period compared to control steers (Smith et al., 2019). Although there were no differences in individual DMI (*P* = 0.51), supplemented animals consumed less feed overall (*P* = 0.02) than FC. Additionally, FS animals tended (*P* = 0.07) to have the greatest feed efficiency relative to FC and S. More specifically, FS animals required approximately 0.55 kg of feed less per kg of BW gain than FC and S animals.

Increased DMI and ADG, along with lack of differences in feed efficiency, are typical characteristics of compensatory gain (Klopfenstein et al., 1999). Steers in FC displayed all of the typical characteristics and achieved approximately 40% compensatory gain between d0 and d84 in the feedlot when compared to S steers. Similarly, steers that were limit-fed a concentrate diet during the growing phase displayed approximately 64% compensation in growth during finishing and the increased DMI in the feedlot accounted for 60 to 104% of the compensation (Sainz et al., 1995). In agreement with Creighton et al. (2003), FC steers had lower NE_m requirements than S steers due to their significantly lower initial feedlot BW; thus the increased DMI observed for FC animals contributed to greater energy available for gain compared to S steers and ultimately supported compensatory gains. Despite the lack of consistency in data, a review by Drouillard and Kuhl (1999) concluded that cattle that grazed high-quality forages during the stocker phase more commonly undergo a period of compensatory growth in the feedlot compared to those that grazed low-quality forage.

Throughout the finishing phase, total DMI for supplemented steers was approximately 415 kg/hd lower (*P* = 0.02) than for FC animals. In agreeance, Hersom et al. (2004) discovered that when steers achieved a high rate of gain during grazing, their DMI as a % of BW was subsequently reduced in the feedlot compared to those that had a lower rate of gain, with no differences in overall ADG or feed efficiency. The lower total DMI and fewer days on feed observed for S steers may imply that they were riper and nearer to finishing upon entering the feedlot than FC steers, which is supported by ultrasound data and in agreement with Coleman et al. (1995). Although S and FS animals entered the feedlot at similar BW, S steers were likely more acclimated to the high-energy finishing diet as they received supplemental DDG cubes at 0.75% of BW/d throughout the grazing season. Additionally, it cost an average of \$159.68/hd less (P = 0.01) to feed supplemented steers than FC steers, likely due to lower DMI and fewer days on feed. Despite the lower feed costs for supplemented steers, cost of gain tended (P = 0.08) to be the lowest for FS animals compared to those in FC and S. In comparison, feed costs in the finishing phase were reduced by approximately \$30/hd when steers were supplemented to achieve a high rate of BW gain on pasture compared to those with a lower rate of BW gain (Loken et al., 2009). However, the cost of gain was also lower for the high BW gain animals in their study. In contrast, no differences were observed for finishing period feed cost or cost of gain due to previous cattle backgrounding system (Kumar et al., 2012). In the current study, the lower cost of gain for animals in FS can be attributed to the additional days on feed required by the FC steers to reach harvest BW. Therefore, the increased feed costs were counterbalanced by the additional BW gain.

Carcass characteristics

Carcass data are presented in Table 4.4. On average, supplemented steers had a 6.69 and 6.83 cm^2 larger REA at processing ($P < 0.01$) and re-implantation ($P = 0.02$), respectively, than FC animals. Similarly, supplemented animals had greater BF at processing (*P* = 0.01) compared to those not supplemented, but FS had the greatest BF at re-implantation (*P* = 0.03). Although BF at re-implantation did not differ between FS and S (*P* = 0.20), there was a tendency (*P* = 0.09) for BF to be similar in S and FC steers as well. More specifically, BF in FS an S steers was 0.15 and 0.08 cm greater, respectively, than FC steers. There were no differences ($P \geq 0.17$) in HCW, REA, BF, marbling, or percent of animals grading choice or higher between treatments at harvest. Data on carcass characteristics as affected by previous supplementation during the grazing season is lacking and rather inconsistent. Similar results were reported when heifers were supplemented loose DDG on native range prior to finishing, with no differences in HCW, REA, BF, or marbling detected (Larson et al., 2019). In contrast, Greenquist et al. (2009) observed greater HCW and improved marbling scores in steers that received supplemental loose DDG on smooth bromegrass prior to the finishing phase. A meta-analysis conducted by Lancaster et al. (2014) evaluating the relationship between stocker performance and carcass characteristics determined that marbling score was positively related and predominantly influenced by HCW ($R^2 = 0.76$) rather than stocker ADG ($R^2 = 0.04$). Similar to final feedlot BW in the current study, the lack of difference in HCW was likely due to FC steers having approximately 37 additional days on feed compared to supplemented steers. This is in agreement with Gadberry et al. (2021) in which 40 additional days on feed allowed further weight gain and resulted in similar harvest BW and HCW. The lack of difference in quality grade should be expected due to being primarily dependent on marbling (Coleman et al., 1995). In the current study, the percent of carcasses that graded choice or higher ranged from 70.2 to 87.2% and resembled a trend similar to that observed for marbling. Animals not supplemented had numerically lower yielding carcasses than FS steers ($P = 0.01$), but did not differ ($P = 0.11$) from S. In contrast, no differences in YG were observed due to loose DDG supplementation (Smith et al., 2019, 2020) or rate of BW gain (Loken et al., 2009; Hersom et al., 2004) during the growing period. However, Felix et al. (2011) reported numerically lower YG carcasses when steers had lower energy consumption during the growing phase. As a percent of BW, DP was greatest ($P < 0.01$) for FC animals compared to supplemented steers by approximately 0.1%.

When shrunk body composition was evaluated for animals at 28% EBF, there were no differences ($P \geq 0.24$) in AFSBW or SWG between supplemental treatments (Table 4.4). In terms of body composition, there were no differences in EBW ($P = 0.25$), EWG ($P = 0.15$), or EBF ($P = 0.15$) between treatments. When steers grazed winter wheat at a targeted rate of gain or grazed native range prior to finishing, differences in final EBW were not detected, but animals targeted for a high rate of gain during grazing had the least EBF (Hersom et al., 2004). In comparison, EBF averaged 30.1, 31.9, and 30.7% for FC, FS, and S, respectively, which was approximately 4% greater than what was observed in their study. Our results are more similar to those reported by Smith et al. (2020), who reported an average EBF of 30% and no differences between steers that received varying levels of loose DDG during grazing. Under the circumstances that growth is not limited by energy, the proportion of empty body protein is typically decreased while the proportion of EBF is increased (Tedeschi and Fox, 2020). Although FC steers likely had greater deposition of muscle than fat during grazing due to their relatively lower plane of nutrition, deposition of fat was recovered when provided adequate nutrition in the feedlot, which is in agreement with Drouillard and Kuhl (1999). In other words, FC steers had greater protein deposition and lower fat deposition compared to S steers at the beginning of the finishing period, but had greater fat deposition than S towards the end of the finishing period (Fox et al., 1972). Therefore, the lack of differences in EBF between treatments suggests that growth of steers supplemented during grazing did not carryover to the finishing period and growth of FC steers may have been limited by energy during grazing. As a result of few differences being observed for carcass characteristics, there was no difference in carcass value (P = 0.52) between treatments, with an average value of $1797.41/hd.

CONCLUSION

Overall, our results implied that extruded DDG cube supplementation during grazing did not negatively affect subsequent feedlot performance. With fewer days on feed in the feedlot having a beneficial impact on profitability (Larson et al., 2019), supplementation of extruded DDG cubes during the summer grazing season may be viable management strategy. Additionally, our results suggest that the relatively short period of compensatory gain for FC steers at the beginning of the finishing phase did not elicit overall improved performance in the feedlot, which is in agreeance with similar studies reviewed by Reuter and Beck (2013). Nevertheless, the value of cattle upon entry into the feedlot is predominantly determined by entry BW (Reuter and Beck, 2013) and should be a principal consideration for stocker cattle producers. Feedlot performance data and carcass characteristics as affected by previous grazing performance and supplemental treatments has been, and continues to be, considerably inconsistent. The abundance of factors that have induced inconsistencies between studies (animal age, frame size, genetic potential, length of grazing period, etc.) continues to be a barrier for comparisons to be made between studies. Further research is pertinent in order to reduce inconsistencies, but all factors must be considered to do so.

Table 4.1 Ingredient and chemical composition of finishing rations fed in the feedlot

	Ration[1]			
Item	1	2	3	4
Ingredient composition, % as-fed				
Alfalfa blend	34.0	25.0	16.0	7.0
Flaked corn	39.5	49.5	60.0	70.5
Wet distillers' grains	22.5	19.0	15.5	12.0
Condensed distillers' solubles	-	1.5	2.0	2.5
Fat	-	1.0	1.5	2.0
Starter liquid	3.0	1.0	-	-
Finisher liquid	-	2.0	4.0	5.0
Micros	1.0	1.0	1.0	1.0
Chemical composition				
DM, %	67.6	68.7	69.7	70.6
CP, %	13.5	13.5	13.6	13.3
Fat, %	3.4	4.9	5.5	6.2
NE_m, Mcal/kg DM	1.8	2.0	2.2	2.3
NE_g, Mcal/kg DM	1.2	1.3	1.5	1.6

[1] Rations 1, 2, and 3 = step up diets fed for 5d each with a 2d transition period between them; Ration 4 = finishing diet fed from d21 to harvest.

Table 4.2 Summary of effects of dried distillers' grains (DDG) cube supplementation on performance of steers grazing introduced pastures during the summer grazing season

	Treatment[1]				
Item	Fertilized Control	Fertilized Supplement	Supplement	SEM[2]	*P*-value
BW, kg					
Initial	238	238	236	2.0	0.78
Final	373^a	408^b	412^b	5.0	<0.01
ADG, kg/d	0.86^a	1.09^b	1.12^b	0.027	<0.01
Supplemental efficiency[3]	-	0.17	0.11	0.036	0.25

[1] Fertilized Control, no supplementation on N fertilized pastures; Fertilized Supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

[2] Group variances estimated separately, the largest SEM is reported.

[3] Calculated as kg of added BW gain per kg of supplement (as-fed basis).

[a-b] Least-squares means followed by different superscripts within rows differ ($P < 0.05$).

Table 4.3 Effect of supplementation of dried distillers' grains (DDG) cubes to stocker cattle during grazing on subsequent feedlot performance

	Treatment[1]				
Item	Fertilized Control	Fertilized Supplement	Supplement	SEM[2]	*P*-value
BW, kg					
d 0	358^{a}	398^{b}	412^{b}	7.6	<0.01
d 84	513^{a}	552^{b}	545^{b}	9.2	0.04
Harvest	663	682	670	7.1	0.23
Days on feed[3], d	199^{b}	157^{a}	167^{a}	7.7	0.01
ADG, kg/d					
d 0-84	1.84^{b}	1.83^{b}	1.59^{a}	0.051	0.02
d 84-harvest	1.28	1.33	1.32	0.054	0.84
d 0-harvest	1.51	1.56	1.44	0.037	0.15
DMI[3]					
Individual, kg/d	10.97	10.71	10.93	0.175	0.51
Total, kg/hd	2202^{b}	1723^{a}	1850^{a}	98.6	0.02
Feed efficiency[4], kg/kg	0.13^{ab}	0.14^{b}	0.13^{a}	0.003	0.07
Feed cost, $/hd	740.73^{b}	560.28^{a}	601.82^{a}	32.134	0.01
Cost of gain, $/kg BW	2.48^{b}	2.03^{a}	2.36^{b}	0.130	0.08

[1] Fertilized Control, no supplementation on N fertilized pastures; Fertilized Supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

[2] Group variances estimated separately, the largest SEM is reported.

[3] Calculated according to Guiroy et al. (2001) and Tedeschi et al. (2004).

[4] Calculated as kg of added BW gain per kg of feed (DM basis).

[a-b] Least-squares means followed by different superscripts within rows differ ($P < 0.05$).

Table 4.4 Effect of dried distillers' grains (DDG) cube supplementation to stocker cattle during grazing on carcass characteristics

	Treatment[1]				
Item	Fertilized Control	Fertilized Supplement	Supplement	SEM[2]	*P*-value
REA, cm^2					
d 0	55.4^a	60.6^b	63.4^b	1.13	<0.01
d 84	77.9^a	85.1^b	84.4^b	1.52	0.02
Harvest	98.8	99.1	98.8	1.55	0.97
Backfat, cm					
d 0	0.27^a	0.36^b	0.33^b	0.015	0.01
d 84	0.64^a	0.79^b	0.73^{ab}	0.031	0.03
Harvest	1.42	1.72	1.52	0.104	0.17
HCW, kg	429	441	433	4.6	0.25
DP, %BW	64.7^b	64.6^a	64.6^a	0.01	<0.01
Marbling[4]	444	473	451	11.3	0.24
YG	2.0^a	2.8^b	2.4^{ab}	0.19	0.04
Choice or higher, %	70.2	87.2	73.3	6.24	0.19
Shrunk body composition[3]					
AFSBW, kg	654	643	652	10.3	0.67
SWG, kg/d	1.86	1.72	1.81	0.056	0.24
Empty body composition[3]					
BW, kg	614	630	620	6.2	0.25
BW gain, kg/d	1.44	1.49	1.38	0.035	0.15
Fat, %	30.12	31.96	30.76	0.628	0.15
Carcass value, \$/hd	1785.50	1815.56	1791.19	19.102	0.52

[1] Fertilized Control, no supplementation on N fertilized pastures; Fertilized Supplement, DDG cubes supplemented at 2.9 kg/d prorated for 3-d/wk feeding on N fertilized pastures; Supplement, DDG cubes supplemented at 0.75% BW/d prorated for 5-d/wk feeding on unfertilized pastures.

[2] Group variances estimated separately, the largest SEM is reported.

[3] Calculated according to Guiroy et al. (2001) and Tedeschi et al. (2004); AFSBW = final shrunk BW adjusted to common EBF, SWG = shrunk weight gain.

[4] Marbling scores: 200 = $Standard^+$, 300 = $Select^+$, 400 = $Choice^-$, 500 = Choice°, 600 = $Choice^+$, 700 = $Prime^-$, 800 = Prime°, 900 = $Prime^+$ (USDA-AMS, 2017).

[a-b] Least-squares means followed by different superscripts within rows differ ($P < 0.05$).

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APPENDICES

Appendix 1. Example calculation for hay and supplemental dried distillers' grains (DDG) cube dry matter intake (DMI) and apparent digestibility (DMD) using internal and external markers[1]

Item[2]	Variables and equations	Value
Inputs		
TiO_2 dosed, g/d	A	10
TiO_2 in feces, g/g	B	0.0028
DDG cubes consumed, g/d	D	900
DDG cube DMD[3]	E	0.86
iNDF in feces, %	H	60.70
iNDF in DDG cubes, %	J	3.54
iNDF in hay, %	N	38.69
Calculations		
FO, g/d	$C = \frac{A}{B}$	3,551
FO from DDG cubes, g/d	$F = D \times (1 - E)$	126
FO from hay, g/d	$G = C - F$	3,425
iNDF in feces, g/d	$I = \frac{(C \times H)}{100}$	2,156
iNDF in DDG cubes, g/d	$K = \frac{(D \times J)}{100}$	31.92
Fecal iNDF from hay, g/d	$L = I - K$	2,124
Fecal iNDF from hay, %	$M = \frac{L}{G} \times 100$	62.00
Hay DMD, %	$O = \left[1 - \left(\frac{N}{M}\right)\right] \times 100$	37.59
Hay DMI, g/d	$P = \frac{G}{(1 - O)}$	5,489
Total diet DMI, g/d	$Q = D + P$	6,389
iNDF in total diet, %	$R = \left(\frac{I}{Q}\right) \times 100$	33.74
Total diet DMD, %	$S = \left[1 - \left(\frac{R}{H}\right)\right] \times 100$	44.41

[1] Adapted from Kartchner (1981).

[2] Titanium dioxide (TiO_2) = external marker, Fecal output = FO, indigestible neutral detergent fiber (iNDF) = internal digestibility marker.

[3] Determined via near-infrared reflectance spectroscopy.

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