

NUTRITION AND MANAGEMENT CONSIDERATIONS FOR BULLS AND BREEDING
FEMALES

BY

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DISSERTATION

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ABSTRACT

The development of bulls and breeding females to productive beef animals represents a substantial economic impact to the producer, and development can ultimately impact reproductive success and longevity within the herd. To maintain herd size and productivity, proper selection and retention of replacement females drives the sustainability of a beef cattle operation. A significant portion of the reproductive failures in cow-calf enterprises is due to the fertility of the herd bull. Thus, the objective of this dissertation was to evaluate nutritional and management strategies to optimize the development of bulls and breeding females.

Research has been inconsistent on what is the ideal heifer development strategy and how it translates to fescue-based production systems. Thus, the objectives of experiment 1 were to evaluate the effect of heifer development system on body weight (BW), body condition score (BCS), fescue toxicosis symptoms, reproductive performance, and subsequent calf growth of fall-calving beef heifers. Angus $\times$ Simmental heifers [$n = 399$; 240 ± 20.0 kg initial BW; age = 252 ± 20 d] were stratified by BW and BCS and assigned to 1 of 12 groups in each of the two production years. Pens were randomly assigned to 4 treatments: drylot (**DL**) development (fed ad-libitum 90% hay and 10% DDGS on a dry matter basis), grazing endophyte-infected fescue supplemented daily (2.3 kg as-fed/heifer/d; 50:50 mix of soybean hulls and DDGS; **E+/S**), grazing endophyte-infected fescue and supplemented from the midpoint of treatment period until breeding (4.5 kg as-fed/heifer/d; 50:50 mix of soybean hulls and DDGS; **E+/LS**), and grazing novel endophyte-infected fescue with no supplementation (**NE+/NS**). Treatments DL and E+/S represent traditional Midwestern development strategies in contrast to the alternative strategies in E+/LS and NE+/NS. Heifers in DL had the greatest ($P \leq 0.05$) BW and BCS from d 28 until d 254. Furthermore, E+/S heifers had a greater ($P \leq 0.05$) BW and BCS than both E+/LS and NE+/NS from d 28 until d 168. On d 56 and 84, E+/LS heifers had lower ($P \leq 0.05$) BW and

BCS compared to NE+/NS, but on d 140, they switched and remained at a greater ($P \leq 0.05$) BW and BCS compared to NE+/NS through the first breeding season. Drylot heifers had the greatest ($P \leq 0.05$) cyclicity, percentage of mature BW at AI (66.6%), and had greater ($P \leq 0.05$) AI and overall pregnancy rates compared to E+/LS and NE+/NS females. The E+/S (55%) and E+/LS (53.7%) heifers were developed to a greater ($P < 0.01$) percentage of mature BW than NE+/NS (49.3%). A greater ($P \leq 0.02$) percentage of DL and E+/S heifers were pregnant at the end of the first breeding season (89.3 and 85.1%; respectively) compared to NE+/NS females (61.5%). In summary, DL heifers had the greatest BW and BCS at AI, percentage cycling, and AI pregnancy rate. However, this strategy did not result in differing overall pregnancy rates between DL, E+/S, and E+/LS, and there were no differences in cow milk production, rebreeding reproductive performance and calf performance between all treatments. This would suggest that DL, E+/S, E+/LS systems are all viable strategies for developing fall-born replacement beef heifers in the Midwest.

Transitioning beef females from the drylot to a grazing setting is one of the most challenging times from a nutritional standpoint especially when it coincides with lush pasture growth. This can lead to cows entering a negative energy balance. The nutritional requirement for growth and lactation of the two-yr-old lactating cow makes her extremely susceptible to a nutritional insult. However, the lack of grazing experience of heifers can cause issues when first exposed to grass. Thus, the objectives of experiment 2 were to evaluate the effect of corn supplementation and age of female on body weight (BW), body condition score (BCS), artificial insemination (AI) pregnancy rate, and blood metabolites. Angus and Angus $\times$ Simmental beef females ($n = 361$) were blocked by location then stratified by BW and BCS and were assigned to 1 of 8 pens/location with 9-14 females/pen over two production yr. The four treatment groups

were: yearling heifers receiving no supplement (**CON-H**); yearling heifers receiving supplement of dry rolled corn [(**SUPP-H**); 1.81 kg as-fed/heifer/d] for 42 d; two-yr-old lactating cow-calf pairs receiving no supplement (**CON-C**); and two-yr-old lactating cow-calf pairs receiving supplement of dry rolled corn [(**SUPP-C**); 1.81 kg as-fed / cow/d] for 42 d. Females receiving SUPP had a greater ($P \leq 0.10$) BW and BCS at d 42 and BW change over the supplementation period. Control females tended ($P = 0.10$) to have greater serum NEFA concentrations compared to SUPP females. Cow BUN increased more ($P = 0.02$) from d 0 to d 12 compared to heifers, whereas, SUPP females tended ($P \leq 0.08$) to have lower BUN at d 12 and d 42 compared to control females. Supplementation effects were not detected ($P \geq 0.25$) for AI or overall pregnancy rate. In conclusion, there were no supplementation $\times$ age interactions excluding d 42 BCS. Supplementation regardless of female age, tended to improve d 42 BW and BW change. Cow NEFA decreased more and BUN increased more from d 0 to d 12 compared to the heifers whereas the supplemented females had lower NEFA and BUN. Even though cows tended to have greater AI pregnancy rates than heifers, supplementation did not affect AI or overall pregnancy rates.

Breeding bulls across the United States are commonly fed high-energy diets by seedstock producers prior to sale, generally in the form of grain. Costs associated with feeding these diets have led producers to consider cheaper alternatives such as distillers grains with solubles. But there is no data available on the impact of coproducts on developing bulls. Thus, the objectives of experiment 3 were to evaluate the effect of distillers grains with solubles supplementation on performance and reproductive traits of bulls. Simmental $\times$ Angus bulls ($n = 28$) were stratified by BW (316 ± 29 kg) and sire. Pens were randomly assigned to 1 of 2 dietary treatments (3 pens/treatment): 1) 40% modified wet distillers grains plus solubles (MWDGS; **DST**; DM basis),

or 2) corn based diet with no MWDGS (**CON**). Treatment $\times$ time interaction was detected ($P < 0.01$) for BW; however, when sliced by time, BW within each day did not differ between treatments ($P \geq 0.43$). Treatment $\times$ time and treatment effects were not detected ($P \geq 0.40$) for BCS, HH, hoof scores, MS and MD. Treatment effects were not detected ($P \geq 0.53$) on ADG, DMI, and G:F. A treatment $\times$ time effect was detected ($P < 0.01$) for RF and BF. Bulls fed DST had greater RF ($P = 0.01$) on d 84 and greater BF ($P \leq 0.04$) on d 56, 84, 112, and 175 than CON bulls. A treatment $\times$ time effect was detected ($P = 0.04$) for scrotal circumference (SC), which tended ($P = 0.07$) to be greater for DST vs. CON bulls on d 210. However, effects of treatment $\times$ time and treatment were not detected ($P \geq 0.12$) for spermatic cord circumference, percent of bulls deemed as satisfactory after BSE, normal morphology, minor defects, percentage overall motility, progressive motility, and total cells. Treatment $\times$ time effect was detected ($P < 0.03$) for major sperm defects and proximal droplets. Bulls fed DST had a greater ($P < 0.01$) percentage of major defects and percentage of proximal droplets ($P = 0.01$) on d 140 than CON bulls. Distillers resulted in slightly fatter bulls and an increase in major semen defects at end of treatment period, but bulls recovered during the common low-energy diet and there were no differences in any other reproductive parameters.

In summary, producers can properly develop fall born beef heifers in the drylot or grazing setting. Supplementing corn daily had no impact on the reproductive performance of heifers or two-yr-old lactating cows when they are grazing lush spring pasture. Finally, producers may include low S distillers grains with solubles into the diet of developing bulls up to 40% (DM basis) in order to reduce ration cost without negative effects on long-term reproductive performance.

DEDICATION

For my wife Christy, you are the ultimate companion in life, and you are my biggest supporter.

For my parents, Darrell and Julie Henley. You have instilled in me the strength, courage, and integrity I needed to finish this journey.

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TABLE OF CONTENTS

	Page
CHAPTER 1: LITERATURE REVIEW	1
Introduction.....	1
Heifer Development.....	2
Diet Modification and Heifer Reproduction	10
Tall Fescue	12
Distillers Grains	17
Bull Development	22
Conclusions.....	33
Literature Cited	34
CHAPTER 2: EFFECTS OF BEEF HEIFER MANAGEMENT SYSTEM ON GROWTH AND REPRODUCTIVE PERFORMANCE	52
Abstract	52
Introduction.....	53
Materials and Methods.....	55
Results.....	63
Discussion	66
Tables and Figures	75
Literature Cited	81
CHAPTER 3: EFFECT OF CORN SUPPLEMENTATION AND AGE ON PERFORMANCE AND REPRODUCTION OF BEEF FEMALES GRAZING LUSH SPRING PASTURE	89
Abstract	89
Introduction.....	90
Materials and Methods.....	92
Results.....	97
Discussion	99
Table and Figures.....	105
Literature Cited	109

CHAPTER 4: INFLUENCE OF DISTILLERS GRAINS WITH SOLUBLES ON BULL GROWTH AND REPRODUCTIVE TRAITS.....	113
Abstract	113
Introduction.....	114
Materials and Methods.....	115
Results.....	122
Discussion	123
Tables and Figures	128
Literature Cited	138
CHAPTER 5: CONCLUSIONS	141

CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

Nutrition and reproduction are the two most important factors driving the financial success of a cow-calf enterprise (Hess et al., 2005). Approaches to decrease feeding costs without compromising animal performance are vital to the viability of the operation. Therefore, economic success depends on the availability and quality of forage throughout the year in relation to the nutrient requirements of the animals. Capitalizing on the ruminant's ability to utilize feed resources not usable for other production industries may represent an alternative to reduce production costs.

In a cow-calf enterprise, the ability of a breeding female to produce one calf per year is one of the key drivers of profitability (Mulliniks et al., 2013). Since production costs for unproductive cows failing to carry and raising an offspring represent a major loss to beef producers, targeting areas of development that could lead to improved likelihood to conceive would greatly benefit the beef industry. Therefore, the development of these heifers to productive beef cows represents a substantial economic impact on the producer, and proper development can ultimately impact a heifer's reproductive success and longevity within the herd.

Reproductive disorders and pregnancy failure could cost beef cattle producers as much as \$502 million in lost income yearly (Bellows et al., 2002). When considering that an important portion of the reproductive failures in cow-calf enterprises is due to bull infertility, proper bull development is just as, if not more important, than heifer development. Across the United States, breeding bulls are commonly fed high-energy diets by seedstock producers prior to sale,

generally in the form of grain. Additional costs associated with feeding high energy diets has led seedstock producers to include by-product feedstuffs as an avenue to reduce costs.

Ethanol production in the United States continues to increase (Renewable Fuels Association, 2019). This growth has kept distillers grains with solubles (**DGS**), an affordable feedstuff for ruminants. However, the current dogma among beef cattle enterprises is that developing bulls should not be fed DGS because of potential negative effects on reproductive performance. Despite widespread and controversy use of DGS, there is no research currently available describing the effects of DGS feeding on beef bull reproductive development and performance. Therefore, there is a critical need to optimizing heifer and bull development to ensure the profitability of beef cattle operations.

HEIFER DEVELOPMENT

Heifer development is one of the most substantial expenses for beef cattle operations due to inherent opportunity and development costs for retaining heifers (Mulliniks et al., 2013). Implementing a heifer development method which is centered on future compatibility with the environment of the cowherd is imperative to a successful cow-calf operation. Since most components of fertility are not highly heritable, management practices have a profound impact on reproduction and consequently the profitability of the operation (Mulliniks et al., 2013). Thus, heifer development method from weaning to the beginning of the first breeding season is a key cost, and the outcome is critical for their subsequent productivity.

Puberty

Conception rates have been reported to be greater in heifers that are bred on their third estrus rather than at pubertal estrus (Byerley et al., 1987). Therefore, heifer development methods have been focused on the physiological processes that influence the earlier onset of puberty

(Patterson et al., 1992). Age at puberty is a significant determinant of production efficiency in beef cattle. The ability to breed animals at younger ages reduces generation intervals and decreases the number of unproductive days and allows for potential genetic gains. In females, time of the first ovulation has been used to denote when puberty is reached (Schillo et al., 1992). However, one should keep in mind that the attainment of puberty is a gradual process and that puberty occurs earlier than does sexual maturity or normal reproductive capacity (Moran et al., 1989).

Puberty is the result of specific endocrine mechanism, negative feedback from estradiol in the hypothalamus on the secretion of gonadotropin-releasing hormone which leads to an increase in the secretion of LH in response to an increment of GnRH release (Rodriguez and Wise, 1989), resulting in maturation and ovulation of ovarian follicles. (Kinder et al., 1987). Increase of GnRH secretion is critical for the establishment of normal estrus cycles in pre-pubertal animals. Secretion of GnRH is mediated greatly by the ovarian steroids estrogen and progesterone, however other hormones and peptides also affect its secretion such as leptin, IGF-I, GABA, glutamate, neuropeptide Y, activin and inhibin (Clark, 2011). Recently, kisspeptin has emerged as a possible key regulator of the function of GnRH neurons (Ojeda et al., 2010). With the recent discovery of the kiss-1 gene that encodes for kisspeptin and its receptor (GPR54) and its localization in the hypothalamus and ovary, it has been hypothesized to be involved in the modulation of reproductive events such as puberty (Smith, 2008). It is involved in the hypothalamic regulation of the secretion of pituitary hormones (LH and FSH) and, more specifically, during the mechanisms involved during the pre-ovulatory release of GnRH by the action of estradiol (Clark, 2011).

In a seminal study, younger heifers developed on higher planes of nutrition were heavier but younger at puberty than were nutritionally restricted animals (Short and Bellows 1971).

However, there are conflicting results as to whether the rate of gain has an effect on the onset of puberty (Clanton et al., 1983; Schillo et al., 1992). Furthermore, it was demonstrated that delaying the gain until the final third of the developmental period results in similar pregnancy rates to heifers that gained at a constant rate during the entire development period (Lynch et al. 1997). Park et al. (1987) used a stair-stepped development system that consisted of feeding low-quality, high-fiber diets followed by a rapid growth phase using high-concentrate diets. Heifers in the stair-stepped growth system responded favorably with no detrimental effect on reproductive performance.

Targeted Body Weights in Heifer Development

Most early research in developing heifers focused on weight as the primary factor affecting the age at puberty. Thus, recommended guidelines have been focused on a target BW of 60 to 65% of mature BW in beef heifers at breeding to optimize reproduction (Patterson et al., 1992). Rutter and Randel (1986), differentially fed lighter (BW = 232 kg) and heavy (BW = 264 kg) heifers to achieve a target weight of 330 kg at the same time, and found that there was a difference between ages but not weight between the heavy and light heifers at first the estrus. These authors suggested that reaching a target weight may trigger estrus signs, but the maturation process that elicits an LH surge sufficient to induce ovulation may not occur in heifers that are not old enough as they noted a high incidence of estrus without the subsequent formation of a functional corpus luteum (CL).

Recently, developing heifers to lighter target BW may be effective in reducing costs while maintaining reproductive performance (Funston and Deutscher, 2004; Martin et al., 2008). Martin et al. (2008) reported that heifers in a 60-d breeding season could be as low as 50% of mature BW and achieve pregnancy rates of 88.4%. Endecott et al. (2013) stated that developing heifers 50 to 57% of mature BW at breeding compared with 60 to 65% BW reduced cost without

compromising reproductive success. Other research focused on developing heifers at similar pre-breeding target BW has reported pregnancy rates from 88 to 90% after a 60-d (Funston and Deutscher, 2004) or 45-d breeding season (Martin et al., 2008), respectively. Roberts et al. (2009) reported restricted heifers consumed approximately 27% less feed, and as a result, had reduced average daily gains (ADG) compared with control heifers during the individual feeding period. The ADG was greater for restricted heifers after the feeding period compared with control heifers, which suggests a compensatory gain effect for restricted heifers. Cow BW and BCS remained lower for individuals developed as restricted compared with control at the beginning of the breeding season at two to five years old (Roberts et al., 2009). Heifers nutrient restricted for 140 d after weaning had reduced proportions attaining puberty by 14 mo, but had similar overall pregnancy rates compared with their control-fed contemporaries (Roberts et al., 2009). The authors noted a \$33 reduction in the cost of a developed pregnant heifer favoring the restricted heifers. In a review, Funston et al. (2012) suggested that heifers could be developed at a lighter target BW ranging from 50 to 57% of mature BW and still maintain reproductive and subsequent calf production. These studies indicate that heifers can be developed at a lower target BW prior to breeding while maintaining adequate pregnancy rates and effectively lowering developmental feeding costs.

Compensatory Gain

The phenomenon of compensatory growth is described as a period of accelerated and more efficient growth that usually follows a period of growth restriction (Drouillard and Kuhl, 1999). Typically compensatory growth results after a period of reduced nutrient intake; however, environmental factors such as extreme temperatures, disease, plant toxins, or parasite infection can also alter cattle growth rate and when alleviated can result in compensatory growth

(Drouillard and Kuhl, 1999). Although the mechanisms by which compensatory gain occurs are not well understood, it has been hypothesized that the increased growth rate is attributed to reduced maintenance requirements for smaller animals, increased feed intake and gastrointestinal tract fill, coupled with increased net energy content of gain, increasing calf BW gain (Sainz et al. 1995; Sainz and Bentley, 1997).

Grings et al. (2007) reported heifers developed to gain rapid weight at the end of development had reduced BW compared with heifers fed to have constant gain at the end of the low-quality forage feeding period (approximately 90 d prior to the breeding season). However, during the rapid growth phase, delayed gain heifers gained 0.44 kg/d (± 0.03 kg/d) faster than control gain heifers, allowing heifer BW at pre-breeding to be similar among constant and late-rapid growth heifers. Similarly, Freetly et al. (2001) reported heifers fed a high ME diet (263 kcal ME/(BWkg)^{0.75}) from weaning to breeding had greater hip height and BW compared with heifers fed a low ME diet (157 kcal ME/(BWkg)^{0.75}) for the first 84 d postweaning followed by a higher ME diet (277 kcal ME/(BWkg)^{0.75}) from d 84 to the breeding season. Freetly et al. (2001) also reported an increase in the ratio of BW gain:ME intake (kg/Mcal) during d 85 to 168 of development for heifers fed the low/high ME diet compared with those fed the high ME diet throughout development. Each study reported similar pregnancy rates among treatment groups (Freetly et al., 2001; Grings et al., 2007).

Heifers developed on low-quality winter forage may offset minimal pre-breeding ADG through the idea of compensatory gain, thus, having the ability to respond to a seasonal improvement in forage quality (Marston et al., 1995; Ciccioli et al., 2005). Delaying gain to take advantage of compensatory gain is more economical than constant gain throughout the developmental period (Clanton et al., 1983; Lalman et al., 1993). Thus, the plane of nutrition

before breeding and timing of compensatory growth seems to be imperative for reproductive success, which may be more important than ADG from weaning to breeding.

Development Strategies and Longevity

The most significant concern with developing heifers on a slow rate of gain is decreasing heifer pregnancy rates and increased calving difficulties that may result in reduced longevity and productivity in the cowherd. Yet, developing heifers on lower levels of nutrient input has been suggested to improve efficiency and enhance longevity in the cowherd (Roberts et al., 2009). In a 10-yr study, Hughes et al. (1978) reported an advantage in the retention rate of beef cows on a lower plane of nutrition compared to higher levels. A long-term study by Mulliniks et al. (2013) evaluated the economics and retention rate of differing heifer development systems. In spring calving system they developed heifers in 1 of 3 treatments which included grazing winter range with supplementation of 0.9 kg/d of supplement that contained 36% rumen undegradable protein (**RUP**), grazing winter range with supplementation of 0.9 kg/d of a supplement that included 50% RUP, or developed in a drylot on a corn silage diet. During the post-weaning period, pasture developed cattle gained 0.27 kg/d and reached a pre-breeding BW of 276 kg (approximately 51% of mature BW), regardless of supplement type. In contrast, drylot developed heifers gained 0.69 kg/d and weighed 315 kg by the start of breeding (approximately 58% of mature BW). Following the treatment period, heifers were comingled and placed on grass during the breeding season. Average daily gains were greatest for the pasture-developed heifers (0.83 kg/d) compared to the drylot heifers (0.61 kg/d) during the breeding season. This is a result of pasture-developed heifers being familiar with how to graze. The proportion retained in the herd over 4 yr was greater for the 50% RUP heifers than the other two groups. Authors noted that heifers developed on pasture had a greater net return compared to drylot heifers. These results

indicate that lower growth rates during postweaning development may not be detrimental to future retention (Mulliniks et al., 2013).

Excess BCS also hinders reproductive efficiency (Patterson et al., 1992) and increases the incidence of dystocia and post-partum complications (Arnett et al., 1971). Heifers with a greater BCS before anestrus required increased weight gains to resume cyclicity (Cassady et al., 2009), and heifers at a lower BCS prior to anestrus began cycling at a lower body weight. Therefore, heifers with a greater BCS prior to anestrus will require greater nutritional intake to resume cyclicity compared to heifers at a lower BCS. Cow energy status highly influences the secretion of LH. Mechanisms that lead to cessation or reinitiating of LH release do not occur at the same time as those activated to sustain life or growth. Developing heifers to appropriate body weights and BCS for the breeding season will ensure increased pregnancy success and minimize dystocia during the calving season.

Pinney et al. (1972) suggested that differences in retention rates are established rather early in a cow's life, and its longevity is maintained after that. However, culling non-pregnant heifers developed on a slower rate of gain may result in the metabolically and physiologically least efficient heifers leaving the more efficient animals in the herd. If additional feed and expenses are needed to ensure less efficient cows remain productive in a sparse nutrient environment, then this connection leads to the inference that current heifer development guidelines may actually be leading to retentions of less efficient cows and thus counterproductive towards greater lifetime productivity (Roberts et al., 2009).

Heifer grazing behavior and management practices that expose heifers to their production environment during development may influence future performance. Research in dairy heifers has shown that previous metabolic status during certain physiological events influences their

ability to reproductively respond later in life (Roche et al., 2005; Chagas et al., 2006).

Transitioning heifers from a drylot back to pasture may impact heifer growth and reproductive response. Olson et al. (1992) indicated that heifers grazing rangeland may have retained superior grazing skills resulting in improved grazing efficiency when compared with their drylot-developed counterparts. For example, transitioning heifers to pasture with no prior grazing experience resulted in reduced AI pregnancy rates compared with heifers that were grazing during post-weaning development (Perry et al., 2013). Heifers developed grazing corn residue exhibited greater AI pregnancy rates (78%) compared to their counterparts (67%) developed in a drylot (Summers et al., 2014). In addition, developing heifers in the environmental plane of nutrition they are expected to perform and reproduce later in life may increase life-time herd retention rate compared to over-developed heifers in an artificial and increased nutritional environment (Endecott et al., 2013; Mulliniks et al., 2013). Exposing heifers to the nutritional environment in which they will be expected to perform long-term seems to be an important management practice to consider. Grazing skills may be retained in heifers grazing with little to no additional harvested feedstuffs may enable them to respond more efficiently to changes in forage quality and periods of nutrient deprivation they will be exposed to long-term.

In summary, heifer development may be a suitable time period to select heifers for fertility and adaptability in their production environment. Periods of nutrient restriction and subsequent re-alimentation may be a viable strategy to apply during heifer development. Furthermore, a period of compensatory growth prior to breeding may alter lifetime nutrient requirements and efficiency of nutrient utilization. However, focusing on low-input heifer development to expose heifers to their grazing production environment early in their productive life may be the most cost-effective production practice.

DIET MODIFICATION AND HEIFER REPRODUCTION

Plane of nutrition before and after the breeding season has been indicated as an imperative time point for reproductive success (Mulliniks et al., 2013; Summers et al., 2014). Furthermore, delaying BW gain may positively impact conception rates to AI in heifers if the timing of gain coincides with the onset of the breeding season (Lynch et al., 1997; Summers et al., 2014). Heifers that had an improved plane of nutrition during the first 21 d post-AI had greater pregnancy rates when compared with heifers that maintained or lost BW (Arias et al., 2012). Conversely, nutrient restriction following AI negatively impacted embryo development (Kruse et al., 2017), resulted in poorer quality embryos (Kruse et al., 2017) and a subsequent reduction in AI pregnancy rates (Perry et al., 2013). Collectively, these data suggest that increased nutrient intake during the breeding season may provide a nutrient flushing effect that can have a positive influence on reproductive performance.

Grazing is a learned behavior that animals acquire from adults prior to weaning (Perry et al., 2013). At weaning, heifers are typically moved to a confined feeding situation to maintain proper nutritional management (Olson et al., 1992). Alternatively, heifers may be developed in a forage setting to ensure that heifers maintain familiarity with the grazing environment. At weaning, heifers exhibit increased forage consumption, as they are no longer reliant on their dams for the majority of their dietary intake through milk (Olson et al., 1992).

During the breeding season heifers are commonly placed in a forage grazing setting. Prior grazing experience impacts heifers' capability to select a diet to meet their nutritional needs successfully. Average daily gains, activity level, and pregnancy success have been compared between heifers developed in a drylot versus grazing setting. Heifers developed in a drylot and subsequently turned out to pasture exhibited reduced ADG (Perry et al., 2013) during the first 27

days and increased activity level (Perry et al., 2015) during the first three days compared to their range developed counterparts. When moved to a grazing situation immediately following AI, drylot-developed heifers also had reduced pregnancy success compared with heifers that were moved to a forage grazing situation 27 d before the start of the breeding season (Perry et al., 2013), indicating that lack of grazing experience resulted in heifers in a negative energy balance.

In a recent study Perry et al. (2016) developed heifers on a forage diet and then allocated heifers to 1) spring forage, 2) spring forage with DDGS supplementation, or 3) continued in a feedlot for 42 days following AI. No differences were observed in final pregnancy rate (88%, 89%, and 86%; respectively) among treatments, and heifers maintained or gained BCS across all treatments. Thus, reduced pregnancy success from previous studies of heifers transitioned from drylot to pasture at AI was not due to sudden alterations in diet and rumen microbial populations but was most likely a result of decreased nutrient intake while learning how to forage. In conclusion, spring pasture turnout is a crucial time point in a heifer's development and may require additional management.

Breeding Season Supplementation

Most cattle systems in the Midwest calve in early spring, between February and April. This timeframe for calving allows peak lactation and breeding to coincide with lush pasture growth. Due to this, most forage available to cows during breeding is lush, wet grass that is relatively high in protein and moisture, and does not meet the nutritional needs of the cow in this energetically demanding period. Because of this nutrient deficit, cow reproduction is likely affected negatively.

Most research looking at the effect of supplementation of beef cattle during the breeding season has been when cattle are grazing low-quality forage. However, additional energy

supplements may need to be considered to ensure cows do not fall into a negative energy balance when grazing lush spring pastures that are high in CP but lower in energy (Gross et al., 2011). In spring, forage grows quickly and is very high in moisture, generally <25% DM (Doungkamchan et al., 2016). Physical fill with wet forage may limit DM intake. Additionally, the lush forage usually contains a high N content and minimal carbohydrates. Imbalances of N:Carbohydrate, along with the high moisture contents of the forage can lead to cows entering a negative energy balance (Arelovich et al., 2003). Previous work by Doungkamchan et al. (2016), at the Orr Beef Research Center at the University of Illinois, evaluated supplementing cows with a low-protein, high-fiber supplement from the initiation of spring grazing through breeding. Cows that were fed supplement (45% ground corncobs, 45% soybean hulls, and 10% dry molasses; DM basis) tended to have decreased blood urea nitrogen levels and, although not statistically significant, greater AI conception rates (51.7% vs. 38.5%). Authors noted that if peak forage CP would have aligned with the breeding season impacts would have likely been greater.

TALL FESCUE

Tall fescue (*Lolium arundinaceum* [Schreb.] Darbysh) is a cool-season, perennial plant and one of the most abundant forages in the United States with over 8.5 million cattle grazing tall fescue pastures (Hoveland, 1993). The agronomic characteristics of tall fescue make it an ideal candidate for pastures as it can withstand drought, poor soil conditions, and intense grazing (Gunter and Beck, 2004; Kallenbach, 2015). Tall fescue has these ideal attributes because of the endophyte infection in the plant (Gunter and Beck, 2004). The proximate analysis of Crude protein, digestible dry matter, amino acid, and mineral content is similar to a high-quality cool-season forage (Gunter and Beck, 2004).

Ergot Alkaloids

Ergot alkaloids fall into a class of compounds that are produced by fungi, which are referred to as secondary metabolites, meaning that they are not necessary for the survival and life processes of the organism that they are produced by. The rate of fungal growth depends on environmental conditions. The favored fungal conditions include warm temperatures, high rainfall and humidity, and high soil fertility (Craig and Hignight, 1991).

Three classes of alkaloids are produced from the toxic endophyte: pyrrolizidine, peramine, and ergot alkaloids (Siegel et al., 1990). Ergot alkaloids are of the greatest concern for causing fescue toxicosis (Strickland et al., 2011). There are numerous ergot alkaloids, including ergocryptine, ergotamine, ergonovine, and lysergic acid amide. Ergovaline has been identified as the most prevalent ergopeptide alkaloid suggesting it causes or contributes to fescue toxicosis due to its biological activity (De Lorme et al., 2007; Strickland et al., 2011). The ergoline ring structure is similar to that of dopamine, norepinephrine, and epinephrine, which is likely the reason why ergot alkaloids can impact animals (Hill et al., 2001; De Lorme et al., 2007).

Total ergot alkaloid concentration in tall fescue was noted to vary with season and amount of nitrogen fertilizer applied to fescue pastures (Rottinghaus et al., 1991; Hill et al., 2001). It has been demonstrated that ergot alkaloid concentrations peak in late spring, decrease through the summer months, and increase again in autumn at the initiation of autumn regrowth (Belesky et al., 1988; Rottinghaus et al., 1991; Rogers et al., 2011). Belesky et al. (1988) attributed the summer depression of ergot alkaloid concentrations as the result of the production of photooxidation metabolites. They suggested oxidation metabolites, higher temperatures, and high light intensity instigated the breakdown of secondary metabolites such as ergovaline (Belesky et al., 1988).

Cattle grazing fescue most commonly exhibit three disorders; fescue foot, fat necrosis, and fescue toxicosis (Schmidt and Osborn, 1993). Although all three disorders can be problematic, fescue foot and fat necrosis are more isolated and not necessarily reversible. Much more subtly but widespread is fescue toxicosis. It is estimated that tall fescue toxicosis costs the beef cattle industry over \$600 million annually (Hoveland, 1993).

Fescue Toxicosis and Animal Performance

Ergot alkaloids can elicit a response that is referred to as fescue toxicosis. The response can have a range of severity with the least severe symptoms being slight physiological and physical debilitations, to severe symptoms that could lead to animal death. The symptoms can include reduced reproductive performance, reduced weight gain, and overall poor performance (Schmidt and Osborn, 1993; Paterson et al., 1995; Strickland et al., 2011; Aiken et al., 2013). Stuedemann and Hoveland (1988) noted that for every 10% that endophyte infection level increased ADG decreased at a rate of 0.05 kg. Cows grazing fescue-legume pastures weaned heavier calves compared to calves from cows grazing E+ (Holloway et al., 1979). However, the influence of E+ preweaning environment may not persist as calves can exhibit compensatory gains following feedlot entry (Long et al., 2012).

Toxic endophyte-infected tall fescue has been detrimental to reproductive processes, including reduced pregnancy and calving rates (Porter and Thompson, 1992; Paterson et al., 1995; Looper et al., 2010). In a study by Burke et al. (2001), heifers were fed endophyte-free (E-) or E+ seed and exposed to either thermoneutral or heat stress conditions. The size of the corpus luteum did not differ between treatment groups (Burke et al., 2001). However, circulating serum progesterone (**P4**) concentrations were decreased in heifers exposed to both E+ and heat stress conditions. The number and size of large follicles were also decreased in heifers exposed to both

E+ and heat stress conditions compared with all other treatment groups (Burke et al., 2001). A study conducted by Jones et al. (2003) investigated P4 concentrations in cattle grazing E- or E+, and reported lower circulating P4 in cattle grazing E+ compared with E-, but no treatment differences in P4 production from luteal cells. Differences in circulating P4 could be attributed to decreased blood flow to the corpus luteum or decreased total circulating cholesterol, which is a precursor to P4 production. It has also been reported that heifers exposed to endophyte-infected seed exhibited shorter estrous cycles, and decreased serum P4 concentrations during mid-cycle (Jones et al., 2003). Heifers receiving ergotamine tartrate to simulate the effects of grazing E+ produced embryos of reduced quality and development (Schuenemann et al., 2005). Embryo recovery rate tended to be reduced in heifers fed ergotamine, possibly due to increased rectal temperatures and lower plasma prolactin concentrations (Schuenemann et al., 2005). Embryos collected from donors not consuming E+ diet transferred on d 7 into recipients consuming ergotamine tartrate resulted in no difference in pregnancy rates between treatment groups, suggesting E+ deleterious effects on pregnancy rates may occur before d 7 on the oocyte or during the early stages of embryonic development (Schuenemann et al., 2005).

Vasoconstriction is another impact from fescue toxicosis, and occurs as the vascular tone contracts and restricts blood flow to many tissues, which then affects the animal's ability to dissipate heat and hinders the reproduction of the animal (Strickland et al., 2011). With the inability to dissipate heat, cattle grazing endophyte-infected tall fescue will also have increased respiratory rates as a mode to attempt to dissipate heat (Finch, 1986).

Reduced prolactin concentrations are common symptoms of fescue toxicosis in cattle (Looper et al., 2010). Dopamine is an antagonist to prolactin, which means that it causes the suppression of prolactin (Fitzgerald and Dinan, 2008). Less dopamine will allow a greater

amount of prolactin, while a higher amount of dopamine will cause a suppression of prolactin (Fitzgerald and Dinan, 2008). Animals who are suffering from fescue toxicosis and a decreased amount of circulating prolactin may display a shaggy hair coat that may be patchy and not look smooth, even in the summer months. The lack of hair shedding is due to the decreased prolactin concentrations and can add to the heat stress that the animal endures during the summer months when they are already suffering from other symptoms of fescue toxicosis (McClanahan et al., 2008). Hair shedding scores are often used to determine the level of shedding that has occurred on cattle and can be used as an indicator of the toxicity levels of pastures. The scores are done on a 1 to 5 scale with 1 being completely shed off and slick, and a 5 being an animal that still has its full winter coat (Gray et al., 2011).

Mitigation Strategies

Since the diagnosis of fescue toxicosis in livestock, research efforts have targeted ways to decrease production loss while still utilizing tall fescue to maximum potential. Endophyte-free varieties of tall fescue were developed but lacked the ability to persist when compared to E+ (Hill et al., 1990).

Recent research focuses have targeted development of “novel” endophytes, which provide positive symbiotic relationships for the plant while not producing ergot alkaloids responsible for fescue toxicosis (Bouton et al., 2002). When grazed by stocker cattle, the novel endophyte-infected varieties (NE+) had similar ADG when compared to E- (Parish et al., 2003). With 8.5 million acres of E+ fescue being grazed, it is evident that producers are not going to eliminate all toxic tall fescue and establish new varieties. Therefore, developments of strategies to utilize this adaptable forage with the least impact on livestock production have been beneficial.

Supplementing growing cattle to alleviate fescue toxicosis has been successful at improving ADG, prolactin level, and hair coat score (Aiken et al., 2008; Carter et al., 2010). Supplementation often decreases forage intake and therefore dilutes tall fescue toxins in the diet. The combination of decreased toxin intake and increased dietary protein or energy from supplements can improve animal performance.

DISTILLERS GRAINS

Distillers Grains are a byproduct of the ethanol industry. In the United States, most ethanol is produced utilizing corn in the dry milling process (Bothast and Schlicher, 2005). According to Bothast and Schlicher (2005), in this process, corn grains are ground to allow for starch fermentation through the distillation column. The remaining mixture following the separation of the ethanol is referred to as stillage. At this point, the stillage is sent through a centrifuge where the grain is separated from the soluble portion. Solubles go through an evaporation process which leaves approximately 30% solid matter suspended in solution. Post-evaporation, this liquid is referred to condensed distillers solubles (CDS) or "syrup." The syrup can be marketed as a feed supplement by itself or recombined with the grain that was separated during centrifugation. When recombined it is referred to as distillers grains with solubles (DGS) and can be marketed in three ways. If not dried, it can be sold as wet distillers grains with solubles (WDGS). If partially dried down to around 48% DM, it is marketed as modified wet distillers grains plus solubles (MWDGS). However, the majority of the recombined syrup and grain is dried to approximately 90% DM and marketed as dried distillers grains with solubles (DDGS) (Bothast and Schlicher, 2005; Gunn et al., 2013).

Chemical Composition

Considering that on a DM basis corn is 72% starch, 9.5% CP, and 4.5% oil (NASEM, 2016), it makes it an ideal starch source for ethanol production. During the distillation process, the starch is fermented and removed, leaving the remaining nutrients such as protein, fat, fiber, and minerals (Bothast and Schlicher, 2005). Therefore, the particles recovered from the distillation process are concentrated in nutritive value (Bothast and Schlicher, 2005; Klopfenstein et al., 2008). On a DM basis, the NASEM (2016) reported DDGS to contain 30.8% CP, 10.7% ether extract, 33.7% NDF, 16.2% ADF, 5.3% ash, and 3.22 Mcal/kg of metabolizable energy (ME). However, due to variation in protocol between ethanol plants across the United States, the chemical composition of resulting byproducts may vary slightly between regions of the country or even between individual plant sites in the same region (Bothast and Schlicher, 2005).

Of the significant nutrient groups listed above, ether extract within the final DDGS product has the potential to vary the most. The CDS that are separated during the centrifugation process has been reported to contain ether extract values between 14% and 32.1% of DM (Kleinhans et al., 2005). These CDS can be added back to the centrifuged grains at any rate before the drying process, and due to this, the fat content of DDGS has the potential to fluctuate between plants, and even batches within individual plants (Bothast and Schlicher, 2005).

The primary component in the concentrated product is protein (Klopfenstein et al., 2008). Protein that remains in DDGS following processing is much higher in RUP than corn due to the rumen degradable protein (RDP) mostly being degraded during fermentation (Schingoethe et al., 2009). Additionally, NDF is also more concentrated in DDGS in comparison to corn, meaning that DDGS is an excellent source of non-forage fiber (Ham et al., 1994). Due to the greater amount of digestible fiber and minimal starch content of DDGS compared to corn, the incidence

of ruminal acidosis may be decreased when DDGS is included in diets (Ham et al., 1994). This reduced incidence of acidosis is most likely because of reduced starch intake.

Besides fundamental proximate analysis, the levels of two minerals, phosphorus, and sulfur, are of particular concern in DGS. Phosphorus levels are a concern due to the occurrence of urinary calculi from excess S or a Ca: P ratio not being balanced to at least 1.2:1. As DDGS contains on average 0.86% phosphorus (NASEM, 2016), dietary levels exceeding 20% DDGS may result in the overfeeding of P. Levels of P in the diet can be managed by adding other minerals to the diet, such as limestone or calcium carbonate. Sulfur (S) is another mineral that is of concern in DDGS. Sulfur requirements in feedlot steers have been set at 0.15% of diet DM, with maximum tolerable levels being dependent on the diet the animal is being fed. For diets containing 85% concentrate, the maximum level of S is set at 0.30%. For diets with greater than 40% forage, it is 0.50% S (NASEM, 2016). Levels of S in the DDGS can vary from 0.30% - 1.70% depending on the ethanol plant (Bothast and Schlicher, 2005). Although the primary concern of a S toxicity is polioencephalomalacia (**PEM**), the much more common problem is its effect on Selenium and copper utilization and absorption (NASEM, 2016). Copper status can be challenged when interactions between Cu, Mo, and S occur in the rumen and cause the formation of S-Mo compounds called thiomolybdates. Thiomolybdates can be present in multiple forms, dithiomolybdates, trithiomolybdates, and tetrathiomolybdates, which scavenge Cu and depreciate the available concentration for biochemical processes (Suttle, 1991).

Use in the Feedlot

As previously discussed, DGS is an excellent source of energy and protein in cattle diets. When fed at levels to supply adequate protein and energy, replacing a portion of corn with DGS has resulted in equal, and sometimes greater performance of feedlot cattle (Klopfenstein et al.,

2008). Feeding of WDGS at varying levels within the diet has resulted in a wide variety of performance results. Most of the studies are in consensus that feeding WDGS to finishing cattle increases both ADG and feed efficiency (G:F) when compared to traditional corn-based diets. However, optimal inclusion rates differ slightly between studies. For instance, Larson et al. (1993) reported a linear increase in both ADG and G:F at up to 40% inclusion of WDGS on a DM basis. However, Vander Pol et al. (2008) reported a quadratic effect of both ADG and feed efficiency with optimal feed efficiency reported at 40% WDGS inclusion, and optimal gains were found when WDGS were included at a rate of only 30%.

To provide a rule of thumb for WDGS addition to finishing diets, Klopfenstein et al. (2008) performed a meta-analysis looking at multiple studies in which WDGS were fed to finishing cattle. In this review, it was reported that ADG and feed efficiency increased linearly with respect to the amount of WDGS added to the diet; on the other hand, DMI of finishing animals decreased linearly with the level of WDGS fed. However, cattle fed 10, 20, and 30% WDGS had greater DMI when compared with control diets.

Carcass characteristics have been influenced when WDGS were fed at levels up to 40% in a study by Larson et al. (1993) which reported a linear increase in hot carcass weight (HCW), yield grade, and marbling score. Similarly, Vander Pol et al. (2008) reported a linear increase in HCW but reported no differences in longissimus muscle (LM) area or marbling score. It was concluded by Klopfenstein et al. (2008) that linear increases in yield grade will be experienced with increasing levels of WDGS in the diets, while marbling scores will be optimal at 30% inclusion of WDGS, with cattle fed 50% WDGS having lower marbling scores than control fed steers. To summarize, feeding cattle, any level of DGS will likely result in increased yield grades.

However, reduction in marbling score and quality grade is apparent in cattle fed DGS at greater than 20-30% of the diet DM.

Use as a Supplement

Klopfenstein (1996) reviewed supplementation studies for growing cattle and found that UIP supplementation increased BW and ADG by meeting a metabolizable protein deficiency and supplementing increased energy. Body weight of cattle is a significant consideration when trying to determine how DDGS supplementation will affect cattle performance (Griffin et al., 2012). Lighter weight and younger cattle have a greater requirement for metabolizable protein per kilogram of BW. Thus, when supplementing DDGS, which is between 15 to 20% UIP (MacDonald et al., 2007), to growing cattle, it is incredibly useful (Griffin et al., 2012). When considering the level of DDGS supplementation in forage-based systems, fat intake must be considered. Dietary fat levels $\geq 6\%$ is said to be the threshold at which fiber digestion is inhibited and performance reduced (Hess et al., 2008). Griffin et al. (2012) noted that 6% dietary fat would be achieved when intake of DDGS reached 3.4 kg/d (1.2% of BW) and forage intake was 4.1 kg/d. This assumes forage to contain 1.25% fat on a DM basis and DDGS to contain 12.5% fat on a DM basis (Griffin et al., 2012).

Supplementation with DDGS has been effective in increasing ADG of grazing cattle. In growing rations Loy et al. (2008) showed that DDGS contains 118 to 130% of the energy value of corn. In a meta-analysis of DDGS supplementation, Griffin et al. (2012) documented additional gain of 0.11 kg/d up to 0.36 kg/d from supplementation of 0.2% BW and 1.2% BW DDGS. However, the efficiency of supplemental feeding has been varied depending on the base forage used in the supplementation regime. The additional gain from supplementation of animals grazing cool-season grasses and supplemented with DDGS ranged from a minimum of 0.20 kg/d

to a maximum of 0.58 kg/d (Watson et al., 2012). Steers and heifers grazing novel endophyte tall fescue and supplemented with 0.39% BW DDGS daily had an ADG of 0.20 kg/d. While increasing supplementation to 0.56% BW and supplementing on alternate days resulted in an ADG of 0.24 kg/d (Beck et al., 2014).

BULL DEVELOPMENT

A significant portion of the reproductive failures in cow-calf enterprises are due to infertility of the herd bull. Breeding bulls across the United States are commonly fed high-energy diets by seedstock producers prior to sale, generally in the form of grain. Additionally, after bulls are sold most bull buyers transition their newly purchased bulls to a lower energy, forage-based diet. The impacts of this dramatic dietary changes are not very well understood.

Puberty

Age at puberty is an important determinant of beef production efficiency. The ability to breed animals at younger ages reduces generation intervals and increases genetic gains. The use of yearling bulls as primary breeders is common throughout North America. To study the effects of nutrition on the sexual development of the bovine, it is essential to be aware of the definition for the time of onset of puberty and related physiological events. In females, a precise mechanism, time of first ovulation, has been used to indicate when the time of puberty is reached (Schillo et al., 1992). However, one should keep in mind that the attainment of puberty is a gradual process and that puberty occurs earlier than does sexual maturity or normal reproductive capacity (Moran et al., 1989).

In the bull, puberty has broadly been defined as the "phase of bodily development during which the gonad secretes hormones in amounts sufficient to cause accelerated growth of the genital organs and the appearance of secondary sex characteristics" (Donovan and Ten Bosch,

1965). The age of puberty in bulls differs significantly in the literature based on breed and applied experimental treatments. Reports generally cite the age of puberty at around ten months of age. More specifically, puberty has been reported at 295 d for Angus, 326 d for Herefords, 296 d for Angus x Hereford (Lunstra and Echternkamp, 1982), and 305 days for Angus x Charolais bulls (Brito et al., 2007). The previous studies all utilized the defined literature definition of puberty established by Wolf et al. (1965) as the age when the bull can ejaculate 50 million sperm with at least 10% of the cells having motility. The efficiency of spermatogenesis and consequently sperm production and semen quality must improve considerably after puberty before bulls can be used for breeding purposes, a process that requires a few months (Lunstra and Echternkamp, 1982). Bulls that attain puberty earlier will have a better chance to be selected as breeding bulls than bulls with delayed puberty.

Influence of Nutrition and Age on the Onset of Puberty

Nutritional manipulation aimed at increasing ruminal propionate formation can result in a decrease of both age and weight at puberty in heifers (McCartor et al., 1979) and bulls (Neuendorff et al., 1985). This LH rise early in life is considered essential to the attainment of puberty (Brito et al., 2007b). Increased LH pulsatility is crucial for the attainment of puberty in both bulls and heifers (Brito et al., 2007a). The overall plane of nutrition has a dominant influence on ADG and the growth of animals and therefore plays a vital role in the age at which animals will reach a specific critical bodyweight. In well-fed bulls, the rate of ADG up to the onset of puberty did not relate to age at puberty (Barber and Almquist, 1975). However, severe undernutrition delays the onset of puberty in heifers (Short and Bellows, 1971) even in animals that have exceeded the so-called critical pubertal bodyweight (Imakawa et al., 1987).

Endocrinology in Bulls

As GnRH is produced in regular pulses from the mature hypothalamus, the anterior pituitary responds by producing and releasing FSH and LH (Senger, 2003). An important differentiation between FSH and LH secretion in bulls centers on the mechanism of secretion. It is known in bulls and heifers that LH is secreted in a pulsatile manner from the pituitary in response to pulsatile release of GnRH from the hypothalamus (Brito et al., 2007c). The primary target tissue for LH is the testicular Leydig cells, which it targets to stimulate the production of testosterone (Senger, 2003). Once produced, the presence of testosterone in the systemic circulation regulates further production of GnRH and LH via negative feedback mechanisms. Follicle stimulating hormone, another glycoprotein, acts on the Sertoli cells to stimulate spermatogenesis and Sertoli cell function. It is also responsible for the activation of the enzyme, aromatase, in the conversion of testosterone to estradiol, taking place in the Sertoli cells (Senger, 2003). Following conversion to estradiol, testosterone crosses the basement membrane into circulation. When testosterone and estradiol are present in systemic circulation, the hypothalamus responds by causing a slowdown in the release of GnRH, which then results in a reduced output of FSH and LH. Inhibin, another glycoprotein within the Sertoli cells, negatively feeds back on the anterior pituitary to selectively suppress FSH (Senger, 2003). Testosterone concentrations will increase steadily once Leydig cells can produce the hormone until six months of age in bulls, and concentration will remain similar from this age through maturity (Miyamoto et al., 1989).

The mature Sertoli cells will produce inhibin upon binding to FSH (de Kretser and Robertson, 1989). In adult males, the concentration of circulating inhibin correlates to the number of Sertoli cells within the testes, and it has therefore been proposed to utilize inhibin

concentrations as an estimation of the number of Sertoli cells when invasive means to collect data are infeasible (Sharpe et al., 1999). Furthermore, Johnson et al. (1984) suggested further predictive power of using inhibin to approximate sperm production because the number of Sertoli cells correlates to mature sperm output in bulls, and the number of Sertoli cells dictates systemic inhibin concentrations. Early Sertoli cells express SRY gene, which is involved in the formation of the testis cord via the downstream induction of anti-müllerian hormone (AMH) production (Barrionuevo et al., 2011). Identifying indicators of proper sperm development is essential. Novel genes *centrobin*, *Hook1*, and *RIM-BP3*, which encode BP3 proteins, play an essential role in the assembly of the head-tail coupling apparatus in animal models (Zhou et al., 2009).

Spermatogenesis

This review of spermatogenesis has been summarized from Senger (2003). Spermatogenesis occurs in the seminiferous tubules of the testes in three main phases: spermatocytogenesis, meiosis, and spermiogenesis. The spermatocytogenesis phase consists of mitotic cell division, proliferation, and maintenance of the spermatogonia and takes place in the basal compartment. Spermatogonia go through many mitotic divisions, the last of which results in primary spermatocytes. The duration of spermatocytogenesis is about 21 d in the bull.

The second stage is meiosis, taking place in the adluminal compartment of the seminiferous tubule, during which the chromosomes are reduced by half in the gamete, moving from the diploid to haploid state. Primary spermatocytes then undergo meiosis I and become secondary spermatocytes, subsequently undergoing meiosis II, resulting in round spermatids. The lifespan of spermatocytes is short-lived (1-2 d).

The third phase of spermatogenesis is spermiogenesis, otherwise known as the differentiation phase and is composed of four sub-phases: the 1) Golgi phase, 2) cap phase, 3) acrosomal phase, and 3) maturation phase. Spermiogenesis takes place in the adluminal compartment. The round spermatids mature into elongated spermatids, and the DNA becomes highly condensed, followed by the formation of the acrosome during the Golgi phase. In the cap phase, the flagellum starts to form, while the acrosomic vesicle spreads over the nucleus, letting the cells become potentially motile. During the acrosomal phase, the spermatid nucleus and cytoplasm elongate, and the acrosome then covers the majority of the anterior nucleus. In the last phase, maturation, the mitochondria are assembled around the flagellum, forming the completed flagellum. The elongated spermatids move closer to the lumen of the seminiferous tubule during this third phase of spermatogenesis.

In the seminiferous epithelium cycle spermatogonia convert to spermatozoa by completing a series of cellular stages along the seminiferous tubule. It is referred to as cycle because it repeats, and the time required for this progression is the duration of the cycle and is unique to each species. In bulls, the length of the seminiferous epithelium cycle is 13.5 days (Senger, 2003). The three phases of spermatogenesis take approximately 21, 23, and 17 d respectively in the bull; thus, the total duration of spermatogenesis is 61 days, which is 4.5 times the duration of the cycle of the seminiferous epithelium (Staub and Johnson, 2018).

Breeding Soundness Exam

Bull breeding soundness is one of the most economically important traits for cow-calf producers (Trenkle and Willham, 1977). Thus, breeding soundness evaluations attempt to measure a bull's potential to achieve satisfactory conception rates. The purpose of a breeding soundness evaluation is to provide information on a bull's ability to satisfactorily meet the

breeding soundness criteria on the day of evaluation (Kennedy et al., 2002). However, it must be emphasized that the breeding soundness evaluation is not a scientific determination, but rather a judgment or opinion based on the results acquired on a specific day. Standards for the current breeding soundness evaluation guidelines are based on parameters of known correlations with field fertility of breeding bulls or things known fully preclude the bull from successfully mounting and ejaculating. The parameters used for breeding soundness examinations include minimum threshold values for scrotal circumference, percentiles of motile sperm and morphologically normal and clinical parameters (e.g., genetic abnormality, physical limitations such as orthopedic conditions, penile and scrotum pathology, and seminal vesiculitis). Therefore, these guidelines are at present the most suitable means to estimate the ability of the bull to get cows pregnant (Kennedy et al., 2002). The current standards for breeding soundness evaluations BSE state that a “failed” status is the result of semen samples exhibiting <30% motility, <70% normal morphology, or an SC lower than recommended for their respective age range (Koziol and Armstrong, 2018).

Research conducted by Rocha et al. (1996) concluded that bull semen obtained by electro-ejaculation differs significantly from that collected from the same bulls using an artificial vagina. However, there is still a positive correlation ($r = 0.78$) between sperm cells in the ejaculate (collected by electro-ejaculation) and daily sperm production. This positive correlation ($r = 0.78$) indicates that electro-ejaculation is a useful indicator of daily sperm production in developing bulls. To achieve repeatable and reliable data, the electro-ejaculation technique should be carried out by an experienced operator that performs it in a consistent manner (Rocha et al., 1996). Additionally, it was shown that young beef bulls going through puberty exhibit low sperm motility and a high percentage of abnormal spermatozoa (Chenoweth et al., 1996).

However, semen traits were shown to improve with age, from 12 to 16 months in *Bos taurus* bulls (Chenoweth et al., 1996).

Dietary Bull Development Strategies

Nutrition during the growth and development stage is the first critical component of bull reproductive success. Because many producers utilize yearling bulls, it is essential that the nutritional plane of the animal allows for the attainment of puberty by 12 to 14 months of age. To achieve this physiological goal, bulls are typically fed a high energy ration intended to attain 0.68 - 0.91 kg ADG from weaning until about a year of age (Pruitt and Corah, 1985). This high energy ration goes beyond energy levels required for maintenance and allows the body to utilize additional energy for growth and reproduction. Yet, this type of diet is only fed until the bull reaches 12 months of age, which usually coincides with a production sale.

Following a production sale, the concentrate component of the ration is reduced. Because bulls are typically managed in a matter to push gain and achieve physical characteristics appealing to buyers at a sale, they have the potential to be over-conditioned upon purchase. This period when the bull is gradually adapted to a lower energy feed, allows the bull to shed excess fat and reach an optimum body condition for the breeding season. Mature bulls also have specific nutrient requirements to maintain optimum reproductive performance. Over- conditioned or under-conditioned bulls should be evaluated and reconditioned 1 to 2 months before the breeding season (Pruitt and Corah, 1985).

High-Energy Diets and Male Reproduction

Martin et al. (1994) and Hötzel et al. (1998) observed increases in ram scrotal circumference when they were fed high protein and energy rations for increased rates of gain. Van Emon et al. (2013) found no differences in scrotal circumference when feeding increasing

levels of DDGS in the ration. Similarly, in bulls, Coulter and Kozub (1984) fed increasing energy in their diets and had a resulting increase in testicular size. Although Van Emon et al. (2013) did not observe increases in SC, testosterone concentrations did increase as the trial continued, as the rams matured. These two values are normally correlated to one another. Therefore, it is unusual that Van Emon et al. (2013) observed an increase in one and not the other, as the increase in testosterone was likely due to the rams maturing throughout the progression of the trial; therefore scrotal circumferences would likely increase as well. Martin et al. (1994) and Hötzel et al. (1998) reported that rams fed diets containing high and intermediate energy and protein had increased testosterone concentrations compared to rams fed diets containing low energy and protein.

However, several reports have shown that high energy diets can have deleterious effects on semen morphology and motility (Coulter and Kozub, 1984; Pruitt and Corah, 1985; Coulter et al., 1997). These effects may be temporary and are thought to be the result of impaired thermoregulation of the testes due to fat deposition in the scrotal region (Coulter and Kozub, 1984). This extra fat in the scrotum neck may cause the testis to be insulated. Increasing the temperature of the testis has detrimental effects on sperm production and the quality of semen (Senger, 2003). More recently, several experiments have provided insight as to how high-energy diets in Holstein bulls positively affect the hypothalamus-pituitary-gonadal axis. Brito et al. (2007b) fed bulls high energy diets beginning at 10 weeks of age and reported larger testes, greater SC, and greater daily sperm production compared to bulls fed control rations.

Coulter et al. (1997) reported bulls fed a 100% forage ration that was a medium energy diet, had more morphologically normal spermatozoa (68.8 vs. 62.5%) and a higher proportion of progressively motile spermatozoa (53.4 vs. 44.5%) than bulls fed a high energy diet comprised

of 80% grain and 20% forage. Morphology of the spermatozoa was not measured in the trial by Van Emon et al. (2013). However, spermatozoa concentrations decreased linearly as DDGS concentrations in the diets increased. In conclusion, Van Emon et al. (2013) reported a negative effect on male reproductive traits when ram lambs were fed increasing amounts of DDGS in the ration and is the first trial of its kind to do so. However in a follow-up study, Crane et al. (2018) noted no treatment differences in any sperm morphology when feeding increasing levels of DDGS, with the highest inclusion being 45% DDGS and the total diet S being 0.4%. Based on the lack of major morphological defects, the authors concluded that S content of the diet was not leading to mineral deficiencies *in vivo* (Crane et al., 2018). In summary, Crane et al. (2018) stated that there were no negative effects on lamb reproductive traits due to increasing DDGS in the diet. However, neither of these studies evaluated the long-term impacts of feeding DDGS to developing animals. Yet, minimal research has been focused in this area, and DDGS possesses multiple factors that should be considered, such as CP, crude fat, and S.

Previous research on human sperm suggests that semen samples with low sperm concentrations, high incidence of abnormal sperm morphology, and diminished fertility had higher sperm creatine phosphokinase (**CK**) activity (Huszar and Vigue, 1993). Higher CK activity was related to an increased content of CK and other proteins in the sperm resulting in those sperm heads being significantly larger and rounder, with increased morphological irregularities and increased cytoplasm believed to be due to failure of spermatogenesis (Huszar and Vigue, 1993). They concluded that higher CK activity results in cellular immaturity and a failure to complete spermatogenesis. Potentially the increased CP in the trial by Van Emon et al. (2013), as a result of increasing DDGS concentration in the diet, contributes to the negative

effects on sperm quality. Additional research is needed to investigate why aspects of male reproduction are being affected.

Trace Minerals and Male Reproduction

In addition to meeting the energy requirements of the developing beef bull, trace mineral requirements are also important. Although all trace minerals are important, Cu, Mn, and Zn are the three that will be covered in this review for their known impact on male reproductive performance. In developing bull rations, 3-10 mg Cu/kg diet is required (NASEM, 2016). Meeting the Cu requirements of the developing bull is necessary to ensure proper bone development, cardiac function, and spermatogenesis (NASEM, 2016). As previously mentioned, Cu status can be challenged when interactions between Cu, Mo, and S occur in the rumen and cause the formation of S-Mo compounds called thiomolybdates. These compounds scavenge Cu and depreciate the available concentration for biochemical processes (Suttle, 1991).

Adequate supplementation of Mn is also necessary. Breeding cattle requirements are much greater than feedlot cattle, at 40 mg Mn/kg of diet (NASEM, 2016). The requirements for Mn can also be altered based on interactions with other minerals, as Ca, P, and Fe have all been shown to antagonize Mn and thus could lead to Mn deficiency via indirect effects of these minerals' interactions (Hidiroglou and Knipfel, 1981). The role Mn plays in reproductive disorders is not fully understood. Research has hypothesized that Mn may play a key role in both cholesterol and steroid synthesis (Davis et al., 1990).

Zinc is required at 30 mg Zn/kg diet (NASEM, 2016). To induce a deficiency, Miller and Miller (1962) fed male Holstein calves low zinc diets with no zinc supplementation and deemed it necessary for effective feed conversion, foot soundness, and testicular growth. Proper Zn concentrations are also necessary for the production and secretion of testosterone (Martin et al.,

1994). In addition to testosterone production, Zn maintains many of the mechanical properties of sperm (Apgar, 1985). Overall sperm motility is also regulated by Zn, as Zn is closely involved with the mechanism that provides energy for progressive sperm movement (Hidiroglou and Knipfel, 1984).

Zinc supplementation can cause many favorable reproductive responses. In a study performed on crossbred 2 yr old bulls, Zn supplementation above the animal's daily requirement increased ejaculate volume, sperm concentration, and the number of sperm per ejaculate. Sperm of supplemented bulls had increased motility, a greater percentage of intact acrosomes, and a greater percentage of live sperm as compared with control bulls (Kumar et al., 2006).

Bull Foot Health

Economic losses caused by foot health problems can be divided into the categories of premature culling, loss of productivity, which includes loss of weight (especially in the winter) and loss of fertility, as well as the costs of medical treatment by a veterinarian (Greenough et al., 1981). Lameness in bulls can cause a rapid reduction in fertility. Considering most breeding seasons are 43-60 d long, and since breeding pastures are not always under constant surveillance, severe lameness in a bull can seriously affect productivity. A study by Barth and Waldner (2002) examined the effect of bull lameness on semen quality of bulls ranging from one to nine years of age. They concluded that lameness was a crucial factor affecting semen quality because only four of 17 lame bulls had satisfactory semen quality. This is expected according to Barth and Bowman (1994) since pain in the feet and legs reduces the endocrine secretion of LH and testosterone, necessary for the production of normal spermatozoa. Diet type and energy density have been known to impact the hoof quality and foot score of cattle (Lean et al., 2013). Yet, most work in this area has been on the relationship between acidosis and laminitis. Very little work

has been done to evaluate how different diet types affect the hoof structure in the absence of acidosis.

CONCLUSIONS

Proper development of beef heifers and bulls can have significant and long-term effects on their lifetime profitability. Utilizing the most cost-effective feedstuffs, such as native forages or byproducts, can lessen the financial burden of development. Even though heifer development has had extensive documentation, it is extremely variable and dependent on the environment. Significant nutritional consideration is needed during the reproductive milestones of the beef animal. Most literature has focused on long-term dietary strategies to improve the reproductive success of beef cattle.

In addition, the potential economic strain that a reproductive failure by a breeding bull can cause a beef cattle enterprise is substantial. As a result, seedstock producers are highly sensitive to utilizing by-products in growing bull diets. Yet, the impact of including byproducts in growing bull diets is unknown. Therefore, research in this dissertation will evaluate heifer development strategies, corn supplementation to cows grazing lush spring pasture, and the impact of including DGS in growing bull diets.

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CHAPTER 2

EFFECTS OF BEEF HEIFER MANAGEMENT SYSTEM ON GROWTH AND REPRODUCTIVE PERFORMANCE

ABSTRACT

This study evaluated the effect of heifer development system on body weight (BW), body condition score (BCS), fescue toxicosis symptoms, reproductive performance, and subsequent calf growth of fall-calving beef heifers. Angus $\times$ Simmental heifers [$n = 399$; 240 ± 20.0 kg initial BW; age = 252 ± 20 d] were stratified by BW and BCS and assigned to 1 of 12 groups in each of the 2 production years. The study utilized a stratified randomized design. Pens were randomly assigned to 4 treatments: drylot (**DL**) development (fed ad-libitum diet consisting of 90% hay and 10% DDGS on a dry matter basis), grazing endophyte-infected fescue supplemented daily (2.3 kg as-fed/heifer/d; 50:50 mix of soybean hulls and DDGS; **E+/S**), grazing endophyte-infected fescue and supplemented from the midpoint of treatment period until breeding (4.5 kg as-fed/heifer/d; 50:50 mix of soybean hulls and DDGS; **E+/LS**), and grazing novel endophyte-infected fescue with no supplementation (**NE+/NS**). Treatments DL and E+/S represent traditional Midwestern development strategies in contrast to the alternative strategies in E+/LS and NE+/NS. Treatments ceased on d 168 [time of artificial insemination (AI)] and heifers were commingled and managed as a group through second breeding season. Heifers in DL had the greatest ($P \leq 0.05$) BW and BCS from d 28 until d 254. Furthermore, E+/S heifers had a greater ($P \leq 0.05$) BW and BCS than both E+/LS and NE+/NS from d 28 until d 168. On d 56 and 84, E+/LS heifers had lower ($P \leq 0.05$) BW and BCS compared to NE+/NS, but on d 140 they switched and remained at a greater ($P \leq 0.05$) BW and BCS compared to NE+/NS through the first breeding season. Drylot heifers had the greatest ($P \leq 0.05$) cyclicity, percentage of

mature BW at AI (66.6%) and had greater ($P \leq 0.05$) AI and overall pregnancy rates compared to E+/LS and NE+/NS females. The E+/S (55%) and E+/LS (53.7%) heifers were developed to a greater ($P < 0.01$) % of mature BW than NE+/NS (49.3%). A greater ($P \leq 0.02$) percentage of DL and E+/S heifers were pregnant at the end of the first breeding season (89.3 and 85.1%; respectively) compared to NE+/NS females (61.5%). In summary, DL heifers had the greatest BW and BCS at AI, percentage cycling, and AI pregnancy rate. However, this strategy did not result in differing overall pregnancy rates between DL, E+/S, and E+/LS and there were no differences in cow milk production, rebreeding reproductive performance, and calf performance between all treatments. This would suggest that DL, E+/S, E+/LS systems are all viable strategies for developing fall-born replacement beef heifers in the Midwest.

Key words: dry lot, heifer development, reproduction, fescue

INTRODUCTION

To maintain herd size and productivity, proper selection and retention of replacement beef females drives the sustainability of an operation. In the Midwest, the lack of grazable acres is one of the major constraints on expanding the cowherd (NASEM, 2016). Land price, feed availability, equipment sharing with row crop enterprise, and manure utilization has allowed the Midwest cattlemen to explore year round management of beef females in the drylot. However, recent studies have compared drylot heifer development with lower-quality forage grazing systems (corn residue or native winter range) and noted that drylot developed heifers had reduced efficiency and in some cases reduced longevity in the cowherd (Funston and Deutscher, 2004; Roberts et al., 2009; Mulliniks et al., 2013; Summers et al., 2014).

Considering the majority of this work was conducted in extensive rangelands in the western United States, little is known about how these systems translate to the lower Midwest

where cow-calf production relies on tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort) systems (Hoveland, 1993). Tall fescue is a cool-season grass that is adaptable, easy to establish, and persistent under adverse conditions (Gunter and Beck, 2004; Kallenbach, 2015).

Unfortunately, most tall fescue contains an endophyte that produces ergot alkaloids, which can cause fescue toxicosis (Gunter and Beck, 2004). Cattle grazing toxic endophyte-infected tall fescue (E+) can suffer fescue toxicosis, which is characterized by elevated body temperature, reduced feed intake, and decreased ADG (Schmidt and Osborn, 1993; Paterson et al., 1995; Strickland et al., 2011; Aiken et al., 2013). This suppressed growth and reduced follicle numbers and preovulatory follicle diameter could be detrimental to reproductive processes including pregnancy rates (Schmidt and Osborn, 1993; Paterson et al., 1995; Burke et al., 2001; Schuenemann et al., 2005). Utilizing supplementation as a strategy to alleviate fescue toxicosis has been successful at improving performance (Aiken et al., 2008; Carter et al., 2010). Whereas utilizing strategic compensatory gain prior to the breeding season has been successful at reducing labor without sacrificing reproductive performance (Freetly et al., 2001; Grings et al., 2007). However, this strategy has not been evaluated in an E+ grazing system.

The adverse effects of cattle grazing E+ led to the development of non-toxic novel endophyte-infected tall fescue (NE+; Bouton et al., 2002). Research has demonstrated cattle grazing NE+ do not exhibit signs of fescue toxicosis and show improved performance compared to cattle grazing E+ (Parish et al., 2003). Drewnoski et al. (2009) demonstrated replacement heifers grazing NE+ during spring growth had increased ADG and reduced prolactin compared to heifers grazing E+. However, no work has been done to investigate allowing heifers to graze NE+ with no supplementation or utilizing strategic compensatory gain when heifers graze E+ as strategies to develop fall-calving beef heifers.

The objectives of this experiment were to compare the growth and reproductive performance of replacement fall-calving beef heifers developed in two common Midwest systems (drylot developed and grazing E+ with daily supplementation) with two alternative strategies (grazing E+ with daily supplementation from the midpoint of treatment period until breeding, or grazing NE+). Authors hypothesized that heifer growth performance would be greatest for drylot developed heifers but would not differ between grazing treatments. Finally, it was hypothesized that reproductive performance and calf growth would not differ between the treatments.

MATERIALS AND METHODS

All experimental procedures were approved by the Institutional Animal Care and Use Committee of the University of Illinois (IACUC #17108) and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animal in Agricultural Research and Teaching (FASS, 2010).

Animals and Experimental Design

Three hundred and ninety-nine fall-born, Angus × Simmental heifers [240 ± 20.0 kg initial body weight (BW); age = 252 ± 20 d; mean $\pm$ standard deviation] from two production years were utilized in a stratified randomized design to identify the most successful management strategy to develop fall-calving beef heifers. Heifers were housed at the Dixon Springs Agricultural Center in Simpson, IL. In both years, heifers were weaned in mid-March and grazed a common pasture with supplementation of dried distillers grains with solubles [DDGS; 2.3 kg as-fed/heifer/d; 31.5% neutral detergent fiber (NDF), 10.2% acid detergent fiber (ADF), 10.7% fat, and 28.2% crude protein (CP)] until the initiation of treatments (late May). Heifers were stratified by body weight (BW) and body condition score (BCS) and assigned 1 of 12

replications. Treatments were randomly assigned to each replicate, resulting in 3 replications per treatment within each year. Treatments included: 1) drylot (**DL**) developed (ad-lib fed a diet consisting of 90% hay and 10% DDGS; 56% NDF, 36% ADF, 0.7% fat, and 12.4% CP); 2) grazing endophyte-infected fescue supplemented daily with a 50:50 mix of soybean hulls and DDGS (2.3 kg as-fed/heifer/d; **E+/S**); 3) grazing endophyte-infected fescue and transitioned to daily supplementation from the midpoint of treatment period until breeding with a 50:50 mix of soybean hulls and DDGS (4.5 kg as-fed/heifer/d; **E+/LS**); or 4) grazing novel endophyte-infected fescue (**NE+/NS**). Composition of the supplement provided to E+/S and E+/LS was 47% NDF, 27% ADF, 5.6% fat, and 19.2% CP. Supplementation for the E+/LS heifers began 80 d after the initiation of the trial at a rate of 2.3 kg as-fed/heifer/d, then was increased to 3.4 kg as-fed/heifer/d on d 86, followed by an increase to 4.5 kg as-fed/heifer/d on d 93. This resulted in E+/S and E+/LS heifers receiving the same amount of supplement for the treatment period. Cattle on E+/S and E+/LS rotationally grazed endophyte-infected tall fescue ('Kentucky-31'; Year 1: 67% infected; total ergot alkaloid concentration: September: 2610 µg/L; Year 2: 86.5% infected; total ergot alkaloid concentration: June: 620 µg/L; July 670 µg/L; September: 1812 µg/L; October: 1715 µg/L) and red clover pastures (*Tri-folium pretense*) pastures. Heifers on NE+/NS treatment rotationally grazed novel endophyte-infected tall fescue ['Jesup' (MaxQ; Madison, GA); Year 1: 63% infected; total ergot alkaloid concentration: September: 0 µg/L; Year 2: 68% infected; total ergot alkaloid concentration: June: 0 µg/L; July 215 µg/L; September: 367 µg/L; October: 256 µg/L] and red clover pastures (*Tri-folium pretense*) pastures. Cattle had free-choice access to a mineral supplement (Southern FS Services, Marion, IL; 12% Ca, 9.5% P, 17% salt, 5.9% Mg, 1.15% K, 24 mg/kg Co, 31 mg/kg I, 3,000 mg/kg Fe, 1,400

mg/kg Cu, 2,000 mg/kg Mn, 26.4 mg/kg Se, 4,000 mg/kg Zn, 550,000 IU/kg vitamin A, 3,300 IU/kg vitamin D, 220 IU/kg Vitamin E, and 6,600 mg/kg chlortetracycline).

Pasture size was 2.05 ± 0.15 ha, with an average of 7.8 heifers/ha. Groups were rotated every 14 d. Available forage was quantified as heifers went in the pastures by using a falling plate meter (Jenquip, Fielding, New Zealand) to collect 12 random measurements. A minimum of 513 kg DM/ha was available to all groups throughout the study, with 950 kg DM/ha of forage available on average. One heifer from the DL treatment was removed at 303 ± 20 d of age for a back injury. Three heifers (1 E+/S and 2 E+/LS) were removed at 389 ± 20 d of age for poor BCS. An additional three heifers from the DL treatment were removed at 418 ± 20 d of age for rectal prolapse.

Immediately following artificial insemination (AI), treatments ended and heifers were combined into 2 groups with an equal representation of each treatment and placed on pasture. For year 1, from 11/17/17 until 12/21/17 they were fed DDGS (2.72 kg as-fed/heifer/d; ADF 8.40%, NDF 29.4%, CP 26.80%, Fat 11.51%) and free choice mixed grass hay (53.5% NDF, 31.4% ADF, and 12.09% CP). On 12/22/17 cattle were provided a total mixed ration consisting of corn silage, mixed grass hay, DDGS, and soybean hull pellets (12.2 kg DM/heifer/d; 36% NDF, 19% ADF, 4.7% fat, and 15.9% CP). Cattle were then transitioned on 1/29/18 to a mixed grass hay, corn, DDGS, and soybean hull pellets (7.1 kg DM/heifer/d; 33% NDF, 17% ADF, 5.1% fat, and 18.4% CP) until 4/11/18. From 4/11/18 until 12/11/18 heifers grazed endophyte-infected fescue (*Festuca arundinacea*) and red clover pastures (*Tri-folium pretense*; spring = 54% NDF, 30% ADF, and 12.7% CP; summer = 56% NDF, 28% ADF, and 12.9% CP, fall = 52% NDF, 27% ADF, and 15.5% CP). For year 2, From 11/15/18 until 2/19/19 they were fed DDGS (3.63 kg as-fed/heifer/d; 33% NDF, 12% ADF, 10.3% fat, and 29.4% CP) and free choice

mixed grass hay (63% NDF, 36% ADF, 1.3% fat, and 9.4% CP). On 2/19/19, heifers were transitioned to corn silage diet (8.3 kg DM/heifer/d; 34% NDF, 17% ADF, 3.1% fat, and 8.1% CP) and DDGS (3.63 kg as-fed/heifer/d; 33% NDF, 12% ADF, 10.3% fat, and 29.4% CP) until 3/26/19. On 3/27/19, they were fed DDGS (1.81 kg as-fed/heifer/d; 37% NDF, 11% ADF, 10.8% fat, and 26.8% CP) and free choice mixed grass hay. From 5/3/19 until 12/11/19 heifers grazed endophyte-infected fescue (*Festuca arundinacea*) and red clover pastures (*Tri-folium pretense*; spring = 60% NDF, 30% ADF, and 14.5% CP; summer = 60% NDF, 31% ADF, and 10.0% CP, fall = 59% NDF, 30% ADF, and 11.3% CP). Pasture groups were rotated under the discretion of trained University of Illinois research personnel based on visual appraisal of forage availability.

As per Dixon Springs Agriculture Center cowherd's annual vaccination schedule, pregnant heifers received 2 mL Leptoform 5 (Zoetis Inc., Parsippany, NJ) via intramuscular injection, and Ivermax (Bayer, Pittsburgh, PA) pour on at 1 mL/9.98 kg BW topically. In June, heifers received 1 mL anaplasmosis vaccine (University Products L.L.C., Baton Rouge, LA), 2 mL autogenous *Moraxella bovis* / *Moraxella bovoculi* (Addison Biological Laboratory Inc., Fayette, MO), 2 mL Leptoform 5 (Zoetis Inc., Parsippany, NJ), and 2 Corathon fly tags (Bayer, Pittsburgh, PA). In August, heifers received 5 mL Bovishield Gold FP5VL5HB (Zoetis Inc. Parsippany, NJ), 2 mL Scourguard 4KC (Zoetis Inc., Parsippany, NJ), 5 mL Covexin 8 (Merck Animal Health, Madison, NJ), and 7 mL Mu-Se (Merck Animal Health, Madison, NJ).

Once heifers calved, their calves received 1 mL vitamin AD (Sparhawk Laboratories, Lenexa, KS), 1 mL Bo-Se (Merck Animal Health, Madison, NJ), 2 mL autogenous *Moraxella bovis* / *Moraxella bovoculi* (Addison Biological Laboratory Inc., Fayette, MO), and 40 mL Bovisera (Colorado Serum Company, Denver, CO) all administered subcutaneously. All bull calves were castrated at birth. Calves were early-weaned (90 ± 14 d of age).

Sample Collection and Analytical Procedures

Heifer BW and BCS [emaciated = 1; obese = 9; as described by (Wagner et al., 1988)] were collected at trial initiation (221 ± 22 d of age), d 28, 56, 84, 112, 148, 168, 201, 253, and at rebreeding AI. Heifer percent of mature BW at AI was based on herd average mature cow BW (567 kg). Hair coat scores (HCS; 1 to 5, in which 1 = slick and 5 = unshed) were also recorded at trial initiation and d 28, 56, 84, and 112 by the same farm technician. Sixty heifers (15 per treatment) per year that were most similar to average initial BW and BCS were selected for additional observation. Respiration rates were collected from these 60 heifers at d 1, 29, 57, 85, and 113 of the trial. This is 1 d following other measures in order to avoid the influence of animal handling on respiration rates. Milk production was estimated via the weigh-suckle-weigh technique (Boggs et al., 1980) at 84 ± 13.7 d postpartum using a representative subset of cows for each replicate ($n = 96$). Cows and calves were separated at 1200 h, allowed to nurse at 1930 h, and then were separated overnight. At 0730 h the next day, an empty calf BW was recorded, calves were allowed to nurse, and a full calf BW was recorded. The BW difference between full and empty calf BW was assumed to be 12 h milk production. Estimate of 12 h milk production was multiplied by 2 to calculate 24 h milk production. Calf BW was recorded at birth and at early-weaning (84 ± 13.7 d of age).

Forage samples were collected by randomly clipping approximately 5 cm from the ground, from 12 different locations, within each pasture. At the same time, fescue stems were collected throughout each field by collecting the bottom 6 inches closest to the ground and were frozen at -20°C . Stems were composited by treatment into 4 time periods. Feed and forage samples were collected every two weeks throughout the experiment. Forage and feed samples were dried at 55°C for a minimum of 3 d, ground through a 1 mm screen using a Wiley mill

(Arthur H. Thomas, Philadelphia, PA). Forage samples were composited by group into 4 time periods and feed samples were composited for the entire experiment. Ground feed and forage were analyzed for NDF and ADF using an Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY) as well as CP (Leco TruMac, LECO Corporation, St. Joseph, MI; Fig. 2.1). Feed samples were also analyzed for crude fat using an Ankom XT10 fat extractor (Ankom Technology, Macedon, NY). Additional samples were freeze-dried and ground to pass a 1-mm screen using a Wiley mill then composited by group into 4 time periods. Frozen stems and ground forage were then packed on ice and shipped to Agrinostics Limited, Co. (Watkinsville, GA). Total ergot alkaloid analysis of forages and percent infected stems were conducted in a commercial laboratory (Agrinostics Limited, Co., Watkinsville, GA).

Prolactin Analysis

Blood samples were collected from all heifers at d 0, 28, 56, 84, and 112 for prolactin analysis. Blood was collected via jugular venipuncture into a 10-mL serum blood collection vacuum tube (Becton, Dickinson, and Co., Franklin Lakes, NJ). Blood was allowed to clot for 2 h at room temperature before being centrifuged at $1,300 \times g$ for 20 min at 5°C. Serum was stored at -20°C for subsequent prolactin analysis. Serum was pooled within each replication. Serum was analyzed for prolactin analysis via a radioimmunoassay as described by Bernard et al. (1993) at the University of Tennessee (Knoxville, TN). The intra- and inter-assay CV for all prolactin analysis were 5.37% and 7.58%, respectively and the sensitivity across assays was 0.05 ng/mL.

Reproductive Development, Estrous Synchronization, and Breeding

Two blood samples from all 399 heifers were collected 10 d apart to determine percent of heifers cycling at approximately fourteen (401 and 411 ± 20 d of age) months of age. Samples were collected via jugular venipuncture in 10 mL K₂EDTA vacuum tubes (Becton, Dickinson, and

Co., Franklin Lakes, NJ) and immediately placed on ice. Samples were centrifuged at $1,300 \times g$ for 20 min at 5°C, and plasma was stored at -20°C until analyzed. Heifers were considered cycling when a single plasma sample contained ≥ 2 ng/mL of progesterone, or when both samples collected 10 d apart contained ≥ 1 ng/mL of progesterone as previously described by Gunn et al. (2015). Plasma progesterone concentration was analyzed using a chemiluminescent enzyme immunoassay (Immulite 1000; Siemens Medical Solutions Diagnostics, Los Angeles, CA) validated by Reis et al. (2015). The intra- and inter-assay CV for all progesterone analysis were 2.44% and 5.63%, respectively and the sensitivity across assays was 0.46 ng/mL.

At 411 ± 20 d of age (early November) heifers were enrolled in a 7-d CO-Synch + controlled internal drug release (CIDR) insert and timed-AI protocol. At protocol initiation, heifers received an intravaginal progesterone insert (CIDR; Pfizer Animal Health, New York, NY) and were administered 100 µg of GnRH (Factrel; Zoetis, Parsippany, NJ). Seven d later, the CIDR was removed, and heifers were administered 25-mg dose of prostaglandin (Lutalyse; Pfizer Animal Health). Fifty-four hours following CIDR removal heifers were bred via timed-AI and administered 100 µg of gonadotropin-releasing hormone (Cystorelin; Merial, Duluth, GA). Both sire ($n = 6$) and AI technician ($n = 5$) were stratified across treatments. Immediately following AI, heifers were combined into 2 groups with an equal representation of each treatment and placed on pasture. Ten d following AI, heifers were placed with 10 bulls (which passed breeding soundness exams; 5 bulls/group) for an 85-d breeding season. The following production season, at 811 ± 20 d of age (early December) cows were synchronized using a 7-day CoSynch + CIDR protocol (Johnson et al., 2012) and were timed-AI. Both sire ($n = 8$) and AI technician ($n = 4$) were stratified across treatments. At 10 d following the rebreeding AI, heifers were placed with 8 bulls (which passed breeding soundness exams; 4 bulls/group) for a 60-d

breeding season. At 455 ± 20 d of age (mid December) and 866 ± 20 d of age (early February), AI pregnancy rates and rebreeding AI pregnancy rates were collected by a trained technician via ultrasonography (Aloka 500 instrument, Hitachi Aloka Medical America, Inc., Wallingford, CT; 7.5 MHz general purpose transducer array). Overall pregnancy rates and rebreeding overall pregnancy rates were determine at 552 ± 20 d of age and 918 ± 20 d of age (respectively, late March) by a trained technician via rectal palpation or ultrasonography (Aloka 500 instrument, Hitachi Aloka Medical America, Inc., Wallingford, CT; 7.5 MHz general purpose transducer array).

Statistical Analysis

A stratified randomized design was used and group served as the experimental unit. Pasture forage classification (ADF, NDF, CP, and forage availability), BW, BCS, HCS, respiration rates and serum prolactin concentrations were analyzed with the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The model included the fixed effects of treatment, and time, the interaction of treatment and time, and sire. Random statements included year and group nested within treatment for BW, BCS, HCS, respiration rates and serum prolactin concentrations. Respiration rates at d 0 were significantly different, thus they were included as a covariate. The REPEATED statement of SAS 9.4 (SAS Institute Inc., Cary, NC) was used to model the repeated measurements within animal for each variable and the autoregressive(1) covariance structure were selected after considering the Akaike and Bayesian information criteria. The SLICE statement of SAS 9.4 (SAS Institute Inc., Cary, NC) was used to separate least square means when the interaction of treatment and time was significant ($P \leq 0.05$). The residuals for serum prolactin concentrations were not normally distributed, so a log

transformation was performed before analysis. Least square means were back transformed for ease of interpretation.

Heifer percentage of mature BW at AI, cow BW and BCS at time of rebreeding, milk production, and calf birth BW and early-wean BW were analyzed with the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The model included the fixed effect of treatment. Calf sire and calf sex were included as fixed effects for calf birth BW and calf early-wean BW. Year and group nested within treatment was included as a random effect. Calf date of birth was included as a covariate for cow milk production. Heifer commingle group was not significant for cow BW and BCS at time of rebreeding and milk production, thus was removed from the model.

Binary data, including percent of heifers cycling, heifer reproductive success (AI and overall pregnancy rates), and cow reproductive success (rebreeding AI and overall pregnancy rates) were analyzed using the GLIMMIX procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The model included the fixed effect of treatment. Year and group nested within treatment was included as a random effect. Technician and AI sire did not improve model fit for AI pregnancy rates and thus were removed from the model. Treatment effects were considered significant at $P \leq 0.05$ and tendencies were noted at $0.05 < P \leq 0.10$. Means reported in tables are least squares means $\pm$ SEM.

RESULTS

Treatment $\times$ time effects were detected ($P \leq 0.05$; Table 2.1) for pasture ADF, NDF, and CP. The E+/S and E+/LS pastures were greater ($P \leq 0.03$) in ADF and NDF for d 1 – 41, d 42 – 83, and d 126 – 168 and lower in CP ($P < 0.01$) for d 42 – 83 and d 126 – 168 compared to NE+/NS. Treatment $\times$ time effects were not detected ($P = 0.39$) for pasture forage availability. A time effect was detected ($P < 0.01$) for all pasture forage analysis. Pasture ADF and NDF

decreased ($P < 0.01$) over time, whereas CP and forage availability decreased ($P < 0.01$) to d 84-125 then increased ($P < 0.01$) to d 126 – 168. Additionally, there was a treatment effect ($P < 0.01$) for all pasture forage analysis. The NE+/NS pastures had the lowest ($P < 0.01$) ADF, NDF, and forage availability, but they had the greatest ($P < 0.01$) CP percent.

Treatment $\times$ time effects were detected ($P < 0.01$; Fig 2.1) for BW and BCS. Heifers in DL had the greatest ($P \leq 0.05$) BW from d 28 until the end of the first breeding season. Furthermore, E+/S heifers had a greater ($P \leq 0.05$) BW than both E+/LS and NE+/NS on d 28, 56, 84, 112, 140, and 168, but on d 203 and 254 E+/S and E+/LS heifers were not different ($P \geq 0.17$), but were still greater ($P \leq 0.05$) than NE+/NS. On d 56 and 84, E+/LS heifers had lower ($P \leq 0.05$) BW compared to NE+/NS, but on d 140 they switched and remained at a heavier ($P \leq 0.05$) BW compared to NE+/NS through the first breeding season. Heifers in DL had the greatest ($P \leq 0.05$) BCS from d 28 until d 254 where they were still greater ($P < 0.01$) than NE+/NS but not different ($P \geq 0.25$) from either E+/S or E+/LS. From d 28 until the end of the first breeding season E+/S heifers had a greater ($P \leq 0.05$) BCS compared to NE+/NS excluding d 56 where they were not different ($P = 0.61$). On d 28, 56, 84, and E+/S heifers had the greater ($P \leq 0.05$) BCS compared to E+/LS heifers but from d 140 until d 254 they were not different ($P \geq 0.16$). On d 56 and 84, E+/LS heifers had the lower ($P \leq 0.05$) BCS compared to NE+/NS, but on d 140 they switched and had the greater ($P \leq 0.05$) BCS compared to the NE+/NS at all remaining time points through the first breeding season.

Treatment $\times$ time effects were detected ($P < 0.01$; Fig 2.2) for HCS. On d 28, E+/S and E+/LS heifers had the greater ($P \leq 0.05$) HCS compared to DL and NE+/NS. On d 56, E+/LS heifers had the greatest ($P \leq 0.05$) HCS; DL had a greater ($P \leq 0.05$) HCS compared to NE+/NS but E+/S was intermediate and not different ($P \geq 0.10$) from either. On d 84, E+/LS heifers had

the greatest ($P \leq 0.05$) HCS compared to E+/S, E+/LS, and NE+/NS, which were not different ($P \geq 0.19$) from each other. On d 112 E+/LS heifers had a greater ($P \leq 0.05$) HCS compared to DL which were also greater ($P \leq 0.05$) than NE+/NS; E+/S heifers were intermediate and not different ($P \geq 0.11$) from either E+/LS or DL but were greater ($P \leq 0.05$) than NE+/NS. On d 140 E+/LS heifers had the greatest ($P \leq 0.05$) HCS; E+/S and E+/LS heifers were intermediate and not different ($P = 0.27$) from each other but still greater ($P \leq 0.05$) than NE+/NS.

Treatment $\times$ time effects were detected ($P < 0.01$) for respiration rate. On day 28, DL heifers had more ($P \leq 0.05$) respirations than E+/LS, but E+/S and NE+/NS females were intermediate and not different ($P \geq 0.16$) from any treatment. On day 56, E+/S and NE+/NS heifers had greater ($P \leq 0.05$) respiration rates compared to DL, but E+/LS females were intermediate and not different ($P \geq 0.17$) from any treatment. On day 112, E+/LS females had the greatest ($P \leq 0.05$) respiration rate, while the E+/S heifers were still greater ($P \leq 0.05$) than both NE+/NS and DL, which were not different ($P = 0.52$) from each other. Finally, on day 140, E+/S and E+/LS heifers had greater ($P \leq 0.05$) respiration rates compared to DL and NE+/NS females. A time effect was detected ($P < 0.01$) for respiration rate. Respiration rates decreased from d 28 until 84, but then sharply increased to d 112.

Treatment $\times$ time effects were detected ($P < 0.01$) for serum prolactin. Heifers in the DL group had elevated ($P \leq 0.05$) prolactin levels compared to E+/S and E+/LS at d 28, 56, 84, and 112, but E+/S and E+/LS were not different ($P \geq 0.14$) from each other at any time point. Whereas NE+/NS heifers were intermediate at d 28 and not different ($P > 0.05$) from DL and E+/S heifers but were greater ($P \leq 0.05$) than E+/LS females. On d 56, 84, and 122, NE+/NS had less ($P \leq 0.05$) respirations compared to DL, but were greater ($P \leq 0.05$) than both E+/S and E+/LS on d 56, and greater ($P \leq 0.05$) than only E+/LS on d 84.

The effects of heifer development system on reproductive performance are displayed in Table 2.2. Treatment effects were detected ($P < 0.01$) in percent of heifers cycling prior to synchronization. Drylot heifers had the greatest (83.7%; $P \leq 0.05$) cyclicity. Whereas E+/S females were intermediate and still greater (60.3%; $P \leq 0.05$) than both E+/LS and NE+/NS, which were not different (32.5 and 28.2%; $P = 0.52$) from each other. Treatment effects were detected ($P < 0.01$) for percentage of mature BW at AI. Drylot heifers had the greatest (66.6%; $P < 0.01$), whereas, E+/S and E+/LS were intermediate and not different ($P = 0.21$) from each other (55.0% vs. 53.7%; respectively), but still greater ($P < 0.01$) than NE+/NS (49.3%). Treatment effects were detected ($P = 0.02$) for AI pregnancy rate. Drylot heifers had a greater ($P < 0.01$) AI pregnancy rate compared to E+/LS and NE+/NS females and tended to be greater ($P = 0.08$) than E+/S females, which were not different ($P \geq 0.21$) from E+/LS and NE+/NS. Finally, treatment effects were detected ($P = 0.02$) for overall pregnancy rate. A greater ($P \leq 0.02$) percentage of DL and E+/S heifers were pregnant at the end of the first breeding season (89.3 and 85.1%; respectively) compared to NE+/NS females (61.5%). Whereas E+/LS heifers were intermediate and not different ($P \geq 0.21$; 78.0%) from any treatment.

Heifer milk production did not differ ($P \geq 0.80$; Table 2.3) regardless of treatment. Additionally Calf BW at birth and early-wean did not differ ($P \geq 0.42$) for any treatment. Furthermore, cow BW and BCS at the start of the second breeding season (d 592) were not different ($P \geq 0.12$; Table 2.4). Finally, rebreeding AI pregnancy rate and rebreeding overall pregnancy rate did not differ ($P \geq 0.85$) regardless of treatment.

DISCUSSION

There has been minimal research that has evaluated contrasting heifer development systems in a Midwestern fall-calving cow-calf operations. Recommendations for developing beef

heifers have changed over time and are regionally specific (Endecott et al., 2013). Previous research in spring calving herds in the western United States indicated that heifers developed in a grazing program to a lower BW at AI can reduce input costs without impairing reproductive performance (Funston and Deutscher, 2004; Roberts et al., 2009; Mulliniks et al., 2013; Summers et al., 2014). In contrast, Schubach et al. (2019) noted that heifers with an ADG of 0.80 kg after weaning hastened puberty attainment and date of first calving. Little is known about how these systems translate to the lower Midwest where cow-calf production relies on tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort) systems. This experiment was designed to evaluate post weaning developmental systems on growth and reproductive performance of heifers. DL heifers were developed to 66.6% of their mature BW and had an ADG of 0.90 kg which was slightly greater than the target of 65% of their mature BW. These gains are similar to the high gain heifers in the study by Schubach et al. (2019). Utilizing supplementation as a strategy to alleviate fescue toxicosis has been successful at improving ADG, prolactin level, and hair coat score (Aiken et al., 2008; Carter et al., 2010). Volk et al. (2019) and Stokes et al. (2018) demonstrated that developing heifers on E+ pastures with supplementation (2.7 kg as-fed/heifer/d; 50:50 mix of corn gluten feed and soybean hulls) can achieve 59 and 54% (respectively) of their mature BW at the start of the breeding season. These two strategies are the most common in the region but require greater labor inputs. Alternatively, limiting gain for a period followed by a period of increased dietary intake can take advantage of compensatory gain resulting in reduced labor costs with similar reproductive performance when heifers are grazing winter range (Clanton et al., 1983; Lalman et al., 1993; Marston et al., 1995; Ciccioli et al., 2005; Freetly et al., 2001; Grings et al., 2007). However, no work has been done evaluating this strategy when fall-born beef heifers are grazing E+ pastures. Utilizing NE+ varieties in the

stocker cattle model has been successful at improving BW (Parish et al., 2003). Drewnoski et al. (2009) demonstrated replacement heifers grazing NE+ during spring growth had increased ADG and reduced prolactin compared to heifers grazing E+. However, no work has been done to investigate allowing heifers to graze NE+ with no supplementation fall-calving production model.

Pasture ADF and NDF was lower and CP was higher in the present study than that of prior recent studies conducted at Dixon Springs Agricultural Center in Simpson, IL (Volk et al., 2019; Stokes et al., 2018; Shoup et al., 2016). However Stokes et al. (2018) noted that forage quality rapidly increased in the late fall which is similar to the present study. Furthermore, the NE+/NS pastures were higher quality than that of the E+/S and E+/LS treatments. The E+/S and E+/LS pastures consisted of a long-established ‘Kentucky-31’ cultivar at the Dixon Springs Agricultural Center (Simpson, IL). The NE+ pastures were established in the fall of 2011 using ‘Jesup MaxQ’ tall fescue (Pennington Seed, Inc., Madison, GA). The study by Shoup et al. (2016) also noted that NE+ pastures were lower in ADF and NDF and greater in CP compared to E+ pastures, which were similar to the pastures used in this trial. Pasture forage availability was similar to that of studies by Shoup et al. (2016) and Stokes et al. (2018) and they noted that forage availability was not limiting at similar stocking densities. However, Lippke et al. (2000) deduced that 850 kg dm/ha was the minimum threshold of forage mass to support steers grazing lush spring pastures. The difference in forage availability between the NE+/NS and the E+ pastures (E+/S and E+/LS) may be explained by the supplementation provided to E+/S and E+/LS treatments. Krysl and Hess (1993) noted that protein supplementation affected time spent grazing: unsupplemented cattle grazed approximately 1.5 h/d more than did supplemented cattle. Additionally, DDGS supplementation to grazing cattle has been reported to replace forage at

0.27 to 0.79 kg/kg of DDGS supplemented (Griffin et al., 2009). Another explanation for the differing forage availabilities is that fescue toxicosis may have restricted intake (Osborn et al., 1992) of the heifers grazing E+ but Osborn et al. (1992) fed a total mixed ration to cattle in confinement. Intake was not measured in the current experiment or in previous grazing studies, so the authors can only speculate that intake may have been affected. Ultimately, NE+/NS heifers likely grazed more and kept their pastures in the early vegetative state, which is likely the reason that ADF and NDF are lower and CP is greater for those pastures.

Ergot alkaloid concentrations in the E+/S and E+/LS pastures were the lowest in the summer and the greatest in the fall (2017: September: 2610 µg/L; 2018: June: 620 µg/L; July 670 µg/L; September: 1812 µg/L; October: 1715 µg/L). These results are similar to those of Volk et al. (2019) and Stokes et al. (2018) at the same station where ergot alkaloid concentrations increased 488 % from July to September. On the other hand, the NE+/NS pastures had minor ergot alkaloid concentrations (2017: September: 0 µg/L; 2018: June: 0 µg/L; July 215 µg/L; September: 367 µg/L; October: 256 µg/L). These values are similar to those found by Shoup et al. (2016) on similar pastures at the same station.

The differences in BW between treatments are not surprising as intake and ADG were not controlled for the grazing treatments. Drylot heifers were targeted to reach 65% of their mature BW by the start of the breeding season. Additionally, DL heifers lost BW from d 168 to d 196, which was expected. Heifers developed in a drylot and subsequently turned out to pasture exhibited reduced ADG (Perry et al., 2013) during the first 27 d and increased activity level (Perry et al., 2015) during the first 3 d compared to their range developed counterparts. The E+/S and E+/LS heifers were expected to reach 55% of their mature BW. In the study by Stokes et al. (2018) at the same station, heifers reached similar pre-breeding BW when they grazed E+

pastures and were supplemented with 2.7 kg/d of DDGS. The E+/LS heifers had a low ADG (0.38 kg) until d 84 followed by an improved ADG (0.51 kg) until breeding. Authors expected this change in ADG because the heifers were only supplemented from d 80 through AI. Heifers were likely benefiting from compensatory gain. Delaying gain to take advantage of compensatory gain is more economical than constant gain throughout the developmental period (Clanton et al., 1983; Lalman et al., 1993). Heifers can offset minimal post-weaning ADG through the idea of compensatory gain (Marston et al., 1995; Ciccioli et al., 2005). Authors had also hypothesized that NE+/NS heifers would have ADG similar to that of the E+/S heifers. This was not observed. Jonshon et al. (2012) compared growth parameters of steers grazing NE+ (Jesup-MaxQ) or KY31 E+ pastures. Results indicated that steer ADG on MaxQ were superior to those on KY31 E+ pastures (0.84 kg/d vs. 0.63 kg/d; respectively). The fact that NE+/NS had an ADG of only 0.30 kg/d and consequently only reached 49.3% of their mature BW prior to the start of the breeding season was not expected and is difficult to explain. Heifers did not exhibit signs of fescue toxicosis and pasture forage quality would be labeled as high quality. Forage availability did fall below 850 kg DM/ha from d 84 – d 125, which is the threshold to impact ADG of steers grazing lush spring pasture (Lippke et al., 2000). Consequently, NE+/NS heifers began to fall behind in BW during this period.

Cattle grazing E+ commonly experience fescue toxicosis that negatively affects the animal's performance (Roberts and Andrae, 2004). One common sign of fescue toxicosis is increased HCS which may be the explanation for why the E+/S and E+/LS heifers had greater HCS. In previous research, steers grazing E+ had greater HCS compared with steers grazing a NE+ (Saker et al., 2001). Increased RR in cattle grazing E+ is associated with vasoconstriction caused by ergot alkaloids (Finch, 1986). The RR for E+/S and E+/LS heifers in this experiment

were consistent with other experiments utilizing heifers at this research station (Stokes et al., 2018). Furthermore, the very small standard error (3.1 breaths/min) for RR likely contribute to differences in RR for d 28 and 56 being significant, but this small difference may not be biologically relevant. However, the dramatic increase in RR on day 112 and 140 for E+/S and E+/LS heifers aligns with the greatest ergot alkaloid concentration and can be attributed to heifers grazing E+.

Prolactin concentrations are typically decreased in cattle grazing E+. Ergot alkaloids can mimic D-2-dopamine and disrupt the dopaminergic pathways (Berde and Stürmer, 1978). Serum prolactin concentrations were not different between E+/S and E+/LS treatments. From early summer to late fall, prolactin concentrations decreased and were very low at d 112. These results are similar to Shoup et al. (2016) and Volk et al. (2019), indicating that E+/S and E+/LS heifers were experiencing fescue toxicity. Additionally, Shoup et al. (2016) noted that cows grazing E+ had reduced prolactin concentrations in July and October compared with cows grazing NE+. These results are consistent with the current experiment. Prolactin is the most responsive to changes in seasons, ambient temperature and photoperiod and is greatest in summer when ambient temperatures are highest and photoperiods are longest (Tucker 1982). Drylot heifers being housed with shade is likely the reason for serum prolactin concentrations >100 ng/mL during the summer months followed by a drop in the fall.

Heifers in DL had the greatest cyclicity (83.7 %) prior to the initiation of the synchronization protocol followed by the E+/S at 60.3%. Similar values were noted by Funston and Larson (2011) when they compared developing heifers in drylot vs grazing setting (88 and 46%; respectively). Authors did not expect E+/LS and NE+/NS heifers to have so low cyclicity (32.5 and 28.2%; respectively). Delaying gain did not result in similar percent of heifers cycling.

In light of the reduced BW gains achieved by the NE+/NS heifers it is reasonable to state that they were likely underdeveloped and as result had not reached puberty by the initiation of the synchronization protocol. As a result, DL heifers had greater AI pregnancy rates compared to both E+/LS and NE+/NS heifers. Improved AI pregnancy rates for drylot developed heifers has been noted in the literature (Funston and Larson, 2011).

However, authors in the current study acknowledge that AI pregnancy rates were low for all treatments. Pregnancy rates at AI have been inconsistent in studies conducted at Dixon Springs Agricultural Center, Simpson, IL. Volk et al (2019) observed AI pregnancy rates of 63.5%. However, Buskirk et al. (1995) and Stokes et al. (2018) observed low first service/AI pregnancy rates (15.1 and 33.5%; respectively). Both authors attributed the low AI pregnancy rates to heifers needing to reach a greater targeted percent of mature BW for optimal reproductive success. Despite the extremely poor AI pregnancy rates, DL, E+/S and E+/LS heifers had very acceptable overall pregnancy rates for the 85 d breeding season. In contrast, the NE+/NS heifers only achieved a 61.5% overall pregnancy rate which was 27 percentage units less than the DL heifers. Although the E+/LS and NE+/NS heifer were not statistically different, E+/LS heifers had a 16.5 percentage unit numerical advantage. Poor reproductive performance by the NE+/NS heifers was not expected. Watson et al. (2004) compared grazing cows on NE+ vs. E+ and noted no difference in overall pregnancy rates. Excluding the NE+/NS heifers, Overall pregnancy of the other three treatments (84%) were similar if not greater than in previous experiments at this station and elsewhere (Lalman et al., 1993; Buskirk et al., 1995; Marston et al., 1995; Ciccioli et al., 2005; Funston and Larson, 2011; Stokes et al., 2018; and Volk et al., 2019).

Endecott et al. (2013) made the recommendation based of previous studies (Funston and Deutscher, 2004; Roberts et al., 2009; Funston and Larson, 2011; Mulliniks et al., 2012) that developing heifers to a 50 to 57% of mature BW at breeding compared with 60 to 65% of mature BW can reduce development costs without compromising reproductive performance. These studies all started the breeding season at approximately 450 d of age to target a calving date of 2 yr of age. In the current study and the study by Schubach et al. (2019) which noted greater reproductive performance for heifers that have reached > 60% of their mature BW, the breeding season began at 420 d of age, which is to target calving at 23 months of age (1 month prior to mature cows). It is common practice for producers to calve their heifers before the mature cows so they have a longer rebreeding period and can manage calving season labor (Funston and Deutscher, 2004). If a producer is required to calve their heifers prior to their cows they may want to consider an increased rate of gain to mitigate the effects of age on reproduction.

There were no differences in calf birth BW or milk production between the treatments. This is similar to the study by Schubach et al. (2019) who compared low, medium, and high ADG pre-breeding. In contrast, Buskirk et al. (1995) reported milk production was improved for heifers with 0.62 kg ADG compared to heifers with 0.43 kg ADG. As a result, there were no differences in calf early-wean BW which is similar to other heifer development studies (Funston and Larson, 2011; Schubach et al., 2019).

In summary, DL heifers had the greatest BW and BCS at AI, percentage of heifers cycling, and this resulted in an increase in AI pregnancy rate. Body weight and BCS of E+/LS heifer did not catch up to E+/S heifers by AI. Likely E+/LS heifers experienced greater fescue toxicosis and were never able to compensate for that. This resulted in a lower percentage of heifers that were cycling compared to E+/S and DL and lower AI pregnancy rates compared to

DL. Finally, NE+/NS were likely in pastures with limited forage availability during the summer which led to lower BW, BCS, and percentage of heifers cycling at AI. This translated into the poorest AI pregnancy rate and overall pregnancy rates. However, these vastly different developmental strategies did not result in differing rebreeding overall pregnancy rates between DL, E+/S, and E+/LS and there were no differences in cow milk production, rebreeding reproductive performance, and calf performance between all treatments. This would suggest that DL, E+/S, E+/LS systems are all viable at developing fall-born replacement beef heifers.

TABLES AND FIGURES

Table 2.1: Pasture forage proximate analysis of the grazing treatments.

Item	Treatment ¹			SEM	P-value ²		
	E+/S	E+/LS	NE+/NS		Trt	Time	Trt × Time
ADF, %					< 0.01	< 0.01	0.05
d 1 - 41	29.9 ^a	29.6 ^a	27.2 ^b	0.95	< 0.01		
d 42 - 83	29.0 ^a	28.6 ^a	26.3 ^b	0.95	< 0.01		
d 84 - 125	26.7	27.4	27.4	0.95	0.58		
d 126 - 168	25.4 ^a	25.3 ^a	23.6 ^b	0.95	0.03		
NDF, %					< 0.01	< 0.01	< 0.01
d 1 - 41	56.3 ^a	55.1 ^a	50.0 ^b	1.16	< 0.01		
d 42 - 83	55.3 ^a	54.9 ^a	50.2 ^b	1.16	< 0.01		
d 84 - 125	54.7	54.1	55.4	1.16	0.62		
d 126 - 168	51.6 ^a	51.1 ^a	48.2 ^b	1.16	0.03		
CP, %					< 0.01	< 0.01	0.03
d 1 - 41	13.3	13.1	14.7	0.76	0.20		
d 42 - 83	13.6 ^b	13.4 ^b	16.5 ^a	0.76	< 0.01		
d 84 - 125	14.6	14.2	13.9	0.76	0.73		
d 126 - 168	16.8 ^b	17.5 ^b	19.8 ^a	0.76	< 0.01		
Forage availability, kg DM/ha					< 0.01	< 0.01	0.39
d 1 - 41	1027	1143	938	75.8			
d 42 - 83	865	834	914	75.8			
d 84 - 125	791	844	730	75.8			
d 126 - 168	1083	1164	1073	75.8			

¹ Grazing treatments included: grazing endophyte-infected fescue supplemented daily with a 50:50 mix of soybean hulls and DDGS (2.3 kg as-fed/heifer/d; E+/S); grazing endophyte-infected fescue and transitioned to daily supplementation from the midpoint of treatment period until breeding with a 50:50 mix of soybean hulls and DDGS (4.5 kg as-fed/heifer/d; E+/LS); grazing novel endophyte-infected fescue (NE+/NS). This study began on June 1st.

²Trt = Treatment effect; Trt × Time = treatment by time effect.

Table 2.2: Effect of heifer development system on reproductive performance.

Item	Treatment ¹				SEM	P-value
	DL	E+/S	E+/LS	NE+/NS		
Cyclicity ² , %	83.7 ^a	60.3 ^b	32.5 ^c	28.2 ^c	-	<0.01
Percent of mature BW ³ , %	66.6 ^a	55.0 ^b	53.7 ^b	49.3 ^c	3.08	<0.01
AI pregnancy rate, %	36.9 ^a	24.5 ^{ab}	16.9 ^b	17.7 ^b	-	0.02
Overall pregnancy rate, %	89.3 ^a	85.1 ^a	78.0 ^{ab}	61.5 ^b	-	0.02

¹Heifers received (for 168 d prior to AI) 1 of 4 treatments (n = 6 pens/treatment): drylot developed [ad-lib fed 90% hay and 10% DDGS (**DL**)]; grazing endophyte-infected fescue supplemented daily with a 50:50 mix of soybean hulls and DDGS (2.3 kg as-fed/heifer/d; **E+/S**); grazing endophyte-infected fescue and transitioned to daily supplementation from the midpoint of treatment period until breeding with a 50:50 mix of soybean hulls and DDGS (4.5 kg as-fed/heifer/d; **E+/LS**); grazing novel endophyte-infected fescue (**NE+/NS**).

²Cyclicity was defined as when 1 plasma sample contained ≥ 2 ng/mL of progesterone or when both samples contained ≥ 1 ng/mL of progesterone. Measurements taken at 401 and 411 $\pm$ 20 d of age.

³Percent of mature BW at breeding based on mature cow size of 567 kg.

^{a-c} Means in a row with different superscripts differ ($P \leq 0.05$).

Table 2.3: Effect of heifer development system on milk production and calf performance.

Item	Treatment ¹				SEM	P-value
	DL	E+/S	E+/LS	NE+/NS		
Cow milk production ² , kg	4.9	4.5	5.3	4.9	1.20	0.80
Calf birth BW, kg	29	28	30	29	1.3	0.42
Calf early-wean BW ³ , kg	92	90	93	89	5.8	0.81

¹Heifers received (for 168 d prior to AI) 1 of 4 treatments (n = 6 pens/treatment): drylot developed [ad-lib fed 90% hay and 10% DDGS (**DL**)]; grazing endophyte-infected fescue supplemented daily with a 50:50 mix of soybean hulls and DDGS (2.3 kg as-fed/heifer/d; **E+/S**); grazing endophyte-infected fescue and transitioned to daily supplementation from the midpoint of treatment period until breeding with a 50:50 mix of soybean hulls and DDGS (4.5 kg as-fed/heifer/d; **E+/LS**); grazing novel endophyte-infected fescue (**NE+/NS**).

²24 h milk production estimated via weigh-suckle-weigh technique; 69 ± 13.7 d postpartum

³Measured at 84 ± 13.7 d of age.

Table 2.4: Effect of heifer development system on reproductive performance at rebreeding.

Item	Treatment ¹				SEM	P-value
	DL	E+/S	E+/LS	NE+/NS		
Cow BW, kg	473	470	481	452	7.8	0.12
Cow BCS	4.6	4.7	5.0	4.9	0.12	0.21
AI pregnancy rate, %	58.1	53.3	50.0	52.8	-	0.89
Overall pregnancy rate, %	92.3	98.1	95.7	95.7	-	0.85

¹Heifers received (for 168 d prior to AI) 1 of 4 treatments (n = 6 pens/treatment): drylot developed [ad-lib fed 90% hay and 10% DDGS (**DL**)]; grazing endophyte-infected fescue supplemented daily with a 50:50 mix of soybean hulls and DDGS (2.3 kg as-fed/heifer/d; **E+/S**); grazing endophyte-infected fescue and transitioned to daily supplementation from the midpoint of treatment period until breeding with a 50:50 mix of soybean hulls and DDGS (4.5 kg as-fed/heifer/d; **E+/LS**); grazing novel endophyte-infected fescue (**NE+/NS**).

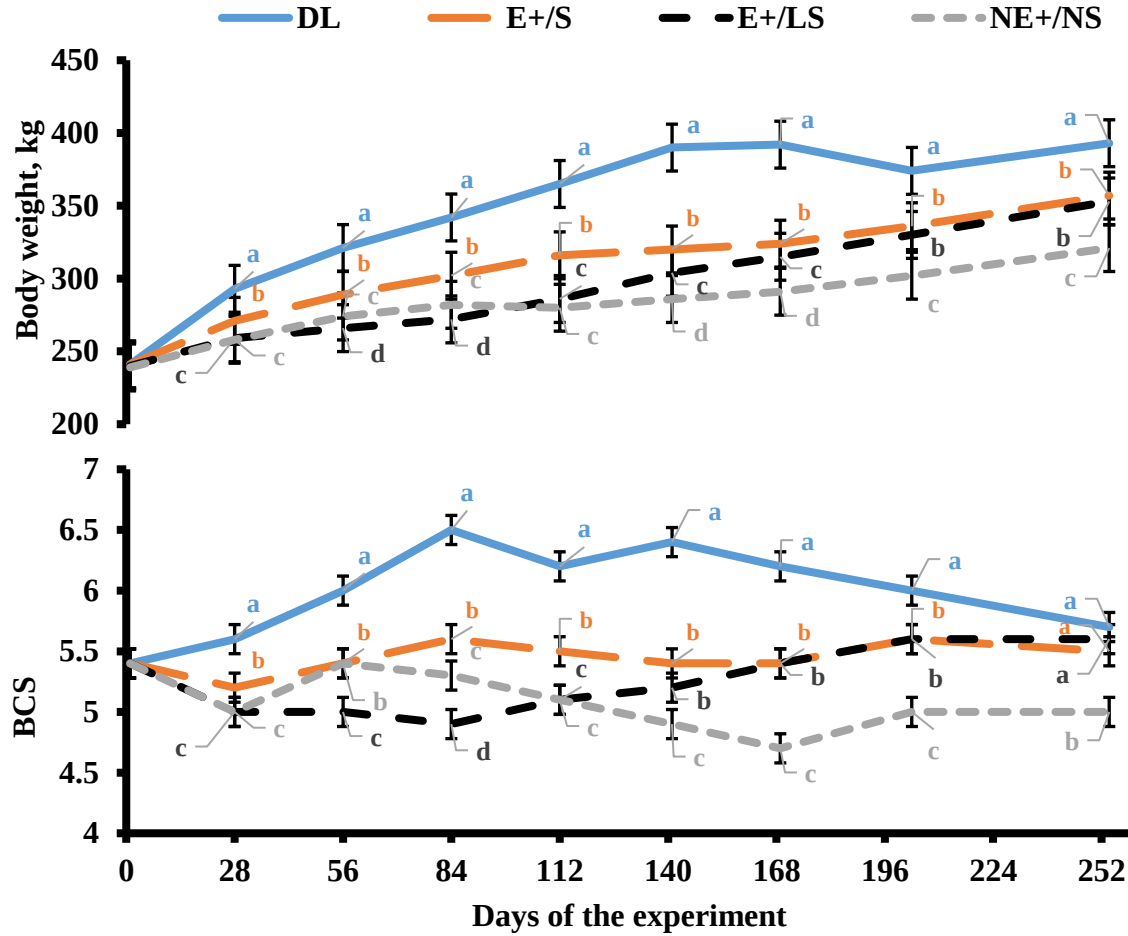


Figure 2.1: Effects of pre-breeding heifer development system on BW and BCS. Heifers received (for 168 d prior to AI) 1 of 4 treatments (n = 6 pens/treatment): drylot developed [ad-lib fed 90% hay and 10% DDGS (**DL**)]; grazing endophyte-infected fescue supplemented daily with a 50:50 mix of soybean hulls and DDGS (2.3 kg as-fed/heifer/d; **E+/S**); grazing endophyte-infected fescue and transitioned to daily supplementation from the midpoint of treatment period until breeding with a 50:50 mix of soybean hulls and DDGS (4.5 kg as-fed/heifer/d; **E+/LS**); grazing novel endophyte-infected fescue (**NE+/NS**). Means at the same time point with different superscripts differ ($P \leq 0.05$). Treatment $\times$ time, time, and treatment effects were detected ($P < 0.01$) for BW and BCS.

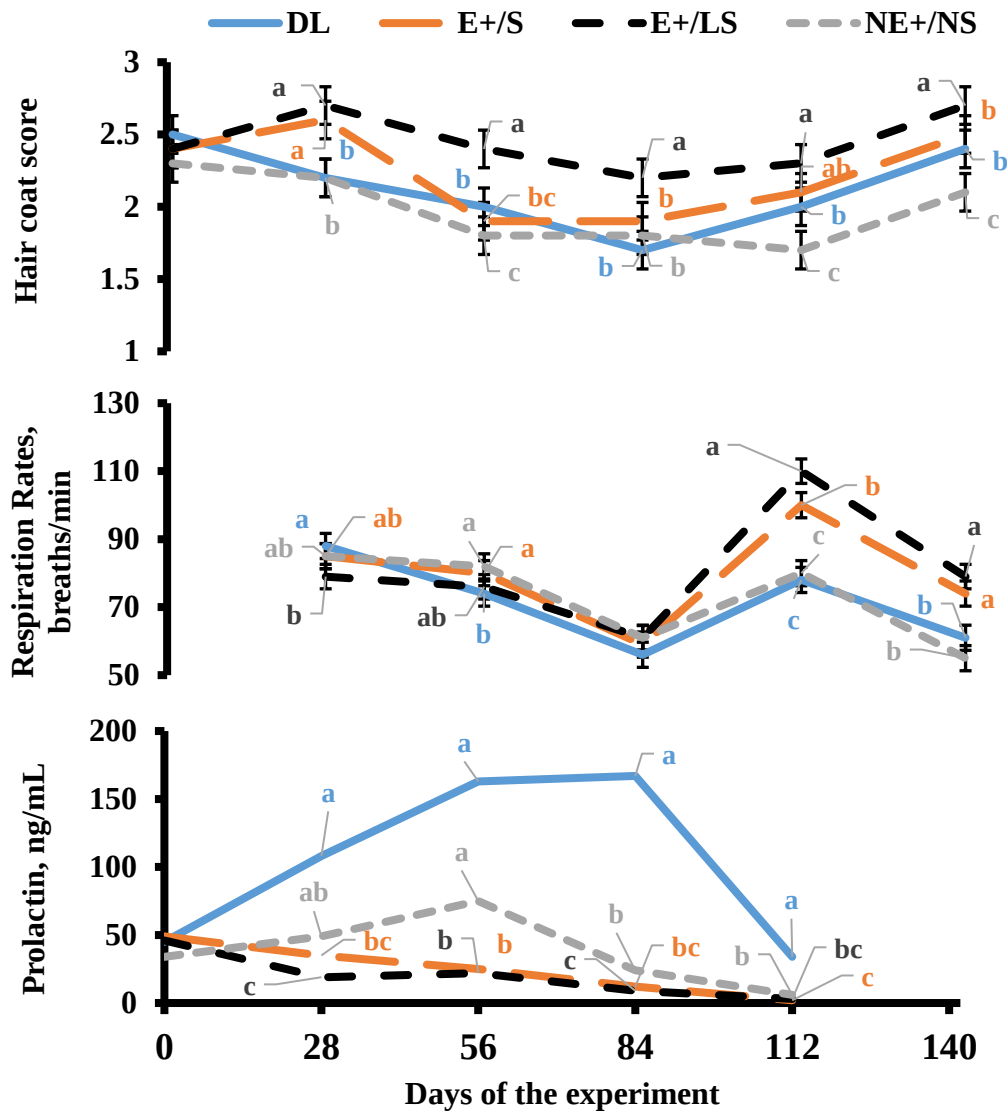


Figure 2.2: Effects of pre-breeding heifer development system on hair coat score (HCS; 1 to 5, in which 1 = slick and 5 = unshed), respiration rates, prolactin concentrations. Heifers received (for 168 d prior to AI) 1 of 4 treatments (n = 6 pens/treatment): drylot developed [ad-lib fed 90% hay and 10% DDGS (**DL**)]; grazing endophyte-infected fescue supplemented daily with a 50:50 mix of soybean hulls and DDGS (2.3 kg as-fed/heifer/d; **E+/S**); grazing endophyte-infected fescue and transitioned to daily supplementation from the midpoint of treatment period until breeding with a 50:50 mix of soybean hulls and DDGS (4.5 kg as-fed/heifer/d; **E+/LS**); grazing novel endophyte-infected fescue (**NE+/NS**). Means at the same time point with different superscripts differ ($P \leq 0.05$). Respiration rates at d 0 were significantly different, thus they were removed and included as a covariate. The residuals for serum prolactin concentrations were not normally distributed, so a log transformation was performed before analysis. Least square means were back transformed for ease of interpretation. Treatment $\times$ time, time, and treatment effects were detected ($P < 0.01$) for HCS, respiration rates, and prolactin concentration.

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CHAPTER 3

EFFECT OF CORN SUPPLEMENTATION AND AGE ON PERFORMANCE AND REPRODUCTION OF BEEF FEMALES GRAZING LUSH SPRING PASTURE

ABSTRACT

This study evaluated how corn supplementation and age of female effected body weight (BW), body condition score (BCS), artificial insemination (AI) pregnancy rate, and blood metabolites [nonesterified fatty acid (NEFA), β -hydroxybutyrate (BHBA), and blood urea nitrogen (BUN)] when grazing lush spring pasture. Angus and Angus $\times$ Simmental beef females ($n = 361$) were blocked by location then stratified by BW and BCS and were assigned to 1 of 8 pens per location with 9-14 females per pen over 2 production yr. The study utilized a randomized complete block design with a 2×2 factorial arrangement of treatments. The 4 treatment groups were: yearling heifers receiving no supplement (**CON-H**); yearling heifers receiving supplement of dry rolled corn [(**SUPP-H**); 1.81 kg as-fed/heifer/d] for 42 d; two-yr-old lactating cow-calf pairs receiving no supplement (**CON-C**); and two-yr-old lactating cow-calf pairs receiving supplement of dry rolled corn [(**SUPP-C**); 1.81 kg as-fed / cow/d] for 42 d. Supplementation began at AI (end of April) when cows were turned out to tall fescue (*Festuca arundinacia* schreb)-red clover (*Trifolium pratense*) pastures. Pasture forage was collected weekly for analysis. Throughout the grazing season, forage crude protein (CP) decreased ($P < 0.01$) over time, but acid detergent fiber (ADF), neutral detergent fiber (NDF), dry matter (DM), forage height and forage mass all increased ($P < 0.01$) over time. Females receiving SUPP had a greater ($P \leq 0.10$) BW and BCS at d 42 and BW change over the supplementation period. Cow BHBA was greater ($P < 0.01$) compared to heifers. Female NEFA increased ($P < 0.01$) from d 12 to 42. Control females had greater ($P = 0.02$) serum NEFA concentrations compared to SUPP

females. Control females had greater ($P = 0.03$) BUN concentrations compared SUPP females. Cow BUN was greater ($P < 0.01$) than heifer BUN. Supplementation effects were not detected ($P \geq 0.25$) for AI or overall pregnancy rate. In conclusion, there were no supplementation $\times$ age interactions excluding d 42 BCS. Supplementation regardless of female age tended to improve d 42 BW and BW change. Cow BHBA and BUN was greater compared to the heifers whereas the supplemented females had lower NEFA and BUN. Even though cows tended to have greater AI pregnancy rates than heifers, supplementation did not affect AI or overall pregnancy rates.

Key words: beef cow, cool-season pasture, excess protein, supplementation, reproduction

INTRODUCTION

Nutrition and reproduction are the two most important factors that drive the financial success of a cow-calf enterprise (Hess et al. (2005). Timely nutritional inputs to the beef female may enhance sustainability by enhancing reproductive performance of the cowherd (Hess et al., 2005). Most cattle systems in the Midwest calve in early spring between February and April. This time frame for calving allows peak lactation and breeding to coincide with lush pasture growth allowing producers to forgo supplementation. However, most forage available to cows during breeding is lush, vegetative grass that is relatively high in protein and moisture, and may not meet nutritional needs of the cow in this energetically demanding period.

In spring, forage grows quickly, and is very high in moisture, generally $<25\%$ dry matter (DM; Dounkamchan et al., 2016). Physical fill with wet forage may limit DM intake (Allen 1996). Additionally, the lush forage usually contains a high nitrogen content and minimal carbohydrates. Imbalances of N:Carbohydrate, along with the high moisture contents of the forage can lead to cows entering a negative energy balance (NEB; Arelovich et al., 2003). Supplementing steers grazing lush spring pasture with cottonseed meal improved ADG (Worrell

et al., 1990). In dairy cattle, blood urea nitrogen (BUN) levels greater than 20 mg/dL altered uterine environment and decreased the ability of oocytes to develop to blastocysts (Hammon et al., 2005; Santos et al., 2009). Nonetheless, the majority of grazing cow supplementation research has been focused on times when forage quality is the poorest. When mature cows grazing lush spring pasture were supplemented daily, they tended to have decreased BUN levels and, although not statistically significant, greater AI pregnancy rates (51.7% vs. 38.5%). According to the NASEM (2016) young females need particular nutritional attention to satisfy their need for growth. The nutritional requirement for growth and lactation of the two-yr-old lactating cow makes her extremely susceptible to an insult (NASEM, 2016). Additionally, transitioning heifers from the dry lot to a grazing setting following AI has resulted in reduced reproductive success (Perry et al., 2013) which has been attributed to their lack of grazing experience (Perry et al., 2013) and increased activity level (Perry et al., 2015).

Therefore, the objectives of this experiment were to evaluate how corn supplementation and age of female effected body weight (BW), body condition score (BCS), artificial insemination (AI) pregnancy rate, and blood metabolites [nonesterified fatty acid (NEFA), β -hydroxybutyrate (BHBA), and blood urea nitrogen (BUN)] when grazing lush spring pasture. We hypothesized that supplementation of corn daily would improve AI pregnancy rate and overall production performance of beef females. Supplement should dilute the high-nitrogen pasture while offsetting the energetic costs of the heifer activity level and increased nutritional requirements of heifers and two-yr-old lactating, thus preventing a NEB. Additionally, we hypothesized that supplementation would have greatest impact on two-yr-old lactating cows because of the additional requirements of lactation.

MATERIALS AND METHODS

All experimental procedures were approved by the Institutional Animal Care and Use Committee of the University of Illinois (IACUC #17108) and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animal in Agricultural Research and Teaching (FASS, 2010).

Animals, Experimental Design, and Treatments

Angus and Angus × Simmental beef females [$n = 361$; heifers (age = 451 ± 23 d; initial BW = 447 ± 41 kg; initial BCS = 5.9 ± 0.62) or cows (cow-calf pairs; age = 902 ± 27 d; initial BW = 560 ± 49 kg; initial BCS = 5.5 ± 0.61)] were blocked by location then stratified by BW and BCS and were assigned to 1 of 8 pens/location with 9-14 females/pen over 2 production yr. Cattle were maintained at two locations, the Beef Cattle and Sheep Field Laboratory in Urbana, IL (yr 1: 44 heifers and 46 cows; yr 2: 52 heifers and 36 cows) or the Orr Agricultural Research and Demonstration Center in Baylis, IL (yr 1: 53 heifers and 36 cows; yr 2: 56 heifers and 40 cows). The study utilized a randomized complete block design with a 2×2 factorial arrangement of treatments. The 4 treatment groups were: yearling heifers receiving no supplement (**CON-H**); yearling heifers receiving supplement of dry rolled corn [(**SUPP-H**); 1.81 kg as-fed/heifer/d; 13.5% neutral detergent fiber (NDF), 3.8% acid detergent fiber (ADF), 4.1% fat, and 7.7% crude protein (CP)] for 42 d; two-yr-old lactating cow-calf pairs receiving no supplement (**CON-C**); and two-yr-old lactating cow-calf pairs receiving supplement of dry rolled corn [(**SUPP-C**); 1.81 kg as-fed/ cow/d; 13.5% NDF, 3.8% ADF, 4.1% fat, and 7.7% CP] for 42 d. Supplementation began at AI (end of April) when cows were turned out to tall rescue (*Festuca arundinacia* schreb)-red clover (*Trifolium pratense*) pastures.

Prior to the initiation of trial cattle were housed in a dry lot and fed a total mixed ration. During this time, cows were limit-fed a corn silage, corn stalks, and modified wet distillers grains diet (11.4 kg of DM/heifer/d; 46% NDF, 25% ADF, 4.0% fat, and 10.2% CP). In addition, heifers were limit-fed a diet consisting of alfalfa haylage, corn silage, corn coproducts, and supplement (8.2 kg of DM/heifer/d; 41.1% NDF, 21% ADF, 4.2% fat, and 10.5% CP). Supplementation began at the time of AI (end of April). As typical in a spring-calving herd, breeding often coincides with turnout to spring pastures. Females grazed pastures with an average coverage area of 30% red clover (*Trifolium pratense*) and 70% endophyte-infected fescue (*Festuca arundinacea*) in each pasture. Cattle continuously grazed a pasture for the duration of the experiment. At the Orr Agricultural Research and Demonstration Center in Baylis, IL and the Beef Cattle and Sheep Field Laboratory in Urbana, IL average pasture size was 2.6 ± 0.2 ha and 3.2 ± 0.5 ha, respectively. This resulted in an average stocking rate of 3.8 cow-calf pairs/ha and 5.0 heifers/ha at the Orr Agricultural Research and Demonstration Center in Baylis, IL and 4.0 cow-calf pairs/ha and 3.8 heifer/ha at the Beef Cattle and Sheep Field Laboratory in Urbana, IL.

Forage mass and nutritive quality were determined by clipping 0.25 m² quadrats (3 in each pasture) before the beginning of grazing and every 7 d during the experiment. A 0.25 m² ring was tossed 3 times while traveling in a zigzag pattern across the pasture to randomly identify the sampling quadrats. Forage within quadrats was mechanically clipped to an aboveground stubble height of approximately 7.62 cm. Fresh-cut forage was then placed into a paper bag, weighed then oven dried at 55°C for a minimum of 3 d, and weighed again. Forage mass was calculated for each pasture based on dry-weight data multiplied by the area of the pasture. Forage samples were ground through a 1 mm screen using a Wiley mill (Arthur H.

Thomas, Philadelphia, PA) then composited by pasture at each time point. Ground forage was analyzed for NDF and ADF using an Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY) as well as CP (Leco TruMac, LECO Corporation, St. Joseph, MI). A commercial mineral (#CP63, Pike Feeds, Pittsfield, IL; 12 to 14% Ca, 8% K, 18 to 20% NaCl, 11% Mg, 90 mg/kg of I, 528,000 IU/kg of vitamin A, 88,000 IU/kg of vitamin D₃, and 2,200 IU/kg of vitamin E) was offered free choice throughout the experiment.

Within location, cows were commingled by age at the end of the supplementation period and grazed common pasture (red clover, white clover, and endophyte-infected fescue). Full 2-d BW measurements collected and averaged at the beginning (d -3 and 0) and end of the experiment (d 41 and 42). Cow BCS were determined at d -3 and d 42 of supplementation and were evaluated using a 1-9 scale [emaciated =1; obese = 9; as described by (Wagner et al., 1988)].

Estrus Synchronization and AI

Cows were synchronized using a 7-day CoSynch + controlled internal drug-release (CIDR) protocol (Johnson et al., 2012) and were artificially inseminated at a fixed time. Sire (n = 4) and AI technician (n = 4) were stratified across treatment combinations. In yr 1, heifers were enrolled in a 7-d CO-Synch + CIDR insert and timed-AI protocol. At protocol initiation, heifers received an intravaginal progesterone insert (CIDR; Pfizer Animal Health, New York, NY) and were administered 100 µg of GnRH (Factrel; Zoetis, Parsippany, NJ). Seven days later, the CIDR was removed, and heifers were administered 25-mg dose of prostaglandin (Lutalyse; Pfizer Animal Health). Fifty-four hours following CIDR removal heifers were bred via timed-AI and administered 100 µg of gonadotropin-releasing hormone (Cystorelin; Merial, Duluth, GA).

In yr 2, heifers were enrolled in a 14-d CIDR (Pfizer Animal Health, New York, NY) insert - PG and timed AI protocol (Mallory et al., 2013).

In yr 1, one bull was added to each pasture group 12 d after AI and remained there for 35 d until conclusion of supplementation period. In yr 2, on d 12, heat detection patches (Estroject Heat Detectors, Rockway Inc., Spring Valley, WI) were placed on all heifers. Trained farm personnel detected estrus and AI females exhibiting estrus 12 hr after standing estrus. On d 27 one bull was added to each pasture group. In both yr, cows were commingled by age at the end of the supplementation period and one bull was added to each group for $10 \text{ d} \pm 3.5$ in both years. Thus, females were exposed to bulls for 43 d in yr 1 and 22 d in yr 2. Pregnancy verification to AI was performed 42 d after AI in yr 1 and 60 d after AI in yr 2. Overall pregnancy check was performed 62 d after bull removal in both years. Pregnancy was confirmed by a trained technician via ultrasonography (Aloka 500 instrument, Wallingford, CT; 7.5-MHz general purpose transducer array).

Blood Sampling and Analysis

Serum samples collected on d 0, 12, and 42 of supplementation were pooled by pasture group and analyzed for BUN, NEFA, and BHBA concentrations to indicate excess protein intake and reduced energy status. Blood was collected using a 38-mm needle into a 10-mL Vacutainer (Becton, Dickinson and Co., Franklin Lakes, NJ) and stored on ice immediately. Blood in the serum tube was allowed to clot at room temperature before being centrifuged (Model HN-S, International Equipment Company, Needham Heights, MA) at $1,300 \times g$ for 20 min at 5° C. 200 μ L from each animal within a group was pooled. Pooled serum was immediately frozen at -20°C until analysis. Composited serum samples were delivered to the University of Illinois, College of Veterinary Medicine Diagnostic Laboratory. Serum BHBA, NEFA, and BUN concentrations

were analyzed using an Olympus AU680 Chemistry-Immuno Analyzer (Olympus Corporation, Center Valley, PA). Analysis of NEFA was conducted via a colorimetric assay [HR Series NEFA-HR (2); Wako Chemicals, Richmond, VA]. Colorimetric analyses were also used for BUN (OSR6134; Beckman Coulter, Indianapolis, IN) and BHBA concentration determination (Ranbut; Randox, Crumlin, UK).

Statistical Analysis

A randomized complete block design with a 2×2 factorial arrangement of treatments was used and pen served as the experimental unit. Pasture forage quality and pooled blood metabolite data were analyzed using the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC). The model included the fixed effect of supplementation, age, time, supplementation $\times$ age, supplementation $\times$ time, age $\times$ time, and supplementation $\times$ age $\times$ time. Baseline values for BHBA, NEFA, and BUN, which were collected at the start of the study, were included as a covariate. Location was included as a block and year was included as a random effect. The REPEATED statement of SAS 9.4 (SAS Institute Inc., Cary, NC) was used to model the repeated measurements within pasture group, and the Autoregressive(1) covariance structure was selected for pasture forage quality and the Toeplitz was selected for pooled blood metabolite data after considering the Akaike and Bayesian information criteria.

Body weight and BCS were also analyzed using the MIXED procedure of SAS 9.4 (SAS Institute Inc., Cary, NC) with the fixed effects of supplementation, age, and the interaction of supplementation and age. Year and group nested within the interaction of supplementation and age was included as a random effect.

Binomial data for AI and overall pregnancy data were analyzed using the GLIMMIX procedure of SAS with the fixed effects of supplementation, age, and the interaction of

supplementation and age. Year and group nested within the interaction of supplementation and age was included as a random effect. Technician and AI sire were not significant for AI pregnancy rates and thus were removed from the model. Main effects were considered significant at $P \leq 0.05$ and tendencies were noted at $0.05 < P \leq 0.10$. Means reported in tables are least squares means $\pm$ SEM.

RESULTS

Supplementation $\times$ age $\times$ time, supplementation $\times$ age, supplementation $\times$ time, age $\times$ time, supplementation, and age effects were not detected ($P \geq 0.28$; Fig 3.1) for pasture CP, ADF, NDF, or DM percentage. Supplementation $\times$ age $\times$ time, supplementation $\times$ time, age $\times$ time, supplementation, and age effects were not detected ($P \geq 0.31$) for forage height or forage mass. However, supplementation $\times$ age effects were detected ($P \leq 0.08$) for forage height and forage mass. Greater forage heights ($P = 0.05$) were noted for SUPP-H compared to CON-H (39.1 vs. 32.0 cm, respectively), yet, the CON-C and SUPP-C were intermediate and were not different ($P \geq 0.11$) from any treatment combination. Furthermore, SUPP-H were in pastures with greater ($P = 0.02$) forage mass compared to CON-H (1955 vs. 1686 kg of DM/ha, respectively). Whereas the CON-C had greater ($P = 0.01$) forage mass than SUPP-C (2019 vs. 1715 kg of DM/ha, respectively). There was a time effect ($P < 0.01$) on all forage classification parameters. Forage CP percentage decreased over time, but ADF, NDF, DM percentage, forage height and forage mass all increased over time.

Supplementation $\times$ age effects were not detected ($P \geq 0.77$; Table 3.1) for d 0 BW, d 42 BW, or BW change. Age effects were detected ($P < 0.01$) for d 0 BW and d 42 BW, the cows were heavier compared to the heifers. Finally, females receiving SUPP tended ($P = 0.10$) to have greater BW at d 42 and greater BW gain over the supplementation period.

Supplementation $\times$ age and supplementation effects were not detected ($P \geq 0.32$) for d 0 BCS and BCS change. However, heifers had a greater d 0 BCS and lost more BCS compared to the cows. Supplementation $\times$ age and supplementation effects were detected ($P \leq 0.09$) for d 42 BCS. Greater BCS ($P < 0.01$) was observed for SUPP-H compared to all other treatment combinations, which were not different ($P \geq 0.25$) from each other. Age effects were not detected ($P = 0.27$) for d 42 BCS.

Supplementation $\times$ age $\times$ time, supplementation $\times$ age, supplementation $\times$ time, age $\times$ time, supplementation and time effects were not detected ($P \geq 0.22$; Fig 3.2) for serum BHBA concentration; but, an age effect was detected ($P < 0.01$). Cow BHBA was greater than heifer BHBA. Supplementation $\times$ age $\times$ time, supplementation $\times$ age, supplementation $\times$ time, age $\times$ time and age effects were not detected ($P \geq 0.11$) for serum NEFA concentration; however, supplementation and time effects were detected ($P \leq 0.02$). Control females had greater serum NEFA concentrations compared SUPP females. Serum NEFA concentrations were lower at d 12 than d 42. Finally, supplementation $\times$ age $\times$ time, supplementation $\times$ age, supplementation $\times$ time, age $\times$ time and time effects were not detected ($P \geq 0.18$) for serum BUN concentration; but, supplementation and age effects were detected ($P \leq 0.03$). Control females had greater BUN concentrations compared SUPP females. Cow BUN was greater than heifer BUN.

Supplementation $\times$ age and supplementation effects were not detected ($P \geq 0.25$; Fig 3.3) for AI or overall pregnancy rate percentage. However, cows tended ($P = 0.07$) to have a greater AI pregnancy rate compared to the heifers (66 vs. 56%, respectively). Nevertheless, age did not affect ($P = 0.98$) overall pregnancy rates.

DISCUSSION

Forage CP was at or greater than 18% at the initiation of the trial (late April) and remained greater than 10% throughout the entire supplementation period. This is comparable to a similar study by Doungkamchan et al. (2016) that was conducted at the Orr Agricultural Research and Demonstration Center in Baylis, IL, where late-April CP levels were approximately 20% and declined to approximately 13% by early-June. Furthermore, early vegetative late-March fescue sampled in Kentucky, averaged approximately 22% CP (Steen et al., 1979) and 24% CP (Beck et al., 2008). Forage CP in the present study declined to approximately 11% by d 35 of supplementation. This is in contrast to previous work, which has noted forage CP only dropping to 13% (Steen et al., 1979; Beck et al., 2008; Doungkamchan et al., 2016) when sampled later in the spring.

Average NDF and ADF of the pastures at d 0 were approximately 43% and 21%, respectively. These results are comparable to the previously mentioned studies by Doungkamchan et al. (2016) and Steen et al. (1979), who found average NDF to be approximately 50 and 43%, respectively, and ADF to be approximately 25 and 30%, respectively.

These CP, NDF, and ADF results indicate that the pastures used in this experiment were vegetative when supplementation began in late April. As the spring commenced, NDF and ADF increased and CP decreased, which is indicative of forage maturity. This experiment's objective was to challenge the cows with high CP, lush pasture at the time of AI, and it was achieved. The CP content for the first 10 d of supplementation would have been classified as a diet high in CP as defined by Butler (2005; 17-19%), which has been associated with decreased reproductive performance (Butler, 2005).

In the present study, DM percentage was at or below 20% for the first 14 d of supplementation, then gradually increased to approximately 28% on d 42 (early June). This is similar to the study by Doungkamchan et al. (2016) where DM percentage dropped to 18% in late April and increased to 24% over the following 30 d.

In the present study, forage mass was approximately 1200 kg DM/ha at d 0 and increased to 2500 kg DM/ha over the 42 d supplementation period. Forage height follows a similar trend; at d 0 forage height was 24 cm and increased to 47 cm by d 42. This rapid forage growth facilitates the assumption that forage availability was not limiting. When forage is of higher quality than is required by the grazing animal, forage intake will be depressed when a concentrate feed is given (Kartchner, 1980). This likely explains why the SUPP-H had a greater forage mass and forage height compared to CON-H. However, the fact that the control cows had a greater forage mass is not supported by literature and cannot be explained. Although there were small differences in forage height and forage mass between the treatments, forage availability was not likely limiting.

Body weight and BCS of the heifers and cows (447 and 559 kg; 5.9 and 5.5, respectively) are different because of their stage in production. We hypothesized that turning young females out on lush spring pasture would challenge them. Thus, we expected heifers and cows would lose or maintain BW and BCS over the supplementation period. Females receiving SUPP did have a greater BW and BCS at d 42. Greater BCS for the SUPP-H on d 42 is supported in the literature. Perry et al. (2016) turned heifers to spring pasture following AI and supplemented them with DDGS (2.2 kg as-fed/d) and compared them to heifers receiving no supplementation. Supplementation resulted in greater BCS (5.9 vs. 5.8) at the end of the supplementation period. Additionally, steers supplemented with energy while grazing irrigated lush pasture noted a

significant improvement in ADG (Lake, 1974; Anderson and Dunn, 1982). In contrast, Doungkamchan et al. (2016) observed no differences in final BW or BCS after supplementing mature cows for 62 d with 1.81 kg of DM/cow/d. Differences in BCS between the CON-H and SUPP-H may be attributed to heifers being naive to grazing. Previous work has noted that heifers developed in a drylot and subsequently turned out to pasture exhibited reduced ADG during the first 27 days (Perry et al., 2013) and increased activity level during the first three days compared to their range developed counterparts (Perry et al., 2015). However, there is only 0.2 BCS difference between the treatment groups. This significance is driven by a small standard error and there is likely little to no biological difference between the groups. Few studies have been conducted evaluating supplementation to beef cows grazing lush spring pasture.

β -Hydroxybutyrate is a ketone body used to reflect the completeness of fat oxidation in the liver and when elevated above 1.20 mmol/L, which is the threshold for a healthy cow, can result in poorer milk production and reduced reproductive performance in dairy cattle (LeBlanc et al., 2010). Females in this experiment had serum BHBA concentrations ranging between 0.2 - 0.4 mmol/L, which indicates that the cows were not ketotic. Thus, the difference in BHBA between heifers and cows is likely not biologically significant.

During periods when digested energy supply is inadequate to meet the cow's nutritional requirements, such as during lactation, stored lipids are mobilized in the form of NEFA for conversion to energy (Richards et al., 1989). According to Garverick et al. (2013), dairy cows with a NEFA concentration greater than 0.20 mEq/L will use more adipose tissue to meet their energy requirement and are more likely to experience BCS loss. In the present study, average NEFA concentrations on d 0 ranged from 0.47 to 0.60 mEq/L which is greater than the threshold 0.20 mEq/L that is associated with a NEB. Doungkamchan et al. (2016) also noted elevated

NEFA values but they attributed this to cows being sampled during estrous. This elevated baseline value may be attributed to irregular intakes associated with estrus in beef cows. Females receiving SUPP had lower NEFA, which can be attributed to the additional dietary energy being supplied by the corn supplement, which may prevent those females from entering a NEB. Overall, it appears that cows were mobilizing stored energy which resulted in an increased NEFA concentration. But, their BHBA levels were normal, so their livers were able to accommodate the increased fatty acid oxidation.

The difference in BUN concentration between control and supplemented females may be due to the dilution effect of the corn supplement. A similar reduction in BUN was noted when mature cows were supplemented 2.2 kg/cow/d of a 45% ground corncobs, 45% soybean hulls, and 10% dry molasses supplement on a DM basis (Doungkamchan et al., 2016). This dilution effect has also been observed in steers grazing irrigated pasture that were provided an energy supplement (Lake, 1974). Control cows had BUN values that exceeded the threshold (20 mg/dL) classified by Hammon et al. (2005) which is noted to result in decreased reproductive performance. Yet, there were no differences in AI pregnancy rate between CON-C and SUPP-C. The BUN level and relationship noted in the cows was not observed in the heifers. Authors hypothesized that young females would be most likely to compromise their reproductive system following a drastic diet alteration such as demonstrated in this experiment. However, these heifers may not have been actually consuming as much of the forage. Grazing is a learned behavior that animals acquire from adults prior to weaning (Perry et al., 2013). Upon heifers leaving a drylot situation and assuming a grazing role heifers have been noted to have reduced ADG and increased activity (Perry et al., 2013; Perry et al., 2015).

There were no differences in AI or overall pregnancy rate percentage except cows had a greater AI pregnancy rate compared to the heifers (66 vs. 56%, respectively. This contradicts our hypothesis that supplementation would improve reproductive performance and that the cow would have had the greatest challenge. These findings contradicted our hypothesis that the low forage DM, elevated N content of the forage and increased BUN of the control females would result in decreased AI pregnancy rate compared with the SUPP females. Gunn et al. (2014) fed diets differing in protein from late gestation until rebreeding and found differences in BUN, but these differences did not translate to significant differences in pregnancy rate. Similarly, in our experiment, BUN concentration of CON-C at d 12 was above the threshold associated with decreased fertility (19 mg/dL) but did not result in a reduction in AI pregnancy rate. This was not expected because high BUN concentrations alter uterine pH and environment (Rhoads et al., 2004). If the uterine environment is in this altered state 10-17 d following ovulation, long-term embryo survival may be compromised (Rhoads et al., 2004). However, a BUN beyond the threshold does not always result in significant reproductive performance differences as Moriel et al. (2012) found. Heifers housed in the drylot and fed low or medium quality hay had had no difference in AI conception rate when BUN concentrations were 17.2 and 22.8 mg/ dL, respectively (Moriel et al., 2012). Other work by Rhoads et al. (2006) investigated the quality of embryos flushed from superovulated lactating cows having moderate or high BUN concentrations. Dairy cows with BUN concentrations > 19 mg/dL produced oocytes that had decreased viability. Authors attributed the decrease to toxic effects of urea on the oocyte or the early embryo. In the present study cows were not exposed to the high CP forage until following AI. The reproductive performance issues attributed to elevated BUN are likely multifactorial, by

not exposing cows to high CP diets during oocyte development may have prevented the effects that elevated nitrogen levels have on AI pregnancy rate.

In conclusion, there were no supplementation $\times$ age interactions excluding d 42 BCS. Supplementation regardless of female age tended to improve d 42 BW and BW change. Cow BHBA and BUN was greater compared to the heifers whereas the supplemented females had lower NEFA and BUN. Even though cows tended to have greater AI pregnancy rates than heifers, supplementation did not affect AI or overall pregnancy rates.

TABLE AND FIGURES

Table 3.1: The effect of corn supplementation on female body weight (BW) and body condition score (BCS)

Item	Treatment ¹				SEM	P-value ²		
	Heifers		Cows			Sup	Age	S × A
	Control	SUPP	Control	SUPP				
BW, kg								
d 0	447	447	559	559	5.1	0.99	<0.01	0.98
d 42	447	456	548	554	7.8	0.10	<0.01	0.77
Change	-1	9	-9	0	5.5	0.10	0.12	0.96
BCS								
d 0	5.9	5.9	5.5	5.5	0.20	0.97	<0.01	0.83
d 42	5.5 ^b	5.7 ^a	5.6 ^b	5.6 ^b	0.12	0.09	0.27	0.04
Change	-0.4	-0.2	0.1	0.1	0.09	0.32	<0.01	0.38

¹Control= no supplement; SUPP = 1.81 kg as-fed/female/d of dry rolled corn; Heifers = yearling heifers; cows = two-yr-old lactating cow-calf pairs.

² Abbreviations are defined as supplementation effect (Sup) and Supplementation × Age effect (S × A).

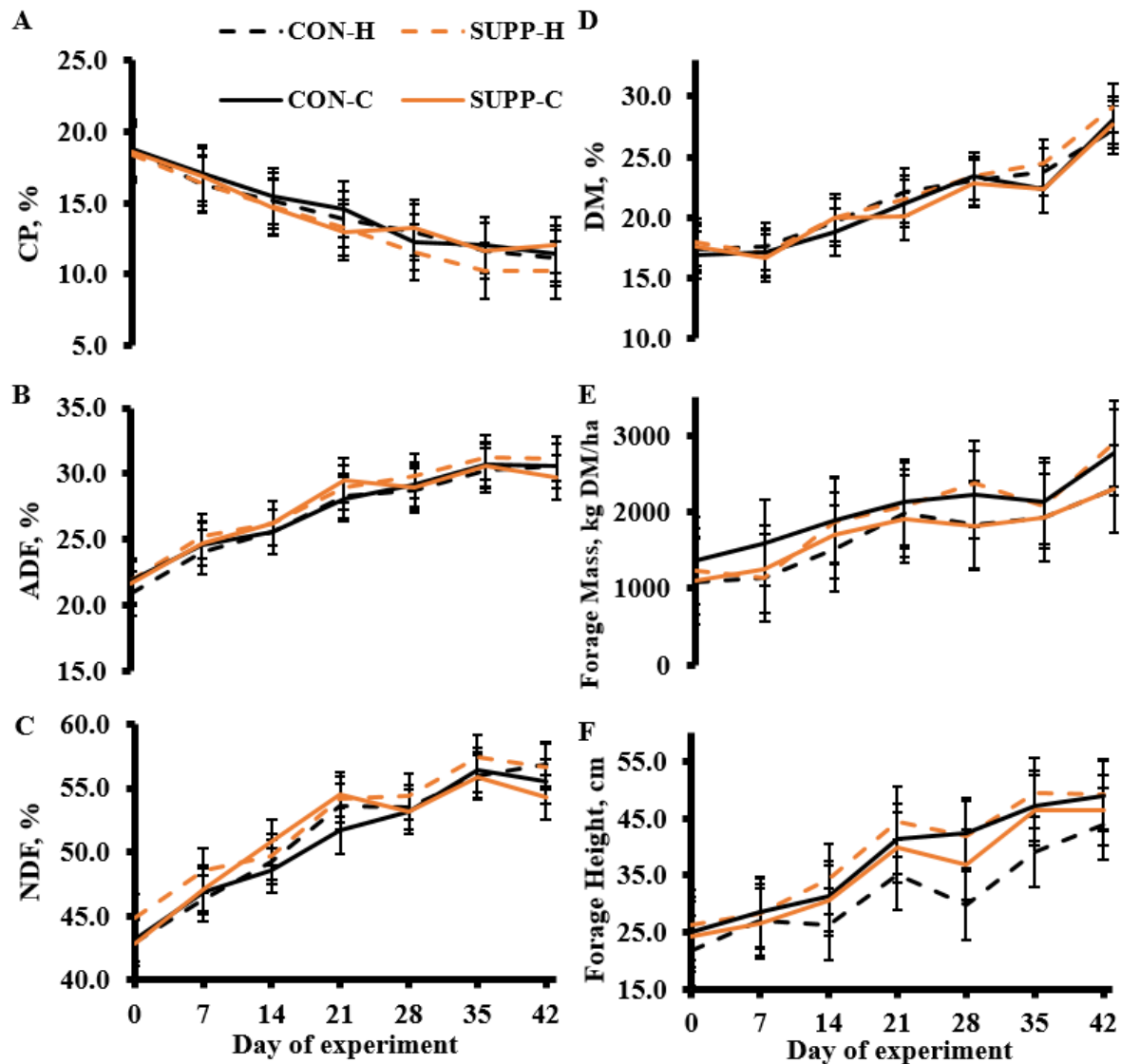


Figure 3.1. Pasture forage classification (crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), dry matter (DM), forage mass, and forage height) of treatment combinations {yearling heifers receiving no supplement (**CON-H**); yearling heifers receiving supplement of dry rolled corn [(**SUPP-H**); 1.81 kg as-fed/heifer/d]; two-yr-old lactating cow-calf pairs receiving no supplement (**CON-C**); and two-yr-old lactating cow-calf pairs receiving supplement of dry rolled corn [(**SUPP-C**); 1.81 kg as-fed/cow/d]} sampled over 42 d from the end of April through early June in 2017 and 2018. Supplementation $\times$ age $\times$ time, supplementation $\times$ age, supplementation $\times$ time, age $\times$ time, supplementation, and age effects were not detected ($P \geq 0.28$) for CP, ADF, NDF, or DM. Supplementation $\times$ age $\times$ time, supplementation $\times$ time, age $\times$ time, supplementation, and age effects were not detected ($P \geq 0.31$) for forage height or forage mass. However, a supplementation $\times$ age effects were detected ($P < 0.01$) forage mass and a trend ($P \leq 0.08$) for forage height. There was a significant time effect ($P < 0.01$) on all forage classification parameters. Error bars = SEM.

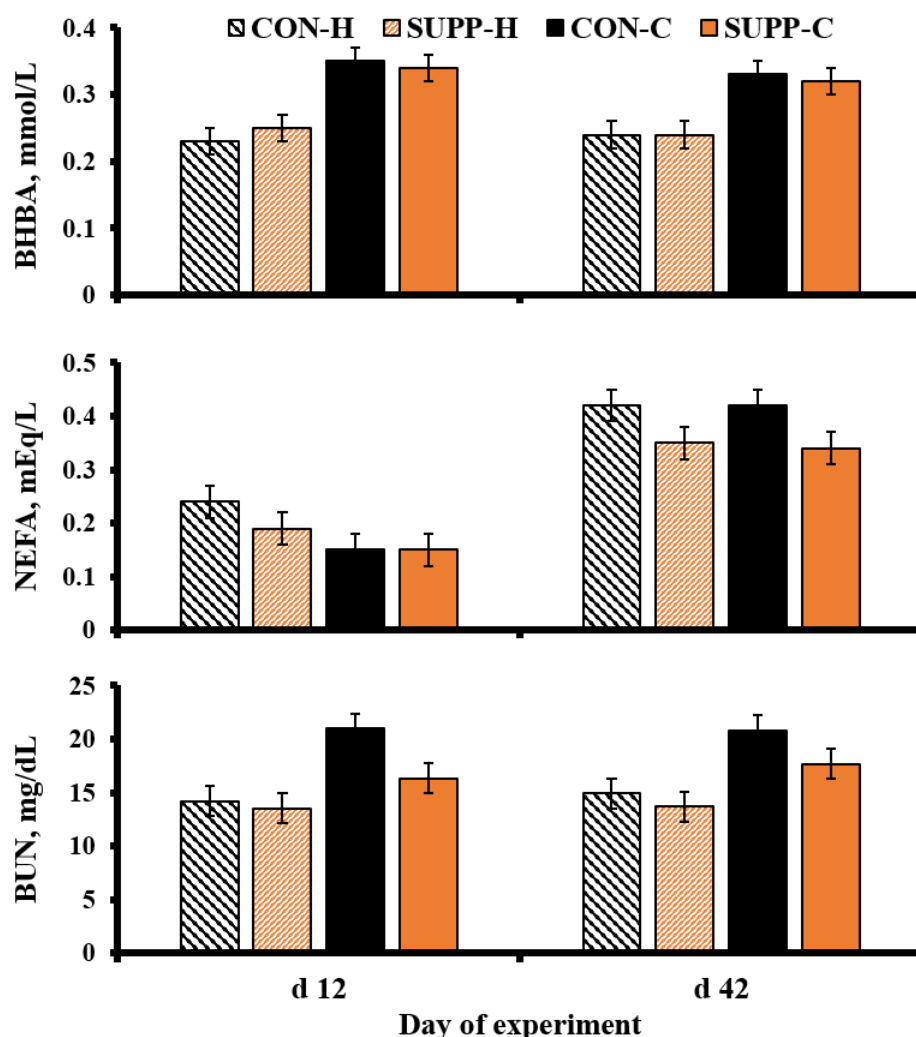


Figure 3.2. Serum concentration of nonesterified fatty acids (NEFA), β -hydroxybutyrate (BHBA), and blood urea nitrogen (BUN) on d 0, 12, and 42 of treatment combinations {yearling heifers receiving no supplement (**CON-H**); yearling heifers receiving supplement of dry rolled corn [(**SUPP-H**); 1.81 kg as-fed/heifer/d]; two-yr-old lactating cow-calf pairs receiving no supplement (**CON-C**); and two-yr-old lactating cow-calf pairs receiving supplement of dry rolled corn [(**SUPP-C**); 1.81 kg as-fed/cow/d]} in a 2-yr experiment. Supplementation $\times$ age $\times$ time, supplementation $\times$ age, supplementation $\times$ time, age $\times$ time, supplementation and time effects were not detected ($P \geq 0.22$) for serum BHBA concentration; but, an age effect was detected ($P < 0.01$). Supplementation $\times$ age $\times$ time, supplementation $\times$ age, supplementation $\times$ time, age $\times$ time and age effects were not detected ($P \geq 0.11$) for serum NEFA concentration; however, supplementation and time effects were detected ($P \leq 0.02$). Supplementation $\times$ age $\times$ time, supplementation $\times$ age, supplementation $\times$ time, age $\times$ time and time effects were not detected ($P \geq 0.18$) for serum BUN concentration; but, supplementation and age effects were detected ($P \leq 0.03$). Error bars = SEM.

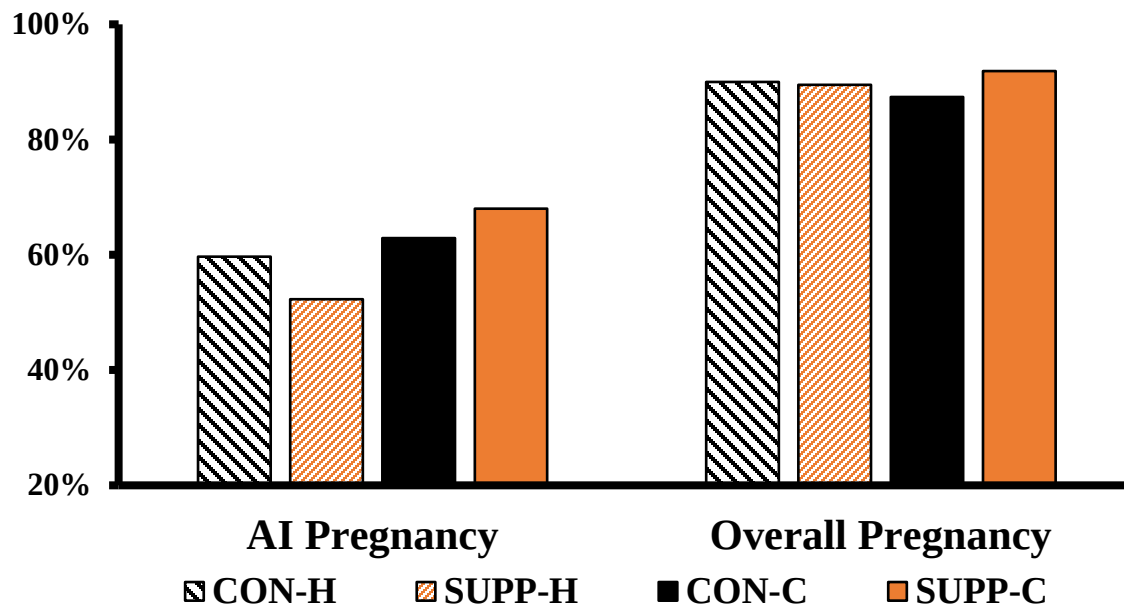


Figure 3.3. Reproductive performance [artificial insemination (AI) pregnancy rate and overall pregnancy rate] of treatment combinations {yearling heifers receiving no supplement (**CON-H**); yearling heifers receiving supplement of dry rolled corn [(**SUPP-H**); 1.81 kg as-fed/heifer/d]; two-yr-old lactating cow-calf pairs receiving no supplement (**CON-C**); and two-yr-old lactating cow-calf pairs receiving supplement of dry rolled corn [(**SUPP-C**); 1.81 kg as-fed/cow/d]} in a 2-yr experiment. Supplementation $\times$ age and supplementation effects were not detected ($P \geq 0.25$) for AI or overall pregnancy rate percentage. Age tended ($P = 0.07$) to affect AI pregnancy rate, but not affect ($P = 0.98$) overall pregnancy rates.

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CHAPTER 4

INFLUENCE OF DISTILLERS GRAINS WITH SOLUBLES ON BULL GROWTH AND REPRODUCTIVE TRAITS

ABSTRACT

This study evaluated the effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on growth, composition, hoof scores, and reproductive performance. Simmental $\times$ Angus bulls ($n = 28$) were stratified by body weight (BW; 316 ± 29 kg), sire, and d 0 semen production (Y/N) and assigned into 1 of 6 pens. Pens were randomly assigned to 1 of 2 dietary treatments ($n = 3$ pens/treatment): 1) offered free choice access to a corn-based diet with no MWDGS (**CON**), or 2) offered free-choice access to a diet with 40% MWDGS (**DST**; DM basis). Bulls were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d. Bull BW, body condition score (BCS), hip height (HH), ultrasound [rump fat depth (RF), 12th rib fat thickness (BF), marbling score (MS), and longissimus muscle depth (MD)], hoof evaluations, breeding soundness examination (BSE), and semen evaluations were performed on d 0, 28, 56, 84, 112, 140, 175, and 210. There was a tendency ($P < 0.09$) for a treatment $\times$ time effect for BW. Bulls fed DST tended ($P \leq 0.10$) to be heavier on d 28 and 56 than CON bulls. A treatment $\times$ time effect was detected ($P < 0.01$) for RF. Bulls fed DST had greater ($P = 0.02$) RF on d 84 than CON bulls. Treatment $\times$ time and treatment effects were detected ($P \leq 0.05$) for BF, which DST bulls had greater ($P \leq 0.05$) BF on d 84, 112, and 175 and tended ($P \leq 0.10$) to be greater on d 56 and 210 than CON bulls. A treatment $\times$ time effect was detected ($P < 0.02$) for percentage of major sperm defects. Bulls fed DST had a greater ($P < 0.01$) percentage of major sperm defects on d 140 than control bulls. There was a tendency ($P = 0.09$) for a treatment $\times$ time effect for percentage of

sperm with proximal droplets. Bulls fed DST had a greater ($P = 0.01$) percentage of sperm with proximal droplets on d 140 than CON bulls. In conclusion, offering growing bulls a diet with 40% MWDGS (DM basis) resulted in heavier BW at d 28 and 56, increased RF at d 84, increased BF, and increases in both major sperm defects and sperm with proximal droplets at d 140. However, after 70 d on the common low-energy diet there were no carryover effects for any growth, composition, hoof, or reproductive measures except for a tendency for BF.

INTRODUCTION

The two most important factors that drive the financial success of a cow-calf enterprise are nutrition and reproduction (Hess et al., 2005). Additionally, Bellows et al. (2002) reported that reproductive conditions and diseases could cost beef cattle producers as much as \$502 million in lost income yearly. A significant portion of the reproductive failures in cow calf enterprises are due to the fertility of the herd bull (Flowers, 2013). A majority of spring-calving seedstock operations in the Midwest market their bulls in the early spring, but, producers generally do not expose them to cows until late spring or early summer. Many seedstock producers develop bulls on grain-based, high energy diets prior to sale. Costs associated with feeding these diets has led producers to consider cheaper alternatives such as distillers grains with solubles. However, distillers grains with solubles can contain relatively high concentrations of S and crude fat, and although variability in new generation ethanol refineries has been decreased, excess crude protein, crude fat, and S in the diet may be a concern. Van Emon et al. (2013) reported a linear decrease in spermatozoa concentration of rams as distillers dried grains with solubles (DDGS) increased in the diet (0, 15, and 30%; DM basis). Additionally, Crane et al. (2018) fed increasing concentrations (0, 15, 30, and 45%; DM basis) of DDGS and observed decreased scrotal circumference but increased spermatozoa concentration and morphologically

normal sperm of rams. Due to minimal research with inconsistent results, it is not clear if distillers grains with solubles should be included in the diet of breeding bulls, thus, further research is warranted. Therefore, the objectives of this study were to evaluate the effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on body weight (BW), body condition score (BCS), hip height (HH), ultrasound [rump fat depth (RF), 12th rib fat thickness (BF), marbling score (MS), and longissimus muscle depth (MD)], hoof evaluations, reproductive measures, percent of bulls that were pubertal, percent of bulls with a satisfactory breeding soundness examination (BSE), and semen motility, morphology, and concentration. Authors hypothesized that offering a diet with 40% MWDGS (DM basis) would negatively impact semen motility, morphology, and concentration at the end of the treatment period. However, bull growth performance, body composition, and hoof evaluations would not be affected.

MATERIALS AND METHODS

All experimental procedures were approved by the Institutional Animal Care and Use Committee of the University of Illinois (IACUC #17240) and followed the guidelines recommended in the Guide for the Care and Use of Agricultural Animal in Agricultural Research and Teaching (FASS, 2010). The experiment was performed over a 210 d period from October 2017 to May 2018.

Animals and Experimental Design

Spring-born, Simmental × Angus bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d, n = 28) housed at the University of Illinois Beef Cattle and Sheep Field Laboratory in Urbana, IL were utilized to evaluate the effects of a diet with 40% MWDGS (DM basis) on bull reproductive and growth performance. Bulls were stratified by BW, sire, and if they produced

semen on d 0 ($n = 7$) and assigned into 1 of 6 pens with 4 or 5 bulls per pen. Bulls were housed in a barn constructed of wood frames with ribbed metal roofs and siding on the north, west, and east sides. The south side of each barn was covered with polyvinyl chloride-coated 1.27-by-1.27-cm wire mesh bird screen and equipped with retractable curtains for wind protection. Within the barn, pens (4.88×9.76 m) had concrete slats covered with rubber mats. Pens were randomly assigned to 1 of 2 dietary treatments ($n = 3$ pens/treatment; Table 1): 1) offered free-choice access to a corn-based diet with no MWDGS (**CON**), or 2) offered free-choice access to a diet with 40% MWDGS (**DST**; DM basis). Bulls were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d. Forty d before the start of the study bulls were weaned and shipped from Orr Agricultural Research and Demonstration Center in Baylis, IL to the Beef and Sheep Field Research Laboratory in Urbana, IL where they were offered free-choice access to a common diet (50% alfalfa haylage, 45% corn silage, and 5% ground corn-based supplement; DM basis) and adapted to the GrowSafe automated feeding system (model 4000E, GrowSafe Systems Ltd., Airdrie, AB, Canada). Fifty-two d prior to weaning, bulls received 5 mL Bovi-shield Gold FP5 VL5 HB (Zoetis, Parsippany, NJ), 2 mL One Shot Ultra 8 (Zoetis, Parsippany, NJ), and 2 mL MpB Guard (American Health Inc., Ronkonkoma, NY). Twenty-one d prior to weaning, bulls received 5 mL Bovi-shield Gold FP5 VL5 HB (Zoetis, Parsippany, NJ), 2 mL Ultra Choice 8 (Zoetis, Parsippany, NJ), 2 mL MpB Guard (American Health Inc., Ronkonkoma, NY), and 1 mL/nostril Inforce 3 (Zoetis, Parsippany, NJ). At the time of weaning all bulls received 1 mL/9.98 kg BW Eprinex (Merial, Duluth, GA). One bull from DST had to be removed from the experiment for chronic respiratory disease.

Sample Collection and Analytical Procedures

Full BW were collected on 2 consecutive days prior to feeding (approximately 0700) at the beginning of the treatment period (d 0 and 1) and at the end of the treatment period (d 139 and 140). Additional full BW were collected prior to feeding (approximately 0700) on d 28, 56, 84, 112, 175, and 210. All BW were taken using a Flying W squeeze chute (Flying W Livestock, Watonga, OK) equipped with a Tru-Test (Tru-Test Inc., Mineral Wells, TX) weighing system. On d 0, 28, 56, 84, 112, 140, 175, and 210, HH was evaluated using a measuring stick (Altitude Stick, Nasco, Fort Atkinson, WI). Individual feed intake was collected using the GrowSafe automated feeding system (model 4000E, GrowSafe Systems Ltd., Airdrie, AB, Canada) throughout the entire study.

Bull RF, BF, MS, and MD were estimated on d 0, 28, 56, 84, 112, 140, 175, and 210 via ultrasound. Ultrasound measurements were taken by trained personnel using an Aloka 500SV (Wallingford, CT) B-110 mode instrument equipped with a 3.5-Mhz general purpose transducer array. Back fat depth, MS, and MD were taken in transverse orientation between the 12th and 13th ribs approximately 10 cm distal from the midline. Images were analyzed using CPEC imaging software (Cattle Performance Enhancement Company LLC., Oakley, KS).

Hoof evaluations were quantified using the American Angus Association's simple foot scoring system, which characterizes cattle for two traits: foot angle and claw set. Both scores are ranked on a 1-9 scoring system with 5 being ideal. An animal characterized as a 5 for foot angle would have a 45-degree angle to the pastern. Animals that are extremely straight in their front-end and up on their toes would score a 1, while an animal with a very shallow heel and extremely long toes would score a 9. Animals must have symmetrical claws with some space between them

in order for an animal to be scored with an ideal claw set, or a 5. Animals scoring a 9 would have extreme scissor claw or screw claw with the curling and crossing of both claws, while animals scoring a 1 for claw set would have extremely weak, open or divergent claws

Feed ingredient samples were collected once every 2 weeks throughout the experiment. Equal portions of each ingredient in each period were composited. Composite samples were dried and ground through a Wiley mill (1-mm screen, Arthur H. Thomas, Philadelphia, PA). Ingredients were analyzed for dry matter (DM; 24 h at 103 °C), neutral detergent fiber (NDF) and acid detergent fiber (ADF; using Ankom Technology method 5 and 6, respectively; Ankom200 Fiber Analyzer, Ankom Technology), crude protein (CP; Leco TruMac, LECO Corporation, St. Joseph, MI), ether extract (EE, Ankom method 2; Ankom Technology), and ash (600 °C for 2 h; Thermolyte muffle oven Model F30420C; Thermo Scientific, Waltham, MA). Additionally, samples were sent to Michigan State University Veterinary Diagnostic Laboratory (Lansing, MI) and concentrations of Ca, Cu, Mn, P, S, and Zn were analyzed using a Varian Vista-Pro Inductively Coupled Plasma Optical Emission Spectrometry (ICP/OES; Agilent Technologies Inc.; Palo Alto, CA).

Reproductive Performance

A complete BSE was performed on d 0, 28, 56, 84, 112, 140, 175, and 210. The examination included a subjective assessment of physical soundness, including evaluation of the legs, feet and eyes. Each bull was assigned a BCS of 1-9, scrotal circumference (SC) was measured, and spermatic cord circumference (SCORD) was measured with a steel tape (Lane Manufacturing, Denver, CO, USA) in cm at the widest portion of the scrotum or spermatic cord, respectively. Palpation of testicles and epididymides was performed to assess tone, symmetry and presence of adhesions, scars, or malformations of external genitalia. Transrectal palpation

was performed to assess the tone and symmetry of the accessory sex glands. During semen collection, the penis was examined for abnormalities. Bulls failed BSE if their semen sample exhibited <30% total motility, <70% normal sperm morphology, or a SC lower than recommended for their respective age range (Koziol and Armstrong, 2018).

Semen samples were collected on d 0, 28, 56, 84, 112, 140, 175, and 210. Sample collection occurred at approximately the same time in the morning, 0700-1100 h, to minimize the effects of daily hormonal fluctuations. To obtain semen samples, a 60-mm upright weighted bull probe (Lane Manufacturing, Inc., Denver, CO) was placed rectally, and the programmed cycle on the electroejaculator (Pulsator IV, Lane Manufacturing, Inc., Denver, CO) was allowed to run. Once at least 3 mL of semen was collected, the electroejaculation was concluded and the probe was removed. If an appropriate ejaculate was not obtained following the cycle, the bull was recorded as no semen was produced. Semen was collected into 15-ml conical tubes using collecting handles and sleeves. Semen samples were transported in a warm water (37°C) bath to the laboratory for no longer than 15 m post-collection. Semen was diluted 1:100 in buffered formalin (10%), and 10 μ L of diluted semen was placed into an hemocytometer chamber to assess the concentration (Improved Neubauer, Hausser Scientific, Horsham, PA). The concentration (n. sperm/mL) was calculated by multiplying the dilution factor to the mean number of sperms counted in 5 squares to a fixed factor (10,000). Computer-Assisted Sperm Analysis (CASA) equipment (Spermvision, MiniTube of America, Inc., Verona, WI) was used to obtain overall and progressive motility by averaging seven readings from various portions of the slide or thousand cells. As per the manufacturer's defaults, CASA-established set-up parameters for bovine sperm were as follows: frame capture speed rate, 60 Hz; cell size (min/max), 18/60 μ m²; threshold straightness, 50%; velocity average path cut-off, 56 μ m/s; and velocity

straight line cut-off, 28 $\mu\text{m/s}$. Morphological abnormalities were assessed by a single-blinded observer by examining high-power images ($100\times$ with phase contrast lens) of multiple sections of the chambered slide. Images were used to classify morphology as normal or abnormal. Abnormalities were further defined as major or minor defects by the same observer for all samples on all collection days based on the standards set forth by Koziol and Armstrong (2018). After assessment of 200 sperm cells from each diluted semen sample, the percentages of normal, major and minor abnormalities were calculated. On d 0, 28, 56, 84, 112, 140, 175, and 210, bulls were evaluated for pubertal status. Bulls were determined to have reached puberty when at least 50 million sperm with at least 10% progressive motility were present in the ejaculate, according to Wolf et al. (1965).

Statistical Analysis

Data were analyzed as a stratified randomized design using pen as the experimental unit in SAS 9.4 (SAS Inst. Inc., Cary, NC). Body weight, BCS, HH, RF, BF, MS, MD, hoof angle score, and hoof claw score were analyzed as repeated measures in the MIXED procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC), with fixed effects of treatment, time, and the interaction of treatment and time. Additionally, the most appropriate expected progeny differences (EPD) estimate was used as a covariate to help account for inherent genetic differences. If no EPD was appropriate, sire was included as a covariate. Baseline values collected at start of the study were included as a covariate. Pen(treatment) was included as a random effect. Bull(Pen) was the subject of the REPEATED statement. The heterogeneous autoregressive (1) covariance structure was selected based on Akaike information criterion and experimental design fit. Reproductive measures, semen evaluation, and semen morphology were analyzed as repeated measures in the MIXED procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC), with fixed effects of treatment, time,

and the interaction of treatment and time. Sire was used as a covariate to help account for inherent genetic differences. Bull semen production on d 0 (yes or no) was included as a covariate. Bull(Pen) was the subject of the REPEATED statement. The autoregressive (1) covariance structure was selected based on Akaike information criterion and experimental design fit. Binomial data (Bull pubertal status and bulls with a satisfactory BSE) were converted to working variables (x) based on the proportion of successes within n groups (6 total pens). The working variables were transformed using $\sin^{-1}(x)^{0.5}$ as described by Humblot et al. (1991) because of nonnormality. When $x = 0$, the observation 0 was replaced with $(1/4) (1/n)$, and when $x = 1$, the observation was replaced with $1 - (1/4) (1/n)$ (Bartlett, 1947). Estimates (of y) were back-transformed using $[\sin(y)]^2$. The residuals for sperm concentration were not normally distributed and were transformed using the BoxCox procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) using $X^{0.25}$. For the percentage of morphologically normal sperm, plots of residual versus fitted values showed a reduction in variation as the percentage normal approached 100%. A log transformation was, therefore, applied $[\log_e (100 - \% \text{ normal})]$. For sperm morphological abnormalities, plots of residuals versus fitted values showed the variation increasing with the mean. A log transformation was performed for all morphologically abnormal traits and sperm concentration before analysis to stabilize the variance. Least square means were back-transformed for ease of interpretation. The SLICE statement was used to separate least square means when the interaction of treatment and time was significant ($P \leq 0.05$). Significance was declared at $P \leq 0.05$ and tendencies were noted at $0.05 < P \leq 0.10$. Means reported in tables and figures are least squares means.

RESULTS

There was a tendency ($P < 0.09$; Fig 4.1) for a treatment $\times$ time effect for BW. Bulls fed DST tended ($P \leq 0.10$) to be heavier on d 28 and 56 than CON bulls. However, a treatment effect was not detected ($P = 0.25$) for BW. Treatment $\times$ time and treatment effects were not detected ($P \geq 0.27$; Fig 4.1) for BCS or HH. Nevertheless, a time effect was detected ($P \leq 0.01$) for BW, BCS, and HH, which BW and HH increased over time whereas BCS increased to d 140 then decreased to d 210. Treatment effects were not detected ($P \geq 0.17$; Table 4.3) for d 1 to 140 ADG, d 140 to 210 ADG, d 1 to 140 DMI, d 140 to 210 DMI, d 1 to 140 G:F, and d 140 to 210 G:F.

A treatment $\times$ time effect was detected ($P < 0.01$; Fig 4.2) for RF. Bulls fed DST had greater ($P = 0.02$) RF on d 84 than CON bulls. However, a treatment effect was not detected ($P = 0.34$) for RF. Treatment $\times$ time and treatment effects were detected ($P \leq 0.05$; Fig 4.2) for BF, which DST bulls had greater ($P \leq 0.05$) BF on d 84, 112, and 175 and tended ($P \leq 0.10$) to be greater on d 56 and 210 than CON bulls. Bulls fed DST had greater ($P = 0.05$) BF than CON bulls. Treatment $\times$ time and treatment effects were not detected ($P \geq 0.16$; Fig 4.2) for MS or MD. A time effect was detected ($P \leq 0.01$) for RF, BF, MS, and MD, which bull RF, BF, MS, and MD increased to d 140 followed by decrease from d 140 to 210.

Treatment $\times$ time and treatment effects were not detected ($P \geq 0.55$; Table 4.4) for foot angle or claw set. However, a time effect was detected ($P \leq 0.01$) for foot angle and claw set. Foot angle initially decreased and then increased over time. Claw set increased over time.

Treatment $\times$ time and treatment effects were not detected ($P \geq 0.13$; Table 4.5) for SC or SCORD. Furthermore, a time effect was detected ($P < 0.01$) for SC and SCORD, which both increased over time. Additionally, Treatment $\times$ time and treatment effects were not detected ($P \geq$

0.53; Table 4.6) for percent of bulls that were pubertal or percent of bulls with a satisfactory BSE. However, time effects were detected ($P < 0.01$) for percent of bulls that were pubertal and percent of bulls with a satisfactory BSE, more bulls became pubertal and had satisfactory BSE over time.

Treatment $\times$ time and treatment effects were not detected ($P \geq 0.12$; Fig 4.3) for percentage of sperm with normal morphology or percentage minor sperm defects. A treatment $\times$ time effect was detected ($P < 0.02$; Fig 4.3) for percentage of major sperm defects. Bulls fed DST had a greater ($P < 0.01$) percentage of major sperm defects on d 140 than control bulls. There was a tendency ($P = 0.09$; Fig 4.3) for a treatment $\times$ time effect for percentage of sperm with proximal droplets. Bulls fed DST had a greater ($P = 0.01$) percentage of sperm with proximal droplets on d 140 than CON bulls. A time effect was detected ($P < 0.01$) for percentage of sperm with normal morphology, percentage minor sperm defects, percentage of major sperm defects, and percentage of sperm with proximal droplets; percentage of sperm with normal morphology increased over time whereas percentage minor sperm defects, percentage of major sperm defects, and percentage of sperm with proximal droplets decreased over time.

Treatment $\times$ time and treatment effects were not detected ($P \geq 0.40$; Fig 4.4) for overall motility percentage, progressive motility percentage, and sperm concentration. However, a time effect was detected ($P < 0.01$) for overall motility percentage, progressive motility percentage, and sperm concentration, which all increased over time.

DISCUSSION

Bulls fed DST had improved BW at d 28 and 56, but this advantage was not observed at any of the remaining time points. Additionally, there were no differences in ADG, DMI, and G:F in the current study. Van Emon et al. (2013) and Crane et al. (2018) did not observe any effects

on ram lamb final BW or ADG when comparing a control with no DDGS to increasing inclusions of DDGS. However, in a study by Lourenco et al. (2016), BW was greater for bulls fed a corn-based diet compared with a diet that contained 24.5% DDGS (DM basis). Conversely, Klopfenstein et al. (2008) in a meta-analysis noted that when wet distillers grains plus solubles (WDGS) were fed to finishing cattle, ADG and feed efficiency increased linearly in respect to the amount of WDGS added to the diet. However, DMI of those finishing animals decreased linearly in relation to the level of WDGS fed, but all levels (10, 20, and 30% WDGS; DM basis) were still greater than cattle on a control diet. In contrast, Richter et al. (2012) observed that steers supplemented with DDGS that was high in S (0.6%; DM basis) responded with decreased ADG compared with steers supplemented with DDGS that was low in S (0.2%; DM basis). In the current study, S was 0.24% of the DST diet (DM basis). The NASEM (2016) indicates potential S toxicity when S content is greater than 0.3% of the diet (DM basis) in concentrate-based diets. There were no observed cases of S toxicity in the current study.

Bulls fed DST did have the composition of gain altered. The DST bulls had increased fat deposition. Larson et al. (1993) reported a linear increase in yield grade and marbling score when WDGS were fed at levels up to 40% (DM basis) to steers. Similarly, it was concluded by Klopfenstein et al. (2008) that linear increases in BF will be experienced with increasing levels of WDGS (10, 20, and 30%; DM basis) in the diets, while MS will be optimal at 30% inclusion (DM basis) of WDGS. In contrast, Lourenco et al. (2016) noted a decrease in ultrasound BF and RF of growing bulls fed a diet that included 25% DDGS (DM basis) compared to a corn-based control. In that same study, they noted no differences in MS or rib eye area.

Diet type and energy density have been known to impact the hoof quality and foot score of cattle (Lean et al., 2013). In the current study, there were no treatment differences in claw set

score or foot angle score. However, over time both scores changed. Foot angle initially got more up right, which is likely due to bulls transitioning to concrete floors covered in mats, followed by scores increasing and becoming more relaxed in angle. This change is expected as bulls mature and get to a heavier BW. Bull claw set became more curled over time which is expected of animals on high-energy diets (Lean et al., 2013).

During the period when the bull is transitioned to a lower energy diet, excessive BF is shed to reach an optimum BCS for the breeding season. This change in dietary energy level was implemented to replicate producer practices as well as to provide an opportunity for reproductive convalescence (not necessarily performance convalescence). In this case, bulls quickly adjusted to the LE diet. Since all of the bulls were receiving the same diet for the final 70 d of the study, treatment differences in BW or ADG were not expected.

It is generally understood that breeding age bulls must have a minimum SC between 28 and 30 cm depending on breed (Wolf et al., 1965; Spitzer and Hopkins, 1997). Because of the relationship between puberty and SC, Koziol and Armstrong (2018) recommend a minimum scrotal circumference of 30 cm in all yearling bulls used for breeding. All bulls in the current study had a SC of 32 cm or greater on d 140, which suggests that all bulls were acceptable. Comparable gains for DST and CON bulls would indicate that net energy for growth was similar and likely the reason for no treatment effect on SC or SCORD. Crane et al. (2018) reported a linear decrease for ram SC when feeding increasing levels (0, 15, 30, and 45%; DM basis) of DDGS. Previous work by Coulter and Kozub (1984) reported feeding bulls increasing energy in their diets resulted in increased testicular size. Similarly, Martin et al. (1994) noted an increase in scrotal circumference when rams were fed the high protein and energy rations compared to the rams fed the low energy and protein rations. Hötzel et al. (1998) also observed an increase in SC

throughout the study in rams fed to have an increased rate of gain. There were no differences in the percent of bulls passing a BSE. On d 140 (bull age = 387 d $\pm$ 6), the percent of bulls passing a BSE for CON and DST was 58% and 44% respectively.

Bulls fed DST had an increase in percentage of major sperm defects on d 140 and this was a result of DST bulls having an increase in the percent of sperm with proximal droplets. Proximal droplets are considered a major sperm defect. Barth and Waldner (2002) noted that it is not uncommon to find a higher percentage of sperm with proximal droplets in semen from yearling bulls. These defects typically resolve with age and a reduction in proximal droplet percentage would be expected at BSE conducted closer to time of sexual maturity (Barth and Waldner, 2002). No other nutritional cause for proximal droplets has been noted in the literature. Furthermore, the only study that has looked at feeding distillers grains with solubles and its impact on sperm morphology was performed by Crane et al. (2018), which actually noted no negative impacts on the morphology of spermatozoa and for some traits, improved morphology when feeding increasing levels (0, 15, 30, and 45%; DM basis) of DDGS. Based on the lack of major morphological defects authors concluded that a total diet S of 0.4% (at 45% inclusion of DDGS; DM basis) was not leading to mineral deficiencies *in vivo* (Crane et al., 2018). This dietary S value is still greater than that of the current study where S was 0.23% of the DST diet (DM basis). In the current study there was a time effect for percent normal sperm. As bulls increased in age and maturity the percent normal sperm increased. Means for percentage of sperm with normal morphology would have met the minimal standards according to Koziol and Armstrong (2018) from d 112 to 210.

Overall motility percentage, progressive motility percentage, and sperm concentration were not affected by offering a diet with 40% MWDGS (DM basis). The previously mentioned

study by Crane et al. (2018), actually noted a linear increase in spermatozoa concentration as DDGS concentration increased (0, 15, 30, and 45%; DM basis) in the diets. However, in a similar study by Van Emon et al. (2013), they observed a linear decrease in spermatozoa concentrations in response to increasing levels of DDGS (0, 15, and 30%; DM basis) in the diet. Van Emon et al. (2013) indicated inadequate utilization of selenium and copper as a possible explanation for the observed reduction in spermatozoa concentration. According to the NASEM (2016), high-dietary levels of S can alter selenium and copper utilization and absorption. Excessive S intake can be toxic and could cause decreased performance and possibly cause PEM and death (Gould, 1998). The NASEM (2016) states that the maximum level of S tolerated in concentrate diets is 0.3% (DM basis). In the study by Van Emon et al. (2013), S was 0.5% (DM basis) when DDGS was included at 30% of the diet (DM basis). Whereas Crane et al. (2018) noted S was 0.4% (DM basis) when DDGS was included at 45% of the diet (DM basis). In the current study, when MWDGS was included at 40% of the diet (DM basis), S was 0.23% of the diet (DM basis).

In conclusion, offering growing bulls a diet with 40% MWDGS (DM basis) resulted in heavier BW at d 28 and 56, increased RF at d 84, increased BF, and increases in both major sperm defects and sperm with proximal droplets at d 140. However, after 70 d on the common low-energy diet there were no carryover effects on any growth, composition, hoof, or reproductive measure except for a tendency for BF.

TABLES AND FIGURES

Table 4.1: Ingredients of diets fed to growing bulls during treatment period and following common low-energy period

Item	CON Transition Steps ¹					DST Transition Steps					Low-energy
	1	2	3	4	5	1	2	3	4	5	
Ingredient inclusion, % DM											
Dry-rolled corn	0	10	20	30	40	-	-	-	-	-	-
MWDGS ²	-	-	-	-	-	0	10	20	30	40	-
Chopped grass hay	-	-	-	-	-	-	-	-	-	-	60
Alfalfa haylage	50	50	40	30	25	50	50	40	30	25	-
Soybean hulls	0	0	5	15	25	0	0	5	15	25	10
Corn Silage	45	35	25	15	0	45	35	25	15	0	20
Supplement ³											
Ground corn	4.37	4.37	5.41	5.41	5.41	4.37	4.37	8.22	8.22	8.22	7.62
Limestone	0.45	0.45	0.90	0.90	0.90	0.45	0.45	1.59	1.59	1.59	1.59
Urea	0.67	0.67	-	-	-	0.67	0.67	-	-	-	0.60
Blood	-	-	3.50	3.50	3.50	-	-	-	-	-	-
Trace mineral premix ⁴	0.089	0.089	0.091	0.091	0.091	0.089	0.089	0.091	0.091	0.091	0.91
Rumensin 90	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.016
Tylosin ⁵	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Fat	0.076	0.076	0.075	0.075	0.075	0.076	0.076	0.075	0.075	0.075	0.075

¹ Treatments were as follows (n = 3 pens/treatment): 1) offered free-choice access to a corn based diet with no modified wet distillers grains plus solubles (MWDGS; CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Diets were fed to bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) as follows: step 1 = d -35 to 1; step 2 = d 1 to 7; step 3 = d 8 to 14; step 4 = d 15 to 21; step 5 = d 22 to 140; low-energy = d 141 to 210.

² Modified wet distillers grains plus solubles.

³ Premix.

⁴ 8.5% Ca, 5% Mg, 7.6% K, 6.7% Cl, 10% S, 0.5% Cu , 2% Fe , 3% Mn , 3% Zn, 278 mg/kg Co, 250 mg/kg I, 150 mg/kg Se, 2,205 KIU/kg Vit A, 662.5 KIU/kg Vit D, 22,047.5 IU/kg Vit E.

⁵ Tylan 40, Elanco Animal Health, Greenfield, IN.

Table 4.2: Chemical composition of diets fed to growing bulls during treatment period and following common, low-energy period

Item	CON Transition Steps ¹					DST Transition Steps					Low-energy
	1	2	3	4	5	1	2	3	4	5	
DM, %	33.3	35.9	41.9	50.2	63.2	33.3	35.1	39.7	45.8	54.5	63.4
Chemical Analysis ²	% of DM										
OM	92.4	92.7	93.1	93.9	94.4	92.4	92.4	92.0	92.5	92.7	90.7
CP	11.0	11.0	14.1	13.5	13.3	11.0	12.6	13.9	14.9	16.4	7.9
NDF	35.9	33.6	31.9	31.4	31.2	35.9	35.7	36.4	38.0	39.9	55.8
ADF	23.9	22.3	21.2	20.6	20.7	23.9	23.1	22.8	23.0	23.9	32.7
EE	2.8	3.0	3.1	3.2	3.2	2.8	3.6	4.2	4.9	5.5	1.7
	mg/kg of diet DM										
Ca	10996	10804	11019	9674	9119	10996	10876	12865	11592	11109	10577
P	2865	2966	2849	2715	2635	2865	3469	3883	4251	4673	1555
S	1534	1518	1555	1475	1430	1534	1768	1948	2118	2323	1108
Cu	15.2	14.9	12.3	11.7	11.3	15.2	15.3	14.3	14.1	14.0	11.1
Mn	81.2	79.8	63.8	59.4	56.5	81.2	80.9	76.2	72.9	71.0	113.2
Zn	71.3	71.2	60.5	60.8	61.5	71.3	74.7	78.7	82.6	86.7	50.0

¹ Treatments were as follows (n = 3 pens/treatment): 1) offered free-choice access to a corn based diet with no modified wet distillers grains plus solubles (MWDGS; CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Diets were fed to bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) as follows: step 1 = d -35 to 1; step 2 = d 1 to 7; step 3 = d 8 to 14; step 4 = d 15 to 21; step 5 = d 22 to 140; low-energy = d 141 to 210.

² Organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and ether extract (EE).

Table 4.3: Effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on average daily gain, dry matter intake, and gain:feed

Item	Treatment ¹		SEM	P-value
	CON	DST		
Average daily gain, kg/day				
d 1 to 140	1.93	1.95	0.05	0.70
d 140 to 210	0.14	0.23	0.10	0.61
Dry matter intake, kg/day				
d 1 to 140	11.1	10.6	0.40	0.44
d 140 to 210	9.5	9.4	0.24	0.69
Gain:Feed, kg/kg				
d 1 to 140	0.17	0.18	0.005	0.17
d 140 to 210	0.02	0.03	0.011	0.63

¹ Treatments were as follows (n = 3 pens/treatment): 1) offered free-choice access to a corn based diet with no MWDGS (CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d.

Table 4.4 Effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on foot angle and claw set over time

Item ³	Treatment ¹			P-Value ²		
	CON	DST	SEM	Trt	Time	Trt × Time
Foot angle				0.99	<0.01	0.91
d 28	5.6	5.7	0.22			
d 56	5.1	5.0	0.24			
d 84	5.5	5.5	0.24			
d 112	5.3	5.3	0.26			
d 140	5.2	5.2	0.23			
d 175	5.6	5.5	0.25			
d 210	5.9	5.9	0.28			
Claw set				0.73	<0.01	0.55
d 28	4.7	4.8	0.16			
d 56	4.9	4.9	0.20			
d 84	5.4	5.6	0.24			
d 112	5.3	5.2	0.16			
d 140	5.5	5.6	0.19			
d 175	6.0	5.7	0.17			
d 210	6.1	5.7	0.19			

¹ Treatments were as follows (n = 3 pens/treatment): 1) offered free-choice access to a corn based diet with no MWDGS (CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d.

² Abbreviations are defined as Treatment effect (Trt) and Treatment × time effect (Trt × Time).

³ Hoof evaluation was quantified using the American Angus Association's simple foot scoring system, which characterizes cattle for two traits: foot angle and claw set. Both scores are ranked on a 1-9 scoring system with 5 being ideal.

Table 4.5 Effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on scrotal circumference (SC) and spermatic cord circumference (SCORD) over time

Item	Treatment ¹			P-Value ²		
	CON	DST	SEM	Trt	Time	Trt × Time
SC ³ , cm				0.35	<0.01	0.13
d 28	27.3	27.4	0.45			
d 56	30.7	31.1	0.45			
d 84	32.7	33.1	0.45			
d 112	36.2	37.0	0.45			
d 140	36.8	36.3	0.46			
d 175	36.8	37.6	0.46			
d 210	39.2	40.6	0.46			
SCORD ⁴ , cm				0.42	<0.01	0.18
d 28	18.0	19.1	1.00			
d 56	24.1	24.9	1.00			
d 84	24.0	24.8	1.02			
d 112	30.6	32.3	1.00			
d 140	32.4	32.6	1.02			
d 175	35.7	35.4	1.02			
d 210	33.3	36.2	1.02			

¹ Treatments were as follows (n = 3 pens/treatment): 1) offered free-choice access to a corn based diet with no MWDGS (CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d.

² Abbreviations are defined as treatment effect (Trt) and treatment × time effect (Trt × Time).

³ SC was measured in cm using a scrotal tape measure placed around the widest portion on the scrotum.

⁴ SCORD was measured in cm using a scrotal tape measure placed around scrotum between the top of the testis and the body wall.

Table 4.6 Effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on the percentage of bulls that were pubertal and passed a breeding soundness examination (BSE) over time

Item	Treatment ¹		P-Value ²		
	CON	DST	Trt	Time	Trt × Time
Pubertal ³ , %			0.53	<0.01	0.81
d 1	0	0			
d 28	13.3	15.0			
d 56	33.3	15.0			
d 84	56.7	43.3			
d 112	71.7	51.7			
d 140	85.0	86.7			
d 175	100.0	93.3			
d 210	100.0	100.0			
BSE ⁴ , %			0.59	<0.01	0.98
d 1	0	0			
d 28	0	0			
d 56	0	0			
d 84	21.7	16.7			
d 112	36.7	23.3			
d 140	58.3	44.3			
d 175	56.7	73.3			
d 210	63.3	75.7			

¹ Treatments were as follows (n = 3 pens/treatment): 1) offered free-choice access to a corn based diet with no MWDGS (CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d. Values are expressed as back-transformed $[\sin(y)]^2$ means.

² Abbreviations are defined as Treatment effect (Trt) and Treatment × time effect (Trt × Time).

³ Bulls were determined to have reached puberty when at least 50 million sperm with at least 10% progressive motility were present in the ejaculate, according to Wolf et al. (1965).

⁴ BSE according to Koziol and Armstrong (2018).

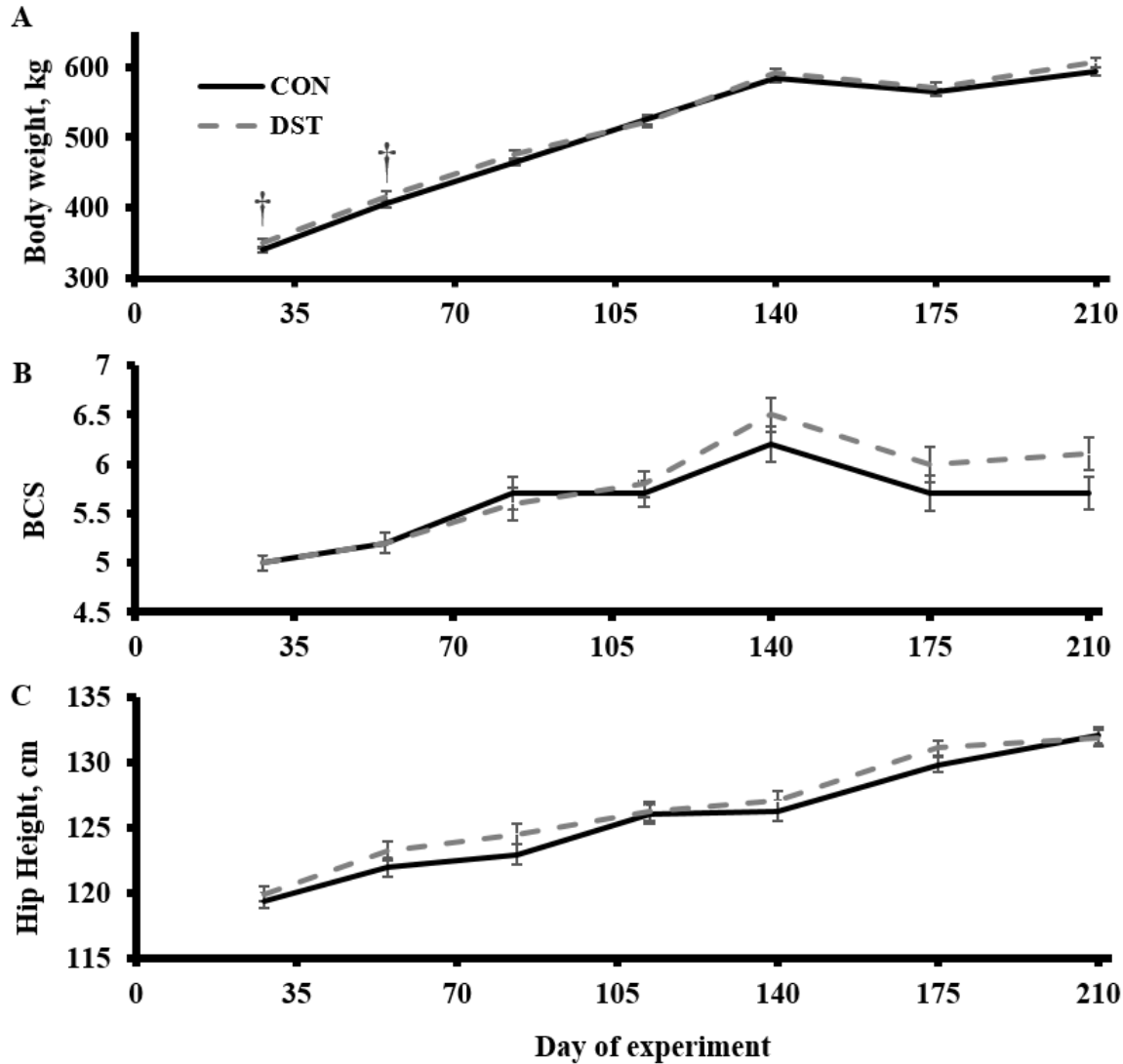


Figure 4.1: Effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on body weight (BW), body condition score (BCS), and bull hip height (HH) over time. Treatments were as follows ($n = 3$ pens/treatment): 1) offered free-choice access to a corn based diet with no MWDGS (CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d. Significance of slice p-values are represented as: $P \leq 0.05$ defined by *, and tendencies from $0.05 < P \leq 0.10$ are defined as †. Vertical bars represent the SEM. There was a tendency ($P < 0.09$) for a treatment $\times$ time effect for BW. Treatment $\times$ time and treatment effects were not detected ($P \geq 0.27$) for BCS or HH. A time effect was detected ($P \leq 0.01$) for BW, BCS, and HH.

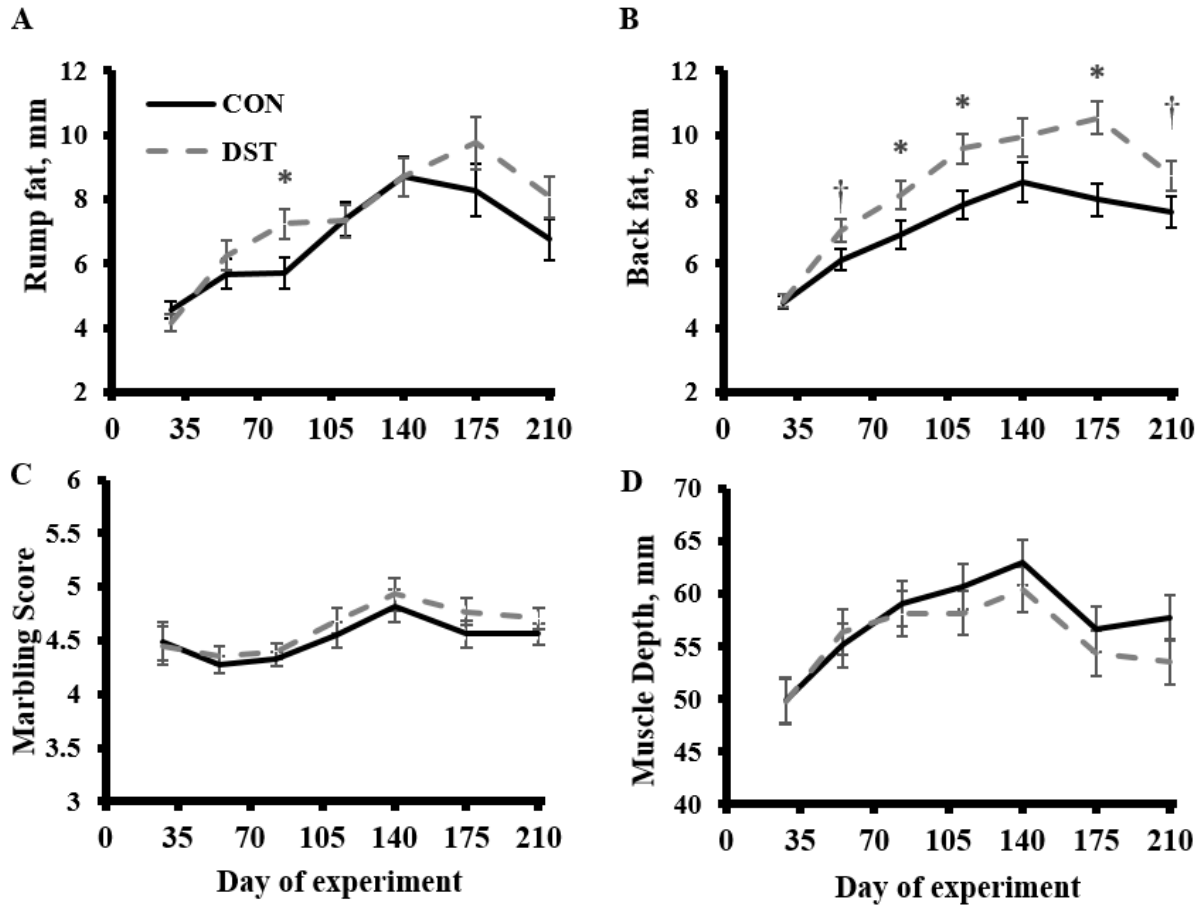


Figure 4.2: Effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on ultrasound parameters rump fat (RF), 12^h rib back fat (BF), marbling score (MS), and loin muscle depth (MD) over time. Treatments were as follows (n = 3 pens/treatment): 1) offered free-choice access to a corn based diet with no MWDGS (CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d. Significance of slice p-values are represented as: $P \leq 0.05$ defined by *, and tendencies from $0.05 < P \leq 0.10$ are defined as †. Vertical bars represent the SEM. A treatment × time effect was detected ($P < 0.01$) for RF. A treatment effect was not detected ($P = 0.34$) for RF. Treatment × time and treatment effects were detected ($P \leq 0.05$) for BF. Treatment × time and treatment effects were not detected ($P \geq 0.16$) for MS or MD. A time effect was detected ($P \leq 0.01$) for RF, BF, MS, and MD.

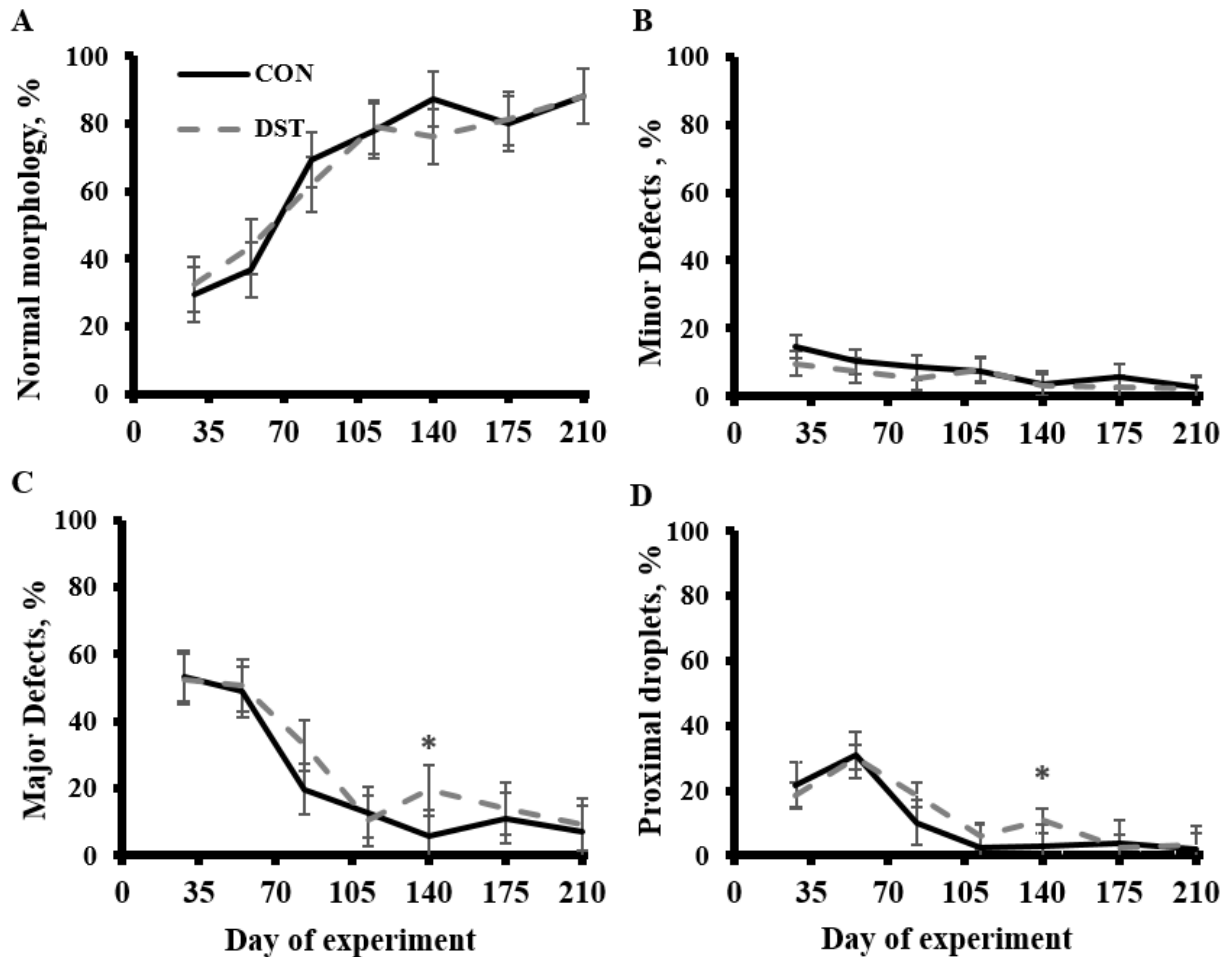


Figure 4.3: Effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on percentage of bull sperm with percentage of sperm with normal morphology (A), percentage of minor sperm defects (B), percentage of major sperm defects (C), and percentage of sperm with proximal droplets (D) in bull semen over time. Treatments were as follows (n = 3 pens/treatment): 1) offered free-choice access to a corn based diet with no MWDGS (CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d. Significance of slice p-values are represented as: $P \leq 0.05$ defined by *, and tendencies from $0.05 < P \leq 0.10$ are defined as †. Values are expressed as back-transformed ($\log_e$) means. Vertical bars represent the SEM of the untransformed means. Treatment × time and treatment effects were not detected ($P \geq 0.12$) for sperm with normal morphology or minor sperm defects. A treatment × time effect was detected ($P < 0.02$) for major sperm defects. There was a tendency ($P = 0.09$) for a treatment × time effect for percentage of sperm with proximal droplets. A time effect was detected ($P < 0.01$) for sperm with normal morphology, minor sperm defects, major sperm defects, and sperm with proximal droplets.

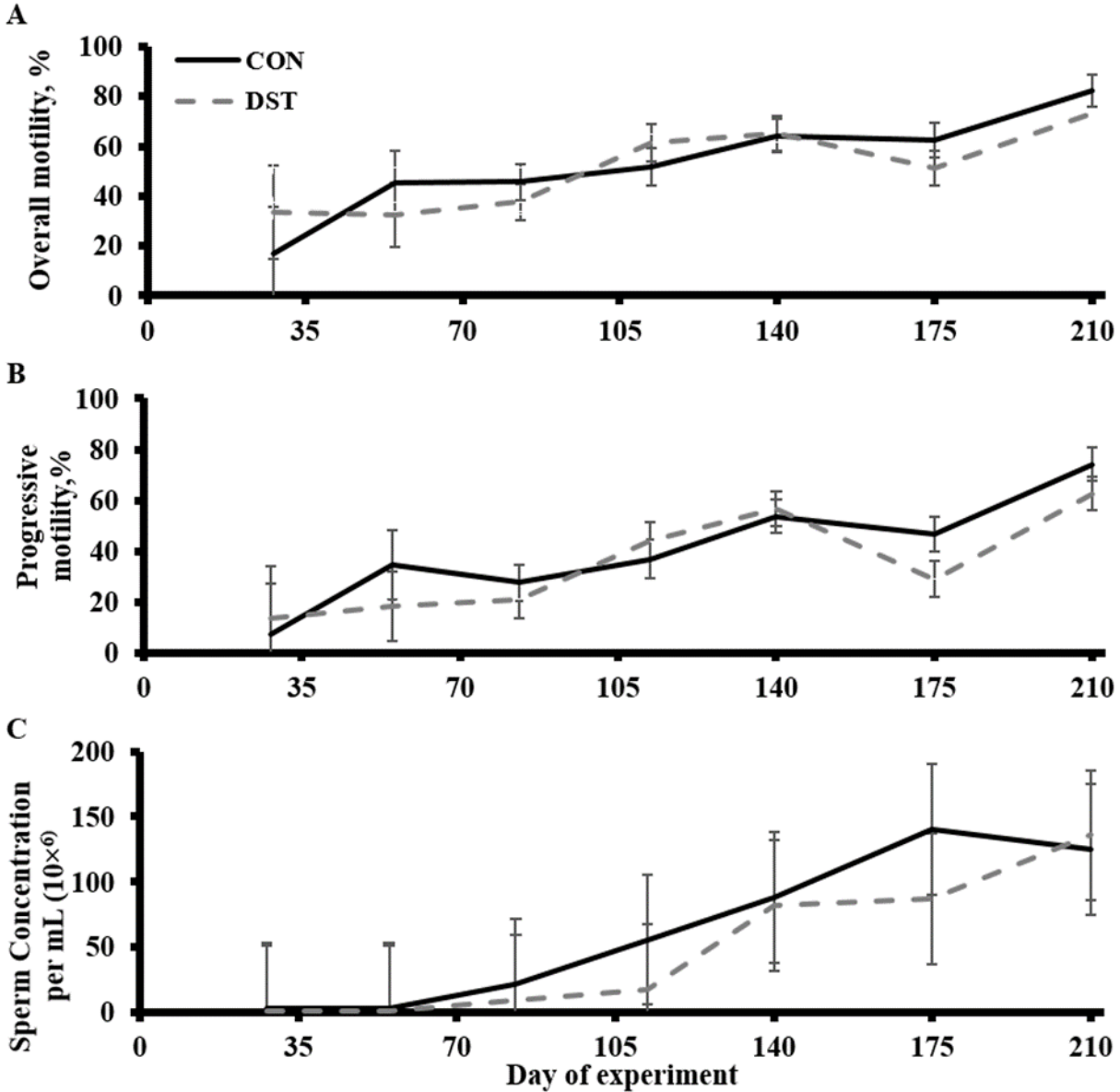


Figure 4.4: Effects of offering growing bulls a diet with 40% modified wet distillers grains plus solubles (MWDGS; DM basis) on the overall sperm motility percentage (A), sperm progressive motility percentage (B), and sperm concentration (C) in bull semen. Treatments were as follows (n = 3 pens/treatment): 1) offered free-choice access to a corn based diet with no MWDGS (CON), or 2) offered free-choice access to a diet with 40% MWDGS (DST; DM basis). Bulls (initial BW = 316 ± 29 kg, initial age = 240 ± 6 d) were offered treatments for 140 d then switched to a free-choice, common, low-energy diet for an additional 70 d. Values for sperm concentration are expressed as back-transformed ($X^{0.25}$) means. Vertical bars represent the SEM of the untransformed means. Treatment × time and treatment effects were not detected ($P \geq 0.40$) for overall sperm motility percentage, sperm progressive motility percentage, and sperm concentration. However, a time effect was detected ($P < 0.01$) for overall sperm motility percentage, sperm progressive motility percentage, and sperm concentration.

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CHAPTER 5

CONCLUSIONS

The development of bulls and breeding females to productive beef animals represents a substantial economic impact to the producer, and proper development can ultimately impact reproductive success and longevity within the herd. Diet and plane of nutrition during development have been linked to physiological changes that result in attainment of puberty of bulls and heifers. Timely nutritional inputs to the beef female may enhance sustainability by enhancing reproductive performance of the cowherd. To maintain herd size and productivity, proper selection and retention of replacement beef females drives the sustainability of an operation. Whereas a significant portion of the reproductive failures in cow calf enterprises are due to the fertility of the herd bull. Thus, this research evaluated nutritional and management strategies to optimize the development of bulls and breeding females.

Land price, feed availability, equipment sharing with row crop enterprise, and manure utilization has allowed the Midwest cattlemen to explore year round management of beef females in the drylot. In the western United States heifers developed in the drylot have reduced efficiency and longevity compared to heifers developed in grazing setting. Considering the majority of this work was conducted in extensive rangelands in the western United States, little is known about how these systems translate to the lower Midwest where cow-calf production relies on tall fescue systems (E+). Thus the objectives of experiment 1 were to compare the growth and reproductive performance of replacement fall-calving beef heifers developed in two common Midwest systems (drylot developed and grazing E+ with daily supplementation) with two alternative strategies (grazing E+ with daily supplementation from the midpoint of treatment period until breeding, or grazing novel E+. Drylot developed heifers had the greatest BW and

BCS at AI, percentage cycling, and AI pregnancy rate. However, this strategy did not result in differing overall pregnancy rates between drylot developed, grazing E+ with daily supplementation, and grazing E+ with daily supplementation from the midpoint of treatment period until breeding and there were no differences in cow milk production, rebreeding reproductive performance, and calf performance between all treatments. Heifers grazing novel E+ had the poorest reproductive performance. This would suggest that developing beef heifers to calve at 23 months of age (1 month prior to the mature cows) may require them to be developed to > 60% of their mature BW.

One of the most challenging times from a nutritional standpoint for a beef female is when they are transitioned from the drylot to a grazing setting especially when it coincides with lush pasture growth. In spring, forage grows quickly, and is very high in moisture and nitrogen while being low in carbohydrates. This can lead to cows entering a negative energy balance. The nutritional requirement for growth and lactation of the two-yr-old lactating cow makes her extremely susceptible to a nutritional insult. Whereas the lack of grazing experience of heifers can cause issues when first exposed to grass. Thus, objectives of experiment 2 were to evaluate the effects of corn supplementation on heifer and two-yr-old lactating cow growth and reproductive performance. There were no supplementation and female age interactions excluding a slight improvement for BCS at the end of treatment period. Supplementation regardless of female age improved BW and BW change. Cow nonesterified fatty acid (NEFA) decreased more and blood urea nitrogen (BUN) increased more from d 0 to d 12 compared to the heifers whereas the supplemented females had lower NEFA and BUN. Even though cows tended to have greater AI pregnancy rates than heifers, supplementation did not affect AI or overall pregnancy rates.

Breeding bulls across the United States are commonly fed high-energy diets by seedstock producers prior to sale, generally in the form of grain. Costs associated with feeding these diets has led producers to consider cheaper alternatives such as distillers grains with solubles. But there is no data available on the impact of co-products on developing bulls. Thus, objectives of experiment 3 were to test the impact of feeding growing bulls a diet that included 40% (DM basis) distillers grains plus solubles (DST). Feeding DST resulted in slightly fatter bulls and an increase in major semen defects at end of treatment period, but, bulls recovered and there were no differences in any reproductive parameters following the common low-energy diet. This suggests that producers may include low S distillers grains plus solubles into the diet up to 40% on a DM basis.