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Low-Input Heifer Development Using Stockpiled Native Forages and Protein Supplementation

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To the Graduate Council:

I am submitting herewith a dissertation written by Zachary David McFarlane entitled "Low-Input Heifer Development Using Stockpiled Native Forages and Protein Supplementation." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

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Low-Input Heifer Development Using Stockpiled Native Forages and Protein Supplementation

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DEDICATION

All the hard work and research presented in this dissertation is dedicated to my mother Karen Moore, my father Craig McFarlane, and my mentor and friend Dan Kiesling. This dedication is also for the cowboys and cowgirls just like them that work diligently to provide a wholesome beef product for consumers world-wide. The grit, determination, and perseverance of the American beef producer is a legacy that inspires researchers like myself.

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ABSTRACT

Three studies were conducted to determine the effects of stockpiled winter forage species and protein supplementation strategy on heifer growth, reproductive performance, nutritional status, rumen fermentation, and the economic implications of forage-based heifer development. In all three studies, spring-born, beef heifers were stratified by BW and randomly assigned to 1 of 3 stockpiled forages: (1) endophyte-infected tall fescue (**TF**, *Schedonorus arundinaceus* (Schreb.) Dumort) (2) big bluestem (*Andropogon gerardi* Vitman) and indiangrass (*Sorghastrum nutans* L.) combination (**BI)**, or (3) switchgrass (**SG,** *Panicum virgatum* L.). Forage treatments were randomly allocated to receive 1 of 2 supplement types: (1) 0.68 kg·heifer^{-1}·d^{-1} of dried distiller's grains with solubles (**DDGS**) or (2) 0.22 kg·heifer^{-1}·d^{-1} of blood meal and fish meal (**BF**), resulting in a 3 × 2 factorial arrangement of treatments. Treatments were initiated in January and concluded in April at the onset of the breeding season. In Exp. 1, BW was greater ($P < 0.01$) for TF heifers, resulting from an increased ($P < 0.01$) ADG from initiation to breeding for TF heifers. From January to April, heifers grazing SG and BI pastures had a negative ADG; however, from breeding to final pregnancy diagnosis, SG and BI heifers compensated and had greater ($P < 0.01$) ADG than TF heifers. Pregnancy rates at fixed timed-AI and overall pregnancy rates did not differ ($P \geq 0.38$) by forage or supplement treatment. In Exp. 2, heifers grazing SG pastures had greater ($P = 0.04$) ruminal acetate concentrations than their counterparts. However, ruminal concentrations of propionate and butyrate were not influenced ($P \geq 0.32$) by forage species. Due to an increase in ruminal acetate concentration, ruminal acetate:propionate ratio was greater ($P = 0.04$) for heifers grazing SG pastures. In Exp. 3, total cost of producing a heifer's first calf using the three forage-based systems was $1,079 to $1,149/head with tall fescue (TF) being the most expensive forage-based heifer development forage system. Overall, low-input heifer development using stockpiled warm-season forages and protein supplementation may be a viable opportunity to extend the grazing season, lower production costs, and select for more efficient replacement females in the southeastern United States.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I:

LITERATURE REVIEW

INTRODUCTION

Heifer development is a critical period in selection of females for fertility and efficiency early in the productive lifespan of a beef female. Due to this, replacement heifers are crucial to the cow-calf sector for replacement of culled cows and improving herd genetic potential (Bagley, 1993). Critical attention to management of heifers during development can have a sustained impact on long-term efficiency. Breakeven for heifer costs may occur up to 13 yr depending on unit cost of production, replacement rate, development costs, and rebreeding of young cows (M. Stockton, personal communication, University of Nebraska). Due to reduced reproductive efficiency of young, beef cows (Meek et al., 1999), development of replacement females to fit their production environment is crucial for efficiency of the cow-calf sector. Developing heifers to a certain target BW has been a recommendation for decades (Patterson et al., 1992) in the goal of maximizing pregnancy rates of heifer development programs. However, feeding to a certain target BW requires substantial feed input, decreases selection pressure for reproduction, and reduces economic efficiency (Mulliniks et al., 2013). Utilizing production practices that minimize input costs and increase selection of reproduction may provide a viable opportunity for increased long-term efficiency of beef cattle production. Ultimately, minimizing the input necessary to achieve production goals may increase profitability for beef producers. Thus, this dissertation covers nutritional management of yearling beef heifers in a low-input grazing developmental period.

PUBERTY ATTAINMENT

Understanding the mechanisms and events associated with puberty in heifers is paramount to successful reproductive performance. Sexual maturity develops primarily in the hypothalamus where a gradual decline in the sensitivity to the negative feedback mechanism of estradiol in GnRH neurons occurs approximately 50 d prior to pubertal estrus expression (Kinder et al., 1995). Day et al. (1987) reported that the prepubertal estradiol feedback mechanism may be in response to a decline in the concentration of estradiol receptors in the hypothalamus. This estradiol feedback decline leads to a rise in frequency of LH pulsatility, which is the primary endocrine influence regulating the onset of puberty in heifers (Kinder et al., 1995; Day and Anderson, 1998). Furthermore, an increase in frequency of LH secretion enhances the progression of follicular development promoting the production of estradiol to prompt behavioral estrus and a preovulatory surge of gonadotrophins (Kinder et al., 1995). Prior to the exhibition of pubertal estrus, the reproductive organs undergo an increase in size and development. Specifically, uterine development increases, follicular wave length increases, and the size of dominant follicles also increase prior to the expression of estrus (Desjardins and Hafs, 1969; Honaramooz et al., 2004; Atkins et al., 2013).

Puberty in heifers can also be defined as the initial ovulatory estrus followed by a luteal phase of normal length (Atkins et al., 2013). Prepubertal heifers often exhibit a short luteal phase following the formation of luteal tissue. Silent ovulations, or ovulations without estrus expression, typically occur 7 to 10 d prior to the onset of puberty. Additionally, it is fairly common for heifers to exhibit nonpubertal estrus, or standing estrus without subsequent luteal activity (Nelsen et al., 1985). Nonpubertal estrus expression can fluctuate in a wide range of frequency and can be affected by a number of variables such as age, breed, and season (Nelsen et al., 1985; Rutter and Randel, 1986). Ultimately, all mechanisms of the hypothalamus-pituitary-ovarian axis must be functioning properly at puberty for normal estrus cyclicity and puberty to occur.

Historically, management of prepubertal heifers has focused on heifers attaining two or three estrous cycles before the breeding season in order to maximize fertility. Previous research has shown that heifer pregnancy rates increase by 21% if bred on their third estrus when compared with pubertal estrus (Byerley et al., 1987). However, a major limitation of these data is that modern management practices typically breed heifers 2 to 4 mo later (Endecott et al., 2013). Furthermore, Endecott et al. (2013) suggested mean BW and age at breeding were confounded by estrus status classification in the Byerley et al (1987) dataset. Large, multi-year studies indicated little or no advantage associated with the expression of more than one estrous cycle by the beginning of the first breeding season (Roberts et al., 2013; Vraspir et al., 2014). However, the subsequent breeding season displayed a positive correlation between pregnancy rate and the number of estrus cycles expressed (Roberts et al., 2013), which may be more associated with age and maturity of heifer rather than number of estrus cycles. Therefore, the number of estrus cycles exhibited by heifers prior to the breeding season may not be as significant a constraint on heifer development strategies as previously reported.

Age at puberty is one of the foremost factors that influences reproductive competence and longevity of beef females. Yearly heifer management programs necessitate puberty to be attained at 12 mo of age to optimize reproductive performance (Schillo et al., 1992). In addition, early puberty attainment leads to early conception in heifers during their first breeding season. Heifers conceiving early in their first breeding season produce more calves that are heavier at weaning during their productive lifespan (Lesmeister et al., 1973). Likewise, heifers that were not pubertal prior to breeding calved later and weaned lighter calves when compared with their contemporaries (Roberts et al., 2017). The timing of puberty attainment was reported to be breed variable and dependent on BW and age (Short and Bellows, 1971). Data from the 1970s and 1980s indicated that heifers developed to lighter BW were older when they reached puberty (Short and Bellows, 1971; Wiltbank et al., 1985). Thus, developing heifers to 65% of mature BW has been a recommendation for decades (Patterson et al., 1992). However, as genetic selection and management practices have progressed in the last 25 yr, such recommendations may not be practical and may hold back progress for livestock producers. Roberts et al. (2017) suggested that maximizing puberty attainment prior to breeding may eliminate the opportunity for selection against later-maturing heifers. In addition, Funston et al. (2012) and Endecott et al. (2013) suggested that production practices have changed rapidly and selection pressure for precocious puberty has likely impacted heifer puberty attainment and subsequent pregnancy rates. For instance, pregnancy rates were similar in heifers developed to a lower target BW (Martin et al., 2008; Roberts et al., 2009; Funston and Larson, 2011). Freetly and Cundiff (1997) reported no differences in age at puberty among heifers developed on a low or high plane of nutrition. Percentage of heifer puberty attainment prior to the breeding season were not different between heifers developed in a drylot and their counterparts grazing corn residue (Summers et al., 2014). Due to genetic and reproductive selection, these data suggest that age of puberty has likely been uncoupled from BW or BW gain. In addition, growing body of evidence has challenged traditional heifer development dogma in order to reduce costs associated with heifer development with no associated decrease in reproductive performance.

HEIFER DEVELOPMENT STRATEGIES AND NUTRITION

Replacement females developed during heifer development programs are the future of the herd. Therefore, matching that heifer's genotype to the given production environment is imperative. The role that nutrition plays during the physiological development period leading to puberty has been investigated in a number of species (Frisch, 1984) and a body fat threshold for puberty attainment in cattle was suggested (Frisch, 1984; Nelsen et al., 1982). Contrasting evidence indicated that puberty attainment was not influenced by achieving a critical body composition in beef heifers (Hall et al., 1995). However, nutritional management during postweaning growth rate was reported to influence age and weight at the onset of puberty (Patterson et al., 1992). Likewise, studies have indicated the significance of postweaning growth rate influencing age at puberty (Short and Bellows, 1971; Wiltbank et al., 1985) and subsequently on pregnancy rates (Short and Bellows, 1971; Byerley et al., 1987). However, as previously mentioned, puberty attainment may not be an issue today as a result of selection pressure for age at puberty over several decades. Recent research has established that developing heifers to a lighter target BW has not impaired reproductive function (Funston and Deutscher, 2004; Roberts et al., 2009; Funston and Larson, 2011; Larson et al., 2011; Mulliniks et al., 2013; Lardner et al., 2014). In addition, Mulliniks et al. (2013) reported heifers developed to 51% of mature BW and fed a high RUP supplement had increased longevity compared to heifers developed to 58% mature BW in a drylot. Heifers developed to 55% mature BW at breeding had no difference in ovarian development, antral follicle counts, or final pregnancy rates during a 47 d breeding season when compared with heifers fed to 64% mature BW (Eborn et al., 2013).

Delaying heifer BW gain until later in the developmental period may be a more viable opportunity to reduce input costs. Research previously mentioned has indicated that a delay in BW gain does not impact reproductive function. Clanton et al. (1983) indicated that timing of gain had no impact on age at puberty. Furthermore, delaying gain until 45 d before the breeding season resulted in similar pregnancy rates as heifers developed at a constant rate of gain (Lynch et al., 1997). Thus, timing of gain may be a more important influence on reproductive success than rate of postweaning growth. Heifer development strategies relying on strategic supplementation and periods of compensatory growth may be an economically viable opportunity for beef producers.

Supplementation Strategies

Beef producers may rely on forage resources to reduce feed input costs associated with heifer development. Environments with multiple forage types and growing seasons, like the Southeastern United States, may benefit from extending the grazing season through stockpiling forage. Endophyte-infected tall fescue is the predominate forage species in the Southeastern United States and stockpiling has been indicated as a viable management practice (Poore et al., 2000). Warm-season grasses are being utilized as complementary grazing systems for cool-season grasses especially in endophyte-infected tall fescue systems during their senescence in summer (Hudson et al., 2010), which may provide another economical alternative to feeding harvested feedstuffs by stockpiling warm-season forages. Stockpiling typically reduces forage nutritive value in response to increased forage maturity (Wheeler et al., 2002). Thus, heifers grazing stockpiled forage during development typically requires supplementation to meet nutrient requirements for adequate growth. Despite adequate forage quality, heifers grazing stockpiled endophyte-infected tall fescue and supplemented with an energy supplement (whole cottonseed) did not achieve optimal BW gain during development (Poore et al., 2006). With that in mind, Poore and Drewnoski (2010) suggested that growing cattle grazing stockpiled tall fescue required protein supplementation to achieve optimal growth performance. Warm-season forages have been suggested to required RDP supplementation to maximize forage digestibility, but additional RUP may be beneficial for increasing gains (Hafley et al., 1993). Overall, source and quantity of protein may be an important consideration when selecting the proper supplementation regimen. In addition, supplementation strategies that improve the efficiency of nutrient utilization may provide the most viability.

Ruminally undegradable protein is not degraded and resynthesized to a different AA profile in the rumen before absorption in the small intestine as RDP. Thus, RUP may represent a more efficient supply of protein available directly to the animal that may support high levels of growth potential. Feeding supplements of slowly degraded protein (i.e., corn gluten meal and blood meal) in combination with urea provided the most efficient conversion of dietary protein to gain and more efficient conversion of feed to gain (Stock et al., 1981). Kempton et al. (1978) reported feed efficiency of 2:1 when growing lambs were provided fish meal and 80 g of glucose while consuming oat chaff. In addition, N retention has been improved when supplementing RUP to steers consuming low-quality forage (Petersen et al., 1985). Providing RUP may also increase energy supply by providing a source of digestible AA that could be catabolized as a source of energy (Wickersham et al., 2009). In support, Batista et al. (2016) reported that supplemental RUP, when RDP requirements were met for ruminal fermentation, increased N retention, N recycling, and tended to increase the amount of urea used for anabolism in Nellore heifers consuming low-quality forage. Furthermore, supplementation of RUP increased average daily gain (ADG) in steers grazing cool-season and warm-season forage, respectively (Anderson et al., 1988; Grigsby et al., 1989). Sources of RDP may also improve heifer growth and forage digestibility. However, RUP supplementation increases MP supply and may increase urea synthesis and recycling (Wickersham et al., 2009).

Providing RUP supplementation may also improve growth and forage utilization along with improving reproductive performance. Supplementing beef heifers with high RUP increased ADG and energy utilization of low-quality native forages, but delayed puberty when compared with heifers provided a control supplement containing monensin (Lalman et al., 1993). Heifers grazing low-quality dormant range and fed a high-RUP animal-based supplement had increased ADG during breeding, pregnancy rates, and longevity compared with a lower RUP plant-based supplement (Mulliniks et al., 2013). Primiparous heifers supplemented with high-RUP (335 g/d) postpartum exhibited increased LH secretion when induced with GnRH (Kane et al., 2002). In contrast, Martin et al. (2007) reported that heifers supplemented dried distillers grains and solubles (DDGS) to provide excess RUP did not differ in age or BW at puberty when compared with an isocaloric control consisting of a dried corn gluten feed pellet with whole corn germ. However, heifers supplemented with DDG had greater timed AI pregnancy rates when compared with their control counterparts (Martin et al., 2007). Ewe lambs consuming blue grama hay were provided supplements designed to be isonitrogenous and isoenergetic (i.e., cottonseed meal, feather meal, blood meal, or different supplement combinations) to evaluate the effects of protein source on circulating metabolites and metabolic hormones (Petersen et al., 1992). Ewe lambs supplemented feather meal had the highest insulin concentrations, while the lowest concentrations were reported for ewes fed a combination of cottonseed meal, blood meal, and feather meal (Petersen et al., 1985). These data suggest that dietary protein source, either plant- or animal-based sources, of varying rumen degradability may elicit changes in nutrient status that could influence reproduction. Thus, quality and source of protein may be important considerations when developing a heifer supplementation regimen.

Supplementing energy supplements in the form of fat or starch/fiber may also be beneficial from a reproductive standpoint. Heifers consuming more energy attain puberty earlier (Schillo et al., 1992). However, DelCurto et al. (1990) determined that increasing supplemental energy without adequate protein depressed forage intake and digestibility of steers consuming low-quality bluestem hay. In addition, starch-based energy supplementation has decreased forage intake (Chase and Hibberd, 1987; Pordomingo et al., 1991; Hess et al., 1996; Olson et al., 1999). Starch-based supplements have adverse effects on ruminal fermentation as a result of reducing rumen pH, thus changing rumen bacterial population (Caton and Dhuyvetter, 1997; Russell et al., 1979; Russell and Dombrowski, 1980). However, high-fiber energy supplements, such as soybean hulls, offer an alternative energy source that does not reduce forage digestibility as drastically as high-starch supplements (Grigsby et al., 1992; Garcés-Yépez et al., 1997).

Energy supplementation also requires daily provision to have a benefit because of the shift in rumen bacterial population. Moriel et al. (2012) indicated that replacement beef heifers should be offered low-starch energy supplements daily while consuming low-quality hay to attain timely puberty. In support, providing daily fibrous energy supplements increased BW gain and enhanced the nutrient status of crossbred Brahman heifers grazing low-quality bahiagrass pastures when compared with supplementation three times weekly (Cooke et al., 2008). Daily supplementation of dry-rolled corn, dry-rolled corn with corn gluten meal, or DDGS increased forage intake and BW gain in heifers compared with supplementation three times weekly (Loy et al., 2008). Additionally, heifers fed native grass hay ad libitum and supplemented DDGS improved BW gain and G:F when supplemented low (0.21% of BW) amounts when compared with similar amounts of dry-rolled corn or dry-rolled corn with corn gluten meal (Loy et al., 2008). Daily supplementation of energy to elicit improvements in performance may not be realistic for all beef producers. Overall, beef producers must evaluate the most economical type of supplementation that best fits their goals and management scenario.

Compensatory Gain

Recent research regarding heifer development has focused on reducing inputs to facilitate production efficiency. Alternative heifer development strategies typically utilize a grazed forage-base and some form of supplementation early in development that generally elicits low BW gains pre-breeding. Therefore, a compensatory growth period following a delay in BW gain may be essential for heifers to be reproductively successful. Supplementing heifers grazing low-quality forage during development increased compensatory growth, which may be in response to lower maintenance requirements and ability to respond to a seasonal improvement in forage quality (Ciccioli et al., 2005). 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 (Bridges et al., 2012), resulted in poorer quality embryos (Kruse et al., 2017) and a subsequent reduction in AI pregnancy rates (Perry et al., 2013). Freetly et al. (2001) reported that delaying BW gain until later in heifer development had no impact on calving rate, postpartum interval, or subsequent second-calf pregnancy rates. 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. Thus, plane of nutrition prior to breeding and timing of compensatory growth seem to be imperative for reproductive success, which may be more important than ADG from weaning to breeding.

Delaying heifer BW gain and relying on compensatory growth during breeding may elicit changes in circulating metabolites and metabolic hormones. In that respect, changes in serum metabolite and hormone concentrations prior to breeding may be crucial for reproductive success. Metabolic fuels and signals in circulation including insulin, glucose, and NEFA may contribute to the regulation of LH release from the hypothalamus and expression of puberty in response to changes in nutritional status (Schillo, 1992). In addition, compensatory gain may lower nutrient requirements and this growth pattern may cause a subsequent improvement of nutrient utilization. Heifers may experience a short period of negative energy balance during nutrient restriction. However, a subsequent increase in nutrient intake and decrease in resting metabolic rate during realimentation may indicate more efficient nutrient utilization (Yambayamba et al., 1996).

Heifers experiencing compensatory growth patterns may alter circulating glucose levels. Glucose concentrations were reduced in heifers during nutrient restriction, but increased within 10 d of realimentation to basal levels (Yambayamba et al., 1996). Circulating glucose elevated in response to increased nutrient intake (Blum et al., 1985; Ellenberger et al., 1989). In addition, glucose concentration was reported to be positively correlated with protein intake (Reilly and Ford, 1971). Yelich et al. (1996) reported that nutrient restriction decreased concentrations of glucose, insulin, and LH pulse frequency causing a subsequent delay in puberty. Therefore, glucose may respond fairly rapidly to changes in nutrient intake.

Insulin is a key metabolic hormone that has been shown to fluctuate concentration during periods of nutrient restriction. Circulating concentrations of insulin were reduced during nutrient restriction (Yambayamba et al., 1996; Webb et al., 2004). However, increased nutrient intake was reported to increase insulin concentrations (Yelich et al., 1995). Furthermore, heifers fed to maintain BW for 95 d had increased circulating insulin concentrations within 10 d of BW realimentation to similar levels as heifers fed ad libitum (Yambayamba et al., 1996). Blum et al. (1985) suggested that increased insulin during a compensatory gain period may signal initiation of anabolic processes as opposed to catabolic processes occurring during nutrient restriction, which will stimulate tissue AA uptake and reduce protein degradation in tissues (Ahmed et al., 1983). In addition, nutrient restricted heifers infused with insulin had increased ovulation rate (Harrison and Randel, 1986) when compared with their nutrient restricted counterparts not provided insulin. Ultimately, insulin may be a major role of the physiological responses to realimentation (Yambayamba et al., 1996).

The utilization of a compensatory gain period during heifer development may also improve N use efficiency. Concentrations of blood urea N were reduced during a compensatory gain period although protein intake was increased, suggesting more efficient N utilization (Ellenberger et al., 1989). In support, Yambayamba et al (1996) reported lower BUN concentrations in heifers during realimentation and no differences in circulating 3-methyl histidine when comparing heifers fed ad libitum and those experiencing realimentation. No differences in 3-methyl histidine concentrations suggest that muscle tissue was not mobilized for energy during feed restriction (Yambayamba et al., 1996). Carstens et al. (1991) conducted a serial slaughter study and reported increased protein accretion in steers experiencing compensatory growth. Supplementation of RUP also increased utilization of urea for anabolic purposes (Batista et al., 2016). Nitrogen recycling to the rumen may preserve dietary N in response to nutrient restriction (Bunting et al., 1989), and N efficiency and metabolic efficiency may improve during compensatory gain following nutrient restriction (Freetly and Nienaber, 1998). These data suggest that compensatory growth patterns may result in a protein sparing event during restriction and subsequent N retention efficiency during realimentation.

Ultimately, metabolites and hormones in circulation may act as signals initiating reproductive response. Compensatory growth patterns following a delay in heifer BW gain prior to breeding may also stimulate more efficient nutrient utilization. Overall, heifer nutrient status during the breeding season may be a more crucial component of reproductive success when compared with pre-breeding BW gain.

Heifer grazing behavior and management practices that expose heifers to their production environment during development may influence future performance. Research 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). Traditional heifer development approaches that necessitate heifers to achieve a target BW prior to breeding often develop heifers in a drylot system. However, 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 (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 and effectively to changes in forage quality and periods of nutrient deprivation they will be exposed to long-term.

In summary, heifer development may be an opportune time period to select heifers for fertility and adaptability in their production environment. Periods of nutrient restriction and subsequent realimentation 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.

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CHAPTER II:

DIRECTION OF PRE-BREEDING BODY WEIGHT CHANGE DOES NOT IMPACT REPRODUCTIVE PERFORMANCE OF YEARLING BEEF HEIFERS

A version of this chapter is being prepared for publication by: Zachary D. McFarlane, Emily R. Cope, Jeremy D. Hobbs, Renata N. Oakes, Ky G. Pohler, and J. Travis Mulliniks.

ABSTRACT

The objective of this study was to determine the effect of protein supplementation strategy and stockpiled forage type on growth, nutritional status, and reproductive performance of yearling beef heifers. Spring-born, beef heifers (n = 266) were stratified by BW at weaning to 1 of 3 stockpiled forages: (1) endophyte-infected tall fescue (**TF**, *Schedonorus arundinaceus* (Schreb.) Dumort; 7.21% CP and 67.13% NDF, DM basis) (2) big bluestem (*Andropogon gerardi* Vitman) and indiangrass (*Sorghastrum nutans* L.) combination (**BI**; 4.32% CP and 71.06% NDF, DM basis), or (3) switchgrass (**SG,** *Panicum virgatum* L.; 3.87% CP and 76.79% NDF, DM basis). Forage treatments were then randomly assigned to receive 1 of 2 supplement types: (1) 0.68 $kg \cdot heifer^{-1} \cdot d^{-1}$ of dried distillers grains with solubles (**DDGS**: 28% CP) or (2) 0.22 $kg \cdot heifer^{-1} \cdot d^{-1}$ of blood meal and fish meal (**BF**: 72.5% CP), resulting in a 3 × 2 factorial arrangement of treatments. Each year, treatments were initiated in January and terminated in April at the onset of the breeding season when heifers were managed together on an ungrazed TF pasture. Heifer BW was recorded monthly until breeding and at final pregnancy diagnosis. Blood samples were collected prior to the onset of the breeding season for nutrient status. Initial BW was not different ($P \geq 0.22$) by forage or supplement type. During the rest of the study, BW was greater ($P < 0.01$) for TF heifers, resulting from an increased ($P < 0.01$) ADG from initiation to breeding for TF heifers. However, ADG was greater ($P < 0.01$) for BI and SG heifers from breeding to final pregnancy diagnosis. Heifers grazing TF pastures had greater ($P < 0.01$) overall ADG than their counterparts. Percent of mature BW (MBW) at breeding was greater ($P < 0.01$) for TF heifers. Heifer BW and ADG was not influenced ($P \geq 0.06$) by supplementation strategy during the entire study period. Serum glucose concentrations were not different ($P \geq 0.44$) among forage type or supplement strategy. Insulin concentrations did not differ ($P \geq 0.34$) based on forage or supplement treatments. Heifers grazing TF had lower ($P < 0.01$) circulating NEFA concentrations than their counterparts. Circulating SUN concentrations were greater ($P < 0.01$) in TF heifers. In addition, BF-supplemented heifers had greater ($P < 0.01$) SUN concentrations than their DDGS counterparts. Pregnancy rates at fixed timed-AI and overall pregnancy rates did not differ ($P \geq 0.38$) by forage or supplement treatment. Ultimately, heifers grazing low-quality, warm-season grasses lost BW prior to the initiation of the breeding season, however, delaying BW gain did not negatively impact overall pregnancy rates or timing of conception.

INTRODUCTION

In the southeastern US, stockpiling endophyte-infected tall fescue is utilized as an economical forage option for heifer development (Poore et al., 2006). Due to low summer forage production of endophyte-infected tall fescue, many livestock producers have incorporated native warm-season forage into their forage production systems (Lowe et al., 2015). However, due to a decline in forage quality when in dormancy, native-warm season forages are often not utilized for winter grazing in these systems. If utilized strategically, stockpiled warm-season forages may offer an alternative opportunity for heifer development as a result of forage mass accumulation potential. A concern of developing heifers on stockpiled endophyte-infected tall fescue is that heifer growth may be limited prior to breeding (Poore et al., 2006). In addition, heifers grazing stockpiled warm-season forages may lose BW during the winter grazing period (McFarlane et al., 2017). Thus, protein supplementation may be required in order to more effectively utilize stockpiled forage. Lalman et al. (1993) reported increased ADG in heifers provided high-RUP likely in response to improved energy utilization of low-quality forages. In support, heifers grazing low-quality native range increased pregnancy rates and herd retention rate when supplemented high-RUP when compared with a low-RUP supplement (Mulliniks et al., 2013). Thus, we hypothesized that heifers grazing low-quality, native warm-season forages with compensatory gain period at the time of breeding would have similar pregnancy rates as heifers grazing higher-quality cool-season forage. Our objectives were to determine the effect of stockpiled winter forage and protein supplementation strategy on BW gain, BCS, serum metabolites, reproductive performance, and first calf performance of yearling beef heifers.

MATERIALS AND METHODS

All animal handling and experimental procedures were conducted according to the guidelines of the Institutional Animal Care and Use Committee (**IACUC**) of the University of Tennessee (IACUC approval number 2146-0116).

Animal Measurements and Treatments

In a 5-yr study, 266 spring-born, predominately Angus influenced yearling heifers (Initial BW = 331.98 ± 1.99 kg) were utilized to determine the effect of winter grazing stockpiled forage types and protein supplementation strategy on growth, reproductive performance, and serum metabolite concentrations. This research was conducted at the Middle Tennessee Research & Education Center, Spring Hill, TN (35º42’27” N, 86º56’31” W). Heifers were stratified by BW to 1 of 3 stockpiled forage types (n = 7 replicates per forage treatment) and received either 1 of 2 protein supplements at weaning in a 3 × 2 factorial arrangement. Stockpiled forages were: (1) endophyte-infected tall fescue (**TF**; *Schedonorus arundinaceus* (Schreb.) Dumort), (2) big bluestem (*Andropogon gerardi* Vitman) and indiangrass (*Sorghastrum nutans* L.) combination (**BI**), or (3) switchgrass (**SG**; *Panicum virgatum* L.). Each forage pasture type was then randomly assigned to receive either 1 of 2 supplement types: (1) 0.68 $kg \cdot heifer^{-1} \cdot d^{-1}$ of dried distillers grains with solubles (**DDGS**: 28% CP, 74% RUP, 88% TDN) or (2) 0.22 $kg \cdot heifer^{-1} \cdot d^{-1}$ of blood meal and fish meal (**BF**: 72.5% CP, 67.5% RUP, 69.5% TDN). Supplements were provided at approximately 0800 twice weekly on Mondays and Fridays. Prior to the initiation of the supplemental period, heifers were adapted to the supplements for a 2-wk period due to potential intake and palatability issues for the BF treatment. After the adaptation period, all fed supplement was consumed and therefore no feed refusals were measured.

All grazing of pastures was terminated in mid- to late-August prior to stockpiling initiation. Stockpiling began on the first day of September prior to each year of the study. Pastures were managed on an annual basis using the following methods: stockpiling began in September, pastures were grazed from January to April during the study grazing period, heifers were removed from pastures in April and forage regrowth occurred from April to June, pastures were either grazed or hayed from June to July at the discretion of research station technicians, and mowed (20-cm residual height for BI and SG, 10-cm residual height for TF) in August to initiate regrowth prior to stockpiling. Pastures that were utilized for hay production were fertilized with 67 kg ha^{-1} N in June every year. Summer grazing of the remaining pastures utilized the put-and-take system based on forage availability with no added fertilizer. All pastures were under continuous grazing management during the winter grazing period. Establishment of warm-season grass pastures (BI and SG) was conducted in May 2008 (Keyser et al., 2016). Cultivars of warm-season forages were Alamo SG and a mixture (1:1 based on seed mass) of big bluestem and indiangrass ecotypes (Roundstone Native Seed, LLC, Upton, KY) for SG and BI pastures, respectively (Keyser et al., 2016). Every year of the study, the grazing period began in January and was terminated in April at fixed timed AI (TAI). Termination of the different developmental treatments occurred at the onset of the breeding season in April when heifers were managed together grazing an ungrazed endophyte-infected tall fescue pasture.

All sample collection was conducted at 0900 h for every sampling period. Heifer BW and BCS (1 = emaciated, 9 = obese; Wagner et al., 1988) were recorded at the initiation of the study and approximately every 28 d until the end of the breeding season in May and again in September at final pregnancy diagnosis. For each development treatment, percent of mature BW at breeding was estimated from the average cow BW at 5 yr of age of the herd of origin. The breeding season began in April every year and all heifers were synchronized utilizing a controlled internal drug-releasing (CIDR) device (Eazi-Breed CIDR, Zoetis Inc., Kalamazoo, MI) with a 7 d CO-Synch + CIDR protocol. Heifers received a single 2 mL intramuscular injection of GnRH (Cystorelin, Merial) and a CIDR on -7 d. The CIDR was removed on -2 d and the heifers were administered a 5 mL intramuscular injection of PGF (Lutelyse, Zoetis Inc., Kalamazoo, MI). All heifers were given an injection of 2 mL of GnRH (Cystorelin, Merial) intramuscularly approximately 66 h after CIDR removal, and were artificially inseminated on 0 d by 1 of 3 bulls each year. Cleanup bulls were turned out 14 d after TAI and were utilized to provide natural service to the heifers for a 60 d breeding season with a heifer-to-bull ratio of 1:30. Timed-AI pregnancy diagnosis occurred 30 d after insemination via transrectal ultrasonography based on the presence or absence of an embryonic heartbeat. A final pregnancy diagnosis was administered by transrectal ultrasonography in September of every year. Pregnancy diagnosis for TAI or natural service was verified by back-calculating from calving date. Subsequent year's calf BW was measured at birth and weaning of heifers in the study.

Nutritional status was assessed by collecting a blood sample (~ 9 mL; Corvac, Sherwood Medical, St. Louis, MO) via coccygeal venipuncture prior to the start of breeding. Serum samples were analyzed for glucose, insulin, NEFA, urea N (SUN), and β-hydroxybutyrate (BHB) concentrations. Commercial kits were utilized to perform the analysis for NEFA (Wako Chemicals, Richmond, VA), SUN (Thermo Scientific, Middletown, VA), and glucose (enzymatic endpoint, Thermo Scientific, Middletown, VA) as previously reported (Mulliniks et al., 2013). Serum samples were analyzed for BHB concentrations as previously described (McCarthy et al., 2015) using DL-β-hydroxybutyric acid sodium salt and a Tris Buffer (10 ml of Tris hydrochloric acid + 40 ml of deionized water, pH 9) with 30 mg of β-Nicotinamide adenine dinucleotide (β-NAD) and an enzyme of 3-hydroxybutyrate dehydrogenase (Sigma-Aldrich, St. Louis, MO). Concentrations of serum insulin were determined by radioimmunoassay (EMD Millipore's Porcine Insulin RIA) using Wizard2 Gamma Counter (Perkin Elmer, Waltham, MA) as previously reported (Kaufman et al., 2018). The intra- and interassay CV were, respectively, 3.22 % and 4.01 % for serum NEFA, 4.51% and 5.11% for serum BHB, 4.27 % and 4.64 % for serum glucose, 4.22% and 4.99% for serum insulin, and 0.79 % and 0.76 % for SUN.

Forage Measurements

Forage samples (10 samples/pasture) were collected each year at the initiation and at the end of the grazing period using a 0.1 m^2 frame at 8 cm residual height to assess forage mass. Forage sampling at the initiation of grazing occurred on the following dates: January 5, 2013, January 13, 2014, January 9, 2015, January 4, 2016, and January 4, 2017. Samples were collected at the termination of grazing on the following dates: March 15, 2013, March 31, 2014, April 1, 2015, April 8, 2016, and April 13, 2017. An additional forage sample was hand-plucked from each pasture for nutritive quality analysis from the mid-point of grazing on the following dates: February 17, 2014, February 13, 2015, February 9, 2015 and February 25, 2017. Forage sampling was conducted randomly by using a 0.1 m^2 area frame. Samples were analyzed for DM, CP, and NDF content. The DM content of the samples was determined by drying at 55°C in a forced-air oven for 48 h. Samples were then ground through a 2-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ). Dry matter and OM were determined according to procedures from AOAC (1990; methods 934.01 and 942.05, respectively). Total N combustion analysis was performed to determine crude protein (Leco-NS2000 [LECO Corp., St. Joseph, MI]; method 976.06 [Horwitz, 2000]). Neutral detergent fiber content was assessed utilizing the ANKOM 200 fiber analysis system (ANKOM Technology Corp., Fairport, NY).

Statistical Analysis

Normality of data distribution and equality of variances of measurements were evaluated using PROC UNIVARIATE. Heifer performance, calf performance, and serum metabolite measurements were analyzed as a completely randomized design using the MIXED procedure (SAS Inst. Inc., Cary, NC, USA) and Kenward-Roger degrees of freedom. Heifer growth performance data were analyzed with pasture as the experimental unit. The model included the fixed effects of forage type, supplement type, year, and the interaction of forage type × supplement type. Serum metabolites were analyzed with heifer as the experimental unit and the model included the fixed effects of forage type, supplement type, year, and the interaction of forage type × supplement type. Calf performance was analyzed with a model including the fixed effects of sire, calf sex, forage type, supplement type, and the interaction of forage type × supplement type with heifer as the experimental unit. Repeated measures was utilized for variables collected over time with sampling period as the repeated factor and compound symmetry as the covariance structure as determined by Akaike's information criterion. Binomial data (pregnancy rate, calving period) were analyzed with PROC GLIMMIX using a model that included the fixed effects of forage type, supplement type, year, sire, and their interactions. Sire was removed from the pregnancy rate analysis due to lack of significant effects on heifer fertility. Heifer was utilized as the experimental unit. Forage mass and chemical composition analyses were performed using the MIXED procedure with a model including fixed effects of grazing month, forage type, year, and the interaction of grazing month × forage type and pasture as the experimental unit. The LSMEANS option was used to calculate treatment means and the PDIFF statement was utilized for the separation of main effects and any interactions. Least squares means were compared using Fisher's LSD at a significance level of $P \leq 0.05$. Tendencies were determined at $0.10 \geq P > 0.05$. The main effect of year was not discussed because year effects do not meet study objectives. Data were presented as main effects if interactions were not determined to be statistically significant.

RESULTS AND DISCUSSION

Forage Characteristics

Environments with multiple forage growing seasons, like the southeastern United States, may benefit from extending the grazing season through stockpiling forage. Stockpiling endophyte-infected tall fescue is a practical management practice in the southeastern United States for use as a winter forage source for growing cattle (Poore et al., 2006; Drewnoski et al., 2009). Warm-season grasses can complement grazing of endophyte-infected tall fescue systems during their summer senescence (Keyser et al., 2016) due to forage mass accumulation even under drought conditions (Sage and Kubien, 2003). Forage mass accumulation potential of warm-season forages may offer another opportunity to extend the grazing season. In the current study, forage mass was lower ($P < 0.01$, Table 2.1) for TF pastures. Forage mass was not different ($P = 0.93$) between BI and SG pastures. Thus, forage mass differences are likely attributed to differences in plant physiology that resulted in increased forage mass accumulation in warm-season forage species (Sage and Kubien, 2003; Lowe et al., 2015). However, forage nutritive value of stockpiled warm-season forages is expected to be even lower than stockpiled TF pastures due to differences in growing season and decreased nutritive value during dormancy (Vona et al., 1984; Reid et al., 1988).

Forage CP content exhibited (P < 0.01; Table 2.2) a forage type × grazing period interaction. Throughout the grazing study, TF pastures had greater (P < 0.01) CP levels than BI or SG pastures. Poore et al. (2006) reported that stockpiled TF increased CP content in late February once forage growth began. Warm-season grasses (SG and BI) did not differ (P = 0.70) in CP content in February at the mid-point of grazing. However, SG pastures had lower (P < 0.01) CP content compared with BI pastures in January and April at study initiation and termination. In addition, a forage type × grazing period interaction was detected (P < 0.01) for NDF content. Pastures of TF had lower (P < 0.01) NDF content the entire grazing period when compared with warm-season pastures. From January to February and February to April, NDF content increased (P < 0.01) for TF and BI pastures, respectively. In contrast, during the entire study, SG pastures did not differ (P ≥ 0.41) in NDF content. Differences in nutritive quality attributes were expected among forage types because of differences in growing season. Warm-season forages generally senesce in October and start growing late March in Tennessee (Keyser et al., 2012). Winter dormancy of native warm-season forage reduces CP content while NDF content increases (Reid et al., 1988; Brandyberry et al., 1991). In contrast, stockpiled TF pastures maintain high nutritive value consistently during winter (Burns and Chamblee, 2000; Poore et al., 2006). As expected, TF pastures had greater nutritive value than warm-season forages throughout the present study.

Animal Performance

Initial BW was not different (*P* = 0.80; Table 2.3) for heifers by forage type. Body weight was greater (*P* < 0.01) for TF heifers in April at breeding, in May at AI pregnancy diagnosis, and in September at final pregnancy diagnosis when compared with BI and SG heifers. From study initiation in January to breeding in April, heifer ADG was greater (*P* < 0.01) for TF heifers compared to heifers grazing warm-season forages. However, heifers grazing BI and SG pastures compensated from the pre-breeding BW loss and had greater (*P* < 0.01) ADG from breeding to final pregnancy diagnosis than heifers grazing TF. At the initiation of grazing, BCS did not differ (*P* = 0.57) among forage types. However, due to differences in ADG, TF heifers had greater (*P* < 0.01) BCS at breeding and at final pregnancy diagnosis in September. As expected, heifers grazing TF had greater BCS than their warm-season forage counterparts during the study period likely in response to differences in ADG before breeding. In the present study, heifers grazing native warm-season grasses may have reduced their maintenance requirements resulting in greater ADG during the breeding season. In support, heifers grazing low-quality forage increased compensatory gain, likely in response to lower maintenance requirements and capacity to respond to improved forage quality (Ciccioli et al., 2005). Likewise, Freetly et al. (2008) reported that developing heifers on low-quality forages improved nutrient utilization efficiency in response to lowered maintenance requirements. However, even with the compensatory gain of the BI and SG heifers, TF heifers had greater ($P < 0.01$) overall ADG from study initiation to final pregnancy diagnosis in September.

Supplementation strategy had no influence ($P \geq 0.13$; Table 2.4) on BW at the initiation of grazing in January or at breeding in April. Heifers supplemented BF tended ($P = 0.06$) to have greater BW in May at AI pregnancy diagnosis when compared with their counterparts fed DDGS. Heifer BW was similar ($P = 0.20$) between protein supplement types at final pregnancy diagnosis in September. Likewise, protein supplement type had no impact ($P \geq 0.47$) on ADG or heifer BCS ($P \geq 0.43$) during the entire study. Heifers supplemented RUP, monensin, or propionic acid did not differ in BW or ADG during the course of the study (Lalman et al., 1993). In agreement, feeding isonitrogenous supplements to provide 36% CP differing in RUP value (36% or 50% RUP) had no influence on heifer BW or ADG (Mulliniks et al., 2013). Ultimately, different isonitrogenous protein sources providing high-RUP had little impact heifer growth during the winter grazing trial.

Heifers grazing SG had the lowest ($P < 0.01$; Table 2.3) percent of mature BW (MBW) at breeding compared to their forage counterparts. In addition, BF-supplemented heifers had greater ($P = 0.05$; Table 2.4) MBW at breeding than DDGS heifers. Patterson et al. (1992) established that heifers should reach 60 to 65% of MBW prior to breeding to optimize reproductive success. However, heifers developed to a lower (53%) mature BW had similar reproductive performance to heifers raised to greater (58%) mature BW (Funston and Deutscher, 2011). Additionally, heifers grazing dormant native range and fed a high RUP supplement reached 51% MBW while achieving a 94% pregnancy rate (Mulliniks et al., 2013).

Pregnancy rates at timed AI (TAI) were not influenced by forage type (P = 0.81; Table 2.3), and did not differ by supplement type (P = 0.49; Table 2.4). Likewise, final pregnancy rates were not impacted (P = 0.72) by forage type and were not influenced (P = 0.38) by supplement strategy. In the present study, heifers grazing warm-season grasses lost BW before breeding but had increased ADG post-breeding that may have influenced reproductive performance. In support, 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). Therefore, conception rates may be improved if direction and magnitude of BW gain coincides with the breeding season (Lynch et al., 1997; Mulliniks et al., 2013; Summers et al., 2014). Overall, reproductive performance was not impacted by grazing low-quality native warm-season forages, which may be partially explained by the compensatory gain at the time of breeding. In addition, developing heifers to as low as 47% of MBW at the time of breeding did not have a negative impact on reproductive performance.

Earlier calving heifers have shown to have increased longevity when compared to their contemporaries that calve later (Cushman et al., 2013). In the current study, calving date was not different by forage type (*P* = 0.66; Table 2.5) or by supplement type (*P* = 0.42; Table 2.6). In agreement, calving date was similar among heifers developed on low-quality native range and supplemented RUP when compared with their cohorts developed in a drylot (Mulliniks et al., 2013). However, percentage of heifers calving in the first 21 d of the calving season exhibited (*P* < 0.01; Table 2.7) a forage type × supplement type interaction. Heifers grazing BI and supplemented with BF had a greater (*P* = 0.04) percentage calve in the first 21 d of the calving season than their forage type counterpart provided DDGS. Additionally, heifers grazing BI and supplemented BF calved at a greater (*P* = 0.02) rate in the beginning of the calving season when compared with BF-supplemented heifers grazing TF and SG pastures. Heifers calving early generally maintain their respective calving groups throughout their productive lifetime and wean heifer calves during their first calving season (Burris and Priode, 1958; Lesmeister et al., 1973; Cushman et al., 2013). In support, Funston et al. (2012) reported 13-yr of calving data indicated that heifer and steer calves from dams calving in the first 21-d calving interval were heavier and more productive. Specifically, heifer calves born during the first 21-d calving interval were heavier at weaning, breeding, and prior to calving, and also had greater pregnancy rates when compared with their cohorts calving in the third 21-d calving interval (Funston et al., 2012). In addition, steers born earlier in the calving season had greater weaning and carcass weights and improved carcass merit when compared with their subsidiaries born later in the calving season (Funston et al., 2012). Overall, calving earlier in the calving season results in progeny with advantages in growth and performance. In the present study, heifers grazing BI and supplemented BF may remain in the herd at a greater rate and produce progeny with an advantage in growth performance.

Calf BW at birth was lower ($P < 0.01$; Table 2.5) for calves born from heifers grazing SG than their other forage counterparts. Supplementation strategy did not influence ($P = 0.31$; Table 2.6) calf birth BW. Calf BW at birth was not affected when heifers were developed to 66 or 60% of mature BW at breeding (Funston and Deutscher, 2004). Likewise, calf birth BW did not differ between heifers grazing dormant winter forage and heifers developed in a drylot (Funston and Larson, 2011). Calf weaning weight also exhibited ($P = 0.05$; Table 2.7) a forage type × supplement type interaction. Heifers grazing BI and supplemented with BF had calves with greater ($P = 0.04$) BW at weaning than their counterparts provided DDGS. Furthermore, TF heifers supplemented with DDGS had calves with greater ($P = 0.05$) BW at weaning than BI heifers supplemented with DDGS. In the present study, heifers grazing BI and supplemented with BF had a greater percentage calving in the first 21-d of the calving season likely leading to heavier calves at weaning. In support, heifers calving in the first 21-d period of the calving season had greater unadjusted weaning BW of their first 6 calves when compared to heifers calving in subsequent 21-d calving periods (Cushman et al., 2013). Thus, this study indicates that heifers grazing BI and supplemented BF may produce calves with an advantage in growth performance in response calving earlier.

Serum Metabolite and Hormone Concentrations

Circulating glucose concentrations did not differ (*P* = 0.44; Table 2.8) among forage types. Insulin concentrations were also not affected (*P* = 0.90) by forage treatment. A lack of glucose concentrations differences among treatments is not surprising since glucose is highly regulated (Kaneko, 1989). Heifers grazing TF had lower (*P* < 0.01) circulating NEFA concentrations than their forage counterparts. Elevated circulating NEFA were expected in heifers grazing the warm-seasons forage treatment groups due to a loss in BW pre-breeding. Circulating NEFA concentrations have been shown to increase in heifers that were fed to maintain BW for 95 d (Yambayamba et al., 1996). Concentrations of BHB were not different (*P* = 0.86) among forage types. Heifers grazing TF had greater (*P* < 0.01) SUN concentrations than their respective counterparts. Roseler et al. (1993) suggested that SUN concentrations can provide an indication of N availability as a result of deamination of endogenous and dietary protein supply. In the current study, TF pastures had greater CP content than warm-season forages during the entire grazing period, which may be resulting in the increase in circulating SUN concentrations.

Supplementation strategy did not influence (*P* = 0.87; Table 2.9) glucose concentrations. Insulin concentrations were also not impacted (*P* = 0.34) by supplement type. As expected, circulating NEFA did not differ (*P* = 0.16) by supplement type due to minimal BW differences associated with supplementation strategy. Heifers supplemented with BF had greater (P = 0.03) BHB concentrations. Heifers supplemented BF had increased ruminal butyrate concentrations relative to their counterparts supplemented DDGS (McFarlane et al., 2017). An increase in ruminal butyrate may have increased BHB concentrations in the current study. In support, increased ruminal butyrate resulted in elevated peripheral BHB concentrations (Krehbiel et al., 1992). In addition, BF-supplemented heifers had greater ($P < 0.01$) circulating SUN than heifers supplemented DDGS. In the current study, heifers were supplemented with isonitrogenous RUP sources, but SUN concentrations were elevated with BF supplementation. The liver catabolizes excess AA to urea (Drackley et al., 2001) resulting in increased circulating urea N. Wickersham et al. (2009) indicated that RUP supplementation increased MP supply and may increase urea synthesis and recycling. Likewise, RUP supplementation may increase utilization of urea for anabolic purposes (Batista et al., 2016). Thus, source of dietary CP, either plant- or animal-based sources, may result in differences in protein catabolism and subsequent N utilization.

Heifers grazing warm-season forages lost or maintained BW from January to April at the start of breeding, but compensated for the restricted gain post-breeding. This delay in heifer BW gain resulted in MBW ranging from 47 to 51% at the start of breeding, which is lower than current recommendations. However, the developmental strategy utilized in this study up to breeding did not negatively influence heifer reproductive performance.

Although, the lack of reproductive response with heifers losing BW prior to breeding may be due to BW and BCS of the heifers coming into the start of the developmental period in January. However, the direction of BW gain at the start of breeding seems to be a more important function of heifer development and subsequent reproductive performance than the direction prior to breeding.

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APPENDIX

Table 2.1 Forage type effects on accumulation of forage mass of stockpiled winter forages during the grazing period.

Measurement	Treatment[1]			SEM	*P*-value
	TF	BI	SG		
Forage Mass (kg DM/ha)	3,123.84[a]	4568.60[b]	4540.12[b]	242.81	< 0.01

[a,b]Within a forage type, means with different superscripts differ ($P < 0.05$).

[1]Forage: tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

Table 2.2 Forage type and grazing period effects (forage type × grazing period) on forage characteristics of stockpiled winter forages from beginning to end of the grazing period.

	Treatment[1]			
Measurement	TF	BI	SG	SEM
CP, %				
January	6.86^{ax}	4.09^{bx}	3.57^{cx}	0.35
February	6.65^{ax}	3.80^{bx}	3.62^{bx}	0.35
April	9.59^{ay}	5.72^{by}	3.42^{cx}	0.40
NDF, %				
January	65.94^{ax}	71.51^{bx}	76.97^{cx}	0.78
February	69.34^{ay}	72.73^{bx}	77.15^{cx}	0.78
April	65.06^{ax}	68.24^{by}	77.87^{cx}	0.87

[a,b,c]Within a forage type, means with different superscripts differ (*P* < 0.05).

[x,y,z]Within a grazing period, means with different superscripts differ (*P* < 0.05).

[1]Forage: tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

Table 2.3 Forage type effects on heifer growth and reproductive performance during the winter grazing period.

Measurement	Forage Type[1]			SEM	*P*-value
	TF	BI	SG		
BW, kg					
Initial[2]	331	332	333	2	0.80
Breeding[3]	355[a]	328[b]	306[c]	3	< 0.01
AI Pregnancy Diagnosis[4]	388[a]	369[b]	353[c]	3	< 0.01
Final Pregnancy Diagnosis[5]	438[a]	422[b]	410[c]	3	< 0.01
ADG, kg					
Initial to Breeding[6]	0.26[a]	-0.05[b]	-0.30[c]	0.03	< 0.01
Breeding to Final Pregnancy Diagnosis[7]	0.71[c]	0.81[b]	0.89[a]	0.02	< 0.01
Initial to Final Pregnancy Diagnosis[8]	0.54[a]	0.44[b]	0.37[c]	0.01	< 0.01
BCS					
Initial[2]	5.70	5.65	5.66	0.04	0.57
Breeding[3]	5.69[a]	5.44[b]	5.25[c]	0.05	< 0.01
Final Pregnancy Diagnosis[5]	6.03[a]	5.79[b]	5.77[b]	0.05	< 0.01
Percentage of mature BW at breeding, %	55[a]	51[b]	48[c]	0.45	< 0.01
Reproductive Performance					
AI Pregnancy Rate, %	59	54	55	5.8	0.81
Final Pregnancy Rate, %	93	90	93	3.6	0.72

[a,b,c]Within a forage type, means with different superscripts differ ($P < 0.05$).

[1]Forage: tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

[2]Initial = January BW.

[3]Breeding = April BW.

[4]AI Pregnancy Diagnosis = May BW.

[5]Final Pregnancy Diagnosis = September BW.

[6]January to May ADG.

[7]May to September ADG.

[8]January to September ADG.

Table 2.4 Supplement type effects on heifer growth and reproductive performance during the winter grazing period.

Measurement	Supplement Type[1] BF	DDGS	SEM	*P*-value
BW, kg				
Initial[2]	333	331	2	0.22
Breeding[3]	332	327	2	0.13
AI Pregnancy Diagnosis[4]	373	367	3	0.06
Final Pregnancy Diagnosis[5]	425	421	2	0.20
ADG, kg				
Initial to Breeding[6]	-0.02	-0.04	0.02	0.47
Breeding to Final Pregnancy Diagnosis[7]	0.80	0.81	0.01	0.50
Initial to Final Pregnancy Diagnosis[8]	0.45	0.45	0.01	0.72
BCS				
Initial[2]	5.69	5.65	0.03	0.43
Breeding[3]	5.46	5.46	0.03	0.98
Final Pregnancy Diagnosis[5]	5.86	5.88	0.04	0.71
Percentage of mature BW at breeding, %	52	51	0.4	0.05
Reproductive Performance				
AI Pregnancy Rate, %	54	58	4.6	0.49
Final Pregnancy Rate, %	90	93	2.7	0.38

[1]Supplement: blood meal and fish meal (BF), and dried distiller's grains and solubles (DDGS).

[1]Forage: tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

[2]Initial = January BW.

[3]Breeding = April BW.

[4]AI Pregnancy Diagnosis = May BW.

[5]Final Pregnancy Diagnosis = September BW.

[6]January to May ADG.

[7]May to September ADG.

[8]January to September ADG.

Table 2.5 Forage type effects on calving performance and first calf growth of heifers developed during the winter grazing period.

	Forage Type[1]				
Measurement	TF	BI	SG	SEM	*P*-value
Calving Date, Julian date	27	25	31	5	0.66
Calf BW, kg					
Birth	32[a]	32[a]	29[b]	0.7	0.05

[a,b]Means with different superscripts differ ($P < 0.05$).

[1]Forage: tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

Table 2.6 Supplement type effects on calving performance and first calf growth of heifers developed during the winter grazing period.

Measurement	Supplement Type		SEM	*P*-value
	BF[1]	DDGS		
Calving Date, Julian date	25	30	4	0.42
Calf BW, kg				
Birth	31	30	0.6	0.31

[1]Supplement: blood meal and fish meal (BF), and dried distiller's grains and solubles (DDGS).

Table 2.7 Forage type × supplement type effects on calving performance and first calf growth of heifers developed during the winter grazing period.

		Forage Type[1]			
Measurement	Supplement[2]	TF	BI	SG	SEM
Calving in the first 21 d of calving season, %	BF	61^{by}	93^{ax}	70^{by}	10
	DDGS	82^{ax}	68^{ay}	85^{ax}	11
Calf BW, kg					
Weaning	BF	237^{ax}	246^{ax}	243^{ax}	7
	DDGS	248^{ax}	229^{by}	246^{ax}	7

^{a,b}Means with different superscripts differ ($P < 0.05$).

^{x,y}Means with different superscripts differ ($P < 0.05$).

[1]Forage: tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

[2]Supplement: blood meal and fish meal (BF), and dried distiller's grains and solubles (DDGS).

Table 2.8 Forage type effects on serum metabolites of heifers during the winter grazing period.

	Forage Type[1]				
Measurement	TF	BI	SG	SEM	*P*-value
Glucose, mg/dl	80.12	78.44	80.78	1.39	0.44
Insulin, ng/mL	0.33	0.30	0.30	0.07	0.90
NEFA, mmol/L	279.90[c]	366.73[b]	436.35[a]	15.40	< 0.01
BHB[2], μmol/L	315.89	307.92	311.76	10.79	0.86
SUN[3], mg/dl	13.86[a]	10.15[c]	11.20[b]	0.30	< 0.01

[a,b,c]Within a forage type, means with different superscripts differ ($P < 0.05$).

[1]Forage: tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

[2]BHB = β-hydroxybutyrate

[3]SUN = serum urea N.

Table 2.9 Supplement type effects on serum metabolites of heifers during the winter grazing period.

	Supplement Type[1]			
Measurement	BF	DDGS	SEM	*P*-value
Glucose, mg/dl	79.91	79.65	1.11	0.87
Insulin, ng/mL	0.35	0.28	0.06	0.34
NEFA, mmol/L	349.32	372.66	12.27	0.16
BHB[2], μmol/L	324.87	298.84	8.50	0.03
SUN[3], mg/dl	12.80	10.68	0.23	< 0.01

[1]Supplement: blood meal and fish meal (BF), and dried distillers grains and solubles (DDGS).

[2]BHB = β-hydroxybutyrate

[3]SUN = serum urea N.

CHAPTER III:

EFFECT OF FORAGE SPECIES AND SUPPLEMENT TYPE ON RUMEN KINETICS AND SERUM METABOLITES IN DEVELOPING BEEF HEIFERS GRAZING WINTER FORAGE

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Z. D. McFarlane analyzed data and wrote the manuscript. R. P. Barbero collected samples and edited the manuscript. R. L. G. Nave, E. B. Maheiros, and R. A. Reis provided valuable feedback and editing for the manuscript. J. T. Mulliniks directed the project, acquired funding, and reviewed the manuscript as the corresponding author.

ABSTRACT

The objective of this study was to determine the effect of stockpiled forage type and protein supplementation on VFA production, serum metabolites, and BW in yearling beef heifers. Over 2 yr, spring-born, Angus crossbred yearling beef heifers (*n* = 42; Initial BW = 305 ± 2.9 kg initial BW) were randomly assigned to 1 of 3 forage pasture types: (1) endophyte-infected tall fescue [**TF**, *Schedonorus arundinaceus* (Schreb.) Dumort], (2) a big bluestem (*Andropogon gerardii* Vitman) and indiangrass (*Sorghastrum nutans* L.) combination (**BI**), or (3) switchgrass (**SG**, *Panicum virgatum* L.). Each pasture was then

randomly assigned to receive either 1 of 2 isonitrogenous CP treatments: (1) 0.68 kg·heifer^{-1}·d^{-1} of dried distiller's grains with solubles (**DDGS**; 28% CP and 88% TDN) or (2) 0.22 kg·heifer^{-1}·d^{-1} of blood meal and fish meal (**BF**; 72.5% CP and 69.5% TDN), resulting in a 3 × 2 factorial arrangement of treatments. Treatments were initiated in January and terminated in April in both years of the study. Body weights and blood samples were collected approximately every 28 d from initiation of grazing until the end of the trial. Heifer BW change from January to February and overall BW change were greater (P < 0.01) for TF heifers. However, BW change from March to April was not different (P = 0.84) among forage types. Supplement type did not influence ($P \geq 0.13$) BW or BW change from January to February and January to April; however, heifers fed DDGS had greater (P = 0.03) BW gain from March to April. Heifer BW change from February to March exhibited (P < 0.05) a forage type × supplement interaction, with BF-fed heifers gaining more BW on BI pastures than DDGS-fed heifers. Serum glucose concentrations, ruminal acetate, and acetate:propionate ratio were greater ($P \leq 0.04$) for SG heifers. However, circulating NEFA and urea N (SUN) concentrations were not different ($P \geq 0.85$) among forage types. Serum glucose and NEFA concentrations were not influenced ($P \geq 0.61$) by supplement type. Circulating SUN concentrations were greater (P < 0.01) in BF-supplemented heifers. Ruminal acetate tended to be greater (P = 0.09) and butyrate concentrations were greater (P < 0.01) for BF-supplemented heifers. The acetate:propionate ratio was not influenced (P = 0.15) by supplement type. These results suggest that a compensatory gain period during the breeding season would be needed for these native warm-season species to be a viable opportunity for growing and developing replacement heifers in the southeastern United States.

INTRODUCTION

Development of replacement females contributes a significant expense to beef producers due to feed costs and innate opportunity costs. The primary cost of developing heifers is supplemental feed required to reach sufficient gains to attain puberty before breeding (Roberts et al., 2009). As such, implementing strategies to achieve production goals while minimizing input costs can enhance production practices. Therefore, extending grazing through the winter using stockpiled cool- or warm-season forages with supplementation may be an economical alternative to feeding harvested feedstuffs. Different growing seasons of cool- and warm-season forages have allowed for management systems to implement sequential grazing to extend the grazing season (Moore et al., 2004). Stockpiling forages does increase total herbage mass available for grazing; however, forage nutritive value is reduced in response to increased forage maturity (Wheeler et al., 2002). Therefore, a concern with stockpiled forages in heifer development systems is that BW gain may be inadequate for heifers to attain 60 to 65% of mature BW prior to breeding (Poore et al., 2006). However, Funston and Deutscher (2004) reported that developing heifers to a lower target BW (~55% mature BW) reduced input costs without impairing reproductive function or subsequent calf performance. Supplementing beef heifers with high RUP supplements has increased ADG and energy utilization of low-quality native forages (Lalman et al., 1993). Furthermore, supplementing low quantities of a high-RUP supplement (40 g/d of CP) may potentially replace greater quantities (160 g/d of CP) while maintaining rumen function (Sawyer et al., 2012). In addition, heifers grazing low-quality dormant range and fed a high-RUP supplement had increased ADG during breeding, pregnancy rates, and longevity compared with those fed a lower-RUP plant-based supplement (Mulliniks et al., 2013). Therefore, our objective was to determine the effect of stockpiled winter forage type and protein supplementation strategy on VFA production, serum metabolites, and heifer BW and BW change.

MATERIALS AND METHODS

All animal handling and experimental procedures were conducted according to the guidelines of the Institutional Animal Care and Use committee of the University of Tennessee. (IACUC Approval Number: 2146-0116).

Animals and treatments

In a 2-yr study, 42 spring-born, crossbred Angus heifers (305 ± 2.9 kg initial BW) were used to determine the effect of winter grazing stockpiled forage types and protein supplementation strategy on growth, VFA production, and serum metabolites. Heifers were managed together before and after the grazing trial. This research was conducted at the Middle Tennessee Research & Education Center, Spring Hill, TN (35°43’7.3056” N, 86°57’54.7884” W), from January 9, 2014 to March 31, 2014 and January 5, 2015 to March

30, 2015. Average annual precipitation at this location was 1,475 mm. Heifers were stratified by BW to 1 of 3 stockpiled forage types (7 replicates per forage treatment; 1.2-ha pastures) and received either 1 of 2 protein supplements at weaning in a 3 × 2 factorial arrangement. One heifer was randomly assigned to each pasture. Stockpiled forages were: (1) toxic endophyte-infected tall fescue (**TF**, *Schedonorus arundinaceus* (Schreb.) Dumort, cool-season forage), (2) big bluestem (*Andropogon gerardi* Vitman) and indiangrass (*Sorghastrum nutans* L.) combination (**BI**; warm-season forage), or (3) switchgrass (**SG**; *Panicum virgatum* L.; warm-season forage). Each forage type was randomly assigned to receive either 1 of 2 supplement types: (1) 0.68 $kg \cdot heifer^{-1} \cdot d^{-1}$ of dried distillers grains with solubles (**DDGS**: 28% CP, 74% RUP, and 88% TDN on a DM basis) or (2) 0.22 $kg \cdot heifer^{-1} \cdot d^{-1}$ of blood meal and fish meal (**BF**: 72.5% CP, 67.5% RUP and 69.5% TDN on a DM basis). Samples were analyzed by a commercial laboratory (Rock River Laboratory, Inc., Watertown, WI). Supplements were provided twice weekly at approximately 0800 h. An adaptation period for the BF supplement occurred over a 2-wk period prior to the start of the study. The BF supplement was mixed at a 50:50 and 75:25 ratio with DDGS for the first and second week, respectively, of the adaptation period. Feed refusals were not recorded because all supplement in both treatment groups were completely consumed.

Forage Treatments and Measurements

Summer grazing of all pastures was terminated in late August prior to the initiation of stockpiling. Forages were stockpiled beginning the first day of September prior to each year of the study with no added fertilizer. Pastures were under continuous grazing management during the grazing trial. The warm-season forage cultivars were Alamo SG and a mixture (1:1 based on seed mass) of big bluestem and indiangrass ecotypes (Roundstone Native Seed, Upton, KY) for SG and BI pastures, respectively (Keyser et al., 2016). Warm-season forage pastures were established in 2008. A complete description of the pasture establishment procedures is discussed by Keyser et al. (2016).

To estimate forage mass in each year, 10 samples per pasture (1.2 ha per pasture) were collected at the initiation (January 9, 2014 and January 5, 2015) and at the end of the study (March 31, 2014 and March 30, 2015) using a 0.1-m^2 frame at 5 cm residual height. Additionally, a forage sample from the mid-point of grazing (February 17, 2014 and February 13, 2015) was hand-plucked from each pasture for nutritive quality analysis. All sampling was conducted randomly in a Z-shape pattern. Samples were analyzed for DM, ash, CP, and NDF content. The DM content of the samples was determined by drying at 55°C in a forced-air oven for 48 h. Samples were then lyophilized and ground through a 2-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ). Dry matter and OM were determined according to procedures published by the Association of Official Analytical Chemists (1990; methods DM (934.01) and OM (942.05), respectively). Crude protein was determined by total N combustion analysis (Leco-NS2000 [LECO Corp., St. Joseph, MI] method 976.06 [Horwitz, 2000]). Neutral detergent fiber content was assessed utilizing the ANKOM 200 fiber analysis system (ANKOM Corp., Fairport, NY).

Animal Measurements

All samples were collected at approximately 0900 h for every sampling period. Heifer BW and BCS (1 = emaciated, 9 = obese; Wagner et al., 1988) were recorded at the initiation of the study and ascertained approximately every 28 d. Heifer BW was an unshrunk BW made using the weighing facilities in the center of the paddocks. At the same time, approximately 30 mL of rumen fluid was sampled with an oral lavage. Samples were stored in 15-mL polypropylene conical tubes at -20°C until analysis of VFA. Volatile fatty acid concentration was determined by gas chromatography. Rumen samples were prepared by centrifuging strained samples at 10,000 × g for 10 min at 4°C. A mixture of 5 mL of ruminal fluid supernatant and 1 mL of meta-phosphoric acid-2ethyl butyric acid solution was then prepared. This mixture was allowed to stand in an ice bath for ≥ 30 min and then prepared for a second centrifuge for 10 min at 10,000 × g and 4°C. The samples were then analyzed using a gas chromatograph (GC-2010; Shimadzu Corp., Kyoto, Japan) with a previously described method (Erwin et al., 1961). Blood samples were collected monthly via coccygeal venipuncture (approximately 9 mL; Monoject Corvac, Sherwood Medical Co., St. Louis, MO). Blood samples were cooled and centrifuged at 2,000 × g at 4°C for 20 min. Serum was separated and stored in plastic vials at -20°C until further analysis. Serum samples were analyzed for glucose, NEFA, and urea N (SUN). Serum samples were analyzed using a 96-well microplate reader spectrophotometer with commercial kits for NEFA (Wako Chemicals, Richmond, VA; sensitivity of 0.01 mmol/L), glucose (Thermo

Electron Corp., Waltham, MA; sensitivity of 0.3 mg/dL), and SUN (Thermo Electron Corp., Waltham, MA; sensitivity of 2.0 mg/dL). The intra- and interassay CV were, respectively, 4.26 % and 4.58 % for serum NEFA, 5.83 % and 4.85 % for serum glucose, and 2.17 % and 1.81 % for SUN.

Statistical Analysis

Normality of the data distribution and equality of variances of measurements were evaluated using PROC UNIVARIATE. Data were analyzed as a complete randomized design, using a mixed procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC) using Kenward-Roger degrees of freedom method and pasture as the experimental unit. The model for rumen fermentation parameters, serum metabolites, and heifer performance data included fixed effects of forage type, supplement type, year, and their interactions. Repeated measures was utilized for variables collected over time with sampling period as the repeated factor and compound symmetry as the covariance structure as determined by Akaike's information criterion. Forage mass and chemical composition analysis were performed including fixed effects of year, month, forage type, and their interactions. The LSMEANS option was used to calculate treatment means and the PDIFF statement was utilized for the separation of main effects and any interactions. Least squares means were compared using Fisher's LSD at a significance level of $P \leq 0.05$. Tendencies were determined at $0.10 \geq P > 0.05$. Data were presented as main effects if interactions were not determined.

RESULTS AND DISCUSSION

Forage Characteristics

Typically, in the southeastern U.S., stockpiled endophyte-infected tall fescue is an economically viable winter forage source for growing cattle (Drewnoski et al., 2009). Warm-season grasses have been utilized to complement grazing of cool-season grasses, especially in TF systems, during their senescence in summer (Hudson et al., 2010). Warm-season grasses are characterized by their high productivity, drought tolerance, and efficient use of N in warm temperatures (Sage and Kubien, 2003). Therefore, due to their high productivity, stockpiling native warm-season forages for winter grazing may offer another winter grazing opportunity. In the current study, forage mass exhibited ($P < 0.01$, Table 3.1) a forage type × grazing period interaction. Forage mass of BI and SG pastures was greater ($P \leq 0.02$) at grazing termination in April when compared with forage mass in January. However, forage mass at the beginning and end of grazing was not different ($P = 0.16$) in TF pastures. Warm-season forages have decreased nutritive value and digestibility during senescence (Reid et al., 1988). Thus, differences in forage growing season and intake of warm-season grasses due to nutrient quality (Vona et al., 1984) may account for forage mass differences at grazing termination.

Crude protein exhibited ($P < 0.01$, Table 3.1) a forage type × grazing period interaction. During the entire grazing study, TF pastures had greater ($P < 0.01$) CP levels than BI or SG pastures. No differences ($P = 0.31$) in CP content were detected between the

2 warm-season grasses in February; however, in April, SG pastures had lower (*P* < 0.01) CP content compared with their warm-season forage counterpart of BI pastures. Additionally, a forage type × grazing period interaction was exhibited (*P* < 0.01) for NDF content. Over the grazing period, TF pastures had lower (P < 0.01) NDF content than warm-season grasses. However, from January to February, NDF content increased (*P* < 0.01) for TF and BI pastures, with no differences (*P* ≥ 0.27) for SG pastures during the entire grazing period. In the southeastern United States, TF starts to accumulate more green tissue and increase CP levels in late February (Poore et al., 2006). In contrast, warm-season forages typically completely senesce in October and begin growing in late March with a rapid growth period starting in late April in Tennessee (Keyser et al., 2012). Thus, CP content of native warm-season forages declines and NDF content increases during winter dormancy (Brandyberry et al., 1991). As expected, TF pastures had greater nutrient quality than warm-season forages during the entire study.

Animal Performance

Heifer BW did not exhibit (*P* ≥ 0.28) a forage type × supplement type interaction during the grazing period. Initial BW in January was not different (*P* = 0.27, Table 3.2) among heifers grazing the different forage types. However, heifer BW from February to April was greater (*P* < 0.01) for heifers grazing TF pastures than their counterparts. At the end of the grazing trial, heifers grazing SG pastures had the lowest (*P* < 0.01) BW than heifers grazing counterpart forage treatments. From January to February, heifers grazing

TF pastures gained ($P < 0.01$) BW, while BI and SG heifers lost BW but did not differ ($P = 0.35$) in amount of BW loss. From March to April, forage type did not influence ($P = 0.84$) heifer BW change. Overall BW gain from January to April was greater ($P < 0.01$) in heifers grazing TF pastures than BI and SG heifers. Body condition score was not influenced ($P \geq 0.12$) by forage type in January or February. Due to differences in BW change, heifers grazing TF pastures had greater ($P < 0.01$) BCS than their counterparts in March and April. As expected, heifers grazing TF had greater BW gain and BCS when compared with heifers grazing warm-season grasses. Heifers grazing BI and SG pastures lost BW initially from January to February; however, heifers grazing the native warm-season forage may have decreased their maintenance requirements, resulting in no difference in BW gain as TF heifers from March to April. Similarly, developing heifers on low-quality forages has been shown improve efficiency of nutrient utilization by lowering maintenance requirements (Freetly et al., 2008).

Heifer BW was not influenced ($P \geq 0.13$, Table 3.3) by supplement type during the duration of the study. In addition, heifer BW change was not different ($P \geq 0.13$) from January to February and January to April. However, heifers fed DDGS from March to April did gain ($P = 0.03$) more BW than heifers fed BF. Feeding DDGS to growing cattle consuming forage-based diets provides energy in the form of highly digestible fiber and fat (Stock et al., 2000). However, more frequent DDGS supplementation may be required for improvement in animal growth (Stalker et al., 2009). From February to March, BW change exhibited ($P < 0.01$, Table 3.4) a forage type × supplement type interaction. Supplement type did not influence ($P \geq 0.26$) heifer BW change in heifers grazing TF or SG pastures; however, heifers fed BF outgained ($P < 0.01$) DDG heifers while grazing BI pastures. Body condition scores during this study were not different ($P \geq 0.25$) between heifers fed DDGS and BF. Lalman et al. (1993) reported no difference in BW and ADG in heifers during supplementation of RUP, propionic acid, or monensin. Likewise, heifers provided with isonitrogenous (36% CP) supplements containing either 36% or 50% RUP exhibited no difference in BW and ADG over the course of the study (Mulliniks et al., 2013). Overall, two different protein supplements had little impact on BW and BW change in the present study.

Serum Metabolites

Serum metabolites did not exhibit ($P \geq 0.30$) a forage type or supplement type × sampling time interaction. Serum glucose concentrations were greater ($P = 0.02$, Table 3.5) in heifers grazing SG pasture than their counterparts. Circulating concentrations of NEFA were not different ($P = 0.88$) among forage types. Elevated NEFA concentrations were expected in heifers grazing warm-season grasses, as indicated by the BW change differences. However, heifers grazing warm-season grasses did have an increased BW gain prior to the end of the grazing trial. Concentrations of NEFA can rapidly decline as animals experience a compensatory growth period (Ellenberger et al., 1989). Additionally, heifers fed to maintain BW for 95 d had decreased circulating NEFA concentrations within 10 d of BW realimentation to not different levels as ad libitum fed heifers (Yambayamba, 1996). Serum urea N concentrations were not different (P = 0.85) among forage types. Differences in circulating SUN were expected due to forage quality differences and BW losses in heifers grazing SG and BI pastures. However, heifers grazing endophyte-infected tall fescue had lower SUN concentrations than expected with regard to forage nutrient value (Poore et al., 2006; Drewnoski et al., 2009; Lyons et al., 2016). Collectively, these authors suggest intake of degradable protein may be limiting growth performance in heifers grazing endophyte-infected tall fescue (Poore et al., 2006; Drewnoski et al., 2009; Lyons et al., 2016). Concentrations of SUN can provide an indication of N availability resulting from deamination of dietary and endogenous protein sources (Roseler et al., 1993). Ruminal N recycling may preserve dietary N in response to nutrient restriction (Bunting et al., 1989), and compensatory gain following nutrient restriction may improve metabolic and N efficiency (Freetly and Nienaber, 1998).

Serum glucose concentrations were not different (P = 0.70, Table 3.6) between protein supplement types. Heifers fed BF had greater (P < 0.01) circulating concentrations of SUN than their counterparts. In the present study, heifers were supplemented with not different amounts of CP; however, BF supplementation increased SUN concentration. Excess AA are catabolized to urea by the liver (Drackley et al., 2001), which results in increased circulating SUN. Slowly fermented forages require less RDP because excess degradable protein may cause N losses from the rumen and may decrease N recycling

(Siddons et al., 1985). Supplement type did not influence (*P* = 0.61) serum NEFA concentration, which was expected due to minimal BW change differences.

VFA Production

All VFA concentrations did not exhibit (*P* ≥ 0.57) an interaction for either forage type or supplementation type × sampling time. Heifers grazing SG pastures had greater (*P* = 0.04, Table 3.5) ruminal acetate concentrations than their counterparts. However, ruminal concentrations of propionate and butyrate were not influenced (*P* ≥ 0.32) by forage species. Due to an increase in ruminal acetate concentration, ruminal acetate:propionate ratio was greater (*P* = 0.04) for heifers grazing SG pastures. Ruminal acetate concentrations increase as plants mature and indicate fermentation of the plant cell wall (McCollum et al., 1985). Typically, warm-season grasses are expected to be lower in nutritional quality (Galyean and Goetsch, 1993). Bohnert et al. (2011) determined low-quality warm-season forage decreased ruminal retention time and increased digestibility with CP supplementation when compared with low-quality cool-season forage. In the present study, SG pastures were lower quality and likely less digestible than BI and TF pastures leading to subsequent changes in molar VFA concentrations.

Heifers fed BF tended (*P* = 0.09, Table 3.6) to have greater ruminal acetate concentration. Ruminal propionate concentration was not influenced (*P* = 0.40) by supplement type. However, acetate:propionate ratio was not influenced (*P* = 0.15) by supplement type. Furthermore, ruminal butyrate concentration was greater (*P* < 0.01) in

BF heifers than their DDGS counterpart. Protein supplementation of beef cattle consuming low-quality forage has increased forage intake (McCollum and Galyean, 1985). Typically, protein supplementation elicits positive responses when forage CP content is less than 6% (Kartchner, 1980). In addition, Köster et al. (1996) reported that supplemental RDP increased ruminal VFA concentrations and decreased the acetate:propionate ratio. Likewise, supplementation of cottonseed meal decreased the acetate:propionate ratio (McCollum and Galyean, 1985). Ruminal butyrate concentrations were increased in steers grazing low-quality range and provided supplemental protein (Caton et al., 1988). Supplementation of fish meal to lactating dairy cows did not influence ruminal VFA concentrations when compared with isonitrogenous corn gluten meal (Spain et al., 1995). Supplementation of BF may have increased forage intake when compared with DDGS, in the present study. Overall, supplementation of two different high-RUP sources had minimal impact on ruminal fermentation end-products.

In conclusion, grazing dormant, native warm-season grasses delayed gain; however, heifers grazing warm-season native forages were on the positive rate of gain by the end of the grazing period. Of the forage types evaluated, only stockpiled switchgrass pastures altered rumen fermentation as a result of forage nutritive value and maturity. However, if using stockpiling warm-season forages for winter grazing is used in heifer development systems, a compensatory gain period may be needed to make these species a viable opportunity for heifers in the southeastern United States.

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APPENDIX

Table 3.1 Forage type and grazing period effects on forage characteristics of stockpiled winter forages from beginning to end of the grazing period.

	Treatment[1]			
Measurement	TF	BI	SG	SEM
Forage Mass (kg DM/ha)				
January	1,225.01^{ax}	1,784.44^{bx}	1,229.72^{cx}	106.14
April	1,029.39^{ax}	2,149.14^{by}	1,657.92^{cy}	103.45
Crude Protein, %				
January	8.66^{ax}	5.06^{bx}	3.82^{cx}	0.37
Feb	7.65^{ay}	4.25^{bx}	3.83^{bx}	0.37
April	9.40^{ax}	4.75^{bx}	3.40^{cx}	0.37
NDF, %				
Jan	61.64^{ax}	69.09^{bx}	76.78^{cx}	0.81
Feb	68.28^{ay}	72.21^{by}	77.99^{cx}	0.81
April	65.55^{az}	68.85^{bx}	77.21^{cx}	0.81

[a,b,c]Within a forage type, means with different superscripts differ (*P* < 0.05).

[x,y,z]Within a grazing period, means with different superscripts differ (*P* < 0.05).

[1]Forage: endophyte-infected tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

Table 3.2 Forage type effects on beef heifer performance during winter grazing in Tennessee.

	Forage[1]				
Measurement	TF	BI	SG	SEM	*P*-value
Heifer BW, kg					
Jan	301	306	307	3	0.27
Feb	318[a]	292[b]	288[b]	4	< 0.01
March	326[a]	292[b]	281[b]	5	< 0.01
April	335[a]	302[b]	289[c]	5	< 0.01
BW change, kg					
Jan to Feb	17[a]	-13[b]	-18[b]	4	< 0.01
March to April	9	9	7	2	0.84
Jan to April	34[a]	-4[b]	-18[c]	4	< 0.01
BCS					
Jan	5.77	5.70	5.85	0.05	0.12
Feb	5.26	5.19	5.26	0.04	0.39
March	5.25[a]	4.98[b]	4.90[b]	0.07	< 0.01
April	5.23[a]	5.00[b]	4.86[b]	0.08	< 0.01

[a,b,c]Means with different superscripts differ ($P < 0.05$).

[1]Forage: endophyte-infected tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

Table 3.3 Supplement type effects on beef heifer performance during the winter grazing period in Tennessee.

	Supplement[1]			
Measurement	BF	DDGS	SEM	*P*-value
Heifer BW, kg				
Jan	302	307	2	0.13
Feb	300	299	3	0.80
March	301	298	4	0.61
April	307	310	4	0.60
BW change, kg				
Jan to Feb	-2	-8	4	0.13
March to April	5	12	2	0.03
Jan to April	5	3	3	0.69
BCS				
Jan	5.77	5.77	0.04	0.98
Feb	5.24	5.19	0.03	0.27
March	5.09	4.89	0.06	0.25
April	5.04	5.02	0.06	0.85

[1]Supplement: blood meal and fish meal (BF), and dried distiller's grains with solubles (DDGS).

Table 3.4 Forage type and supplement type effects (forage type × supplement type) on beef heifer production during the winter grazing period in Tennessee.

	Forage[1]			
Measurement	TF	BI	SG	SEM
Feb to March[2]				
BW change, kg				
BF	7[ax]	5[ax]	-9[bx]	2
DDGS	8[ax]	-5[by]	-6[bx]	3

[a,b]Within a forage, means with different superscripts differ (*P* < 0.05).

[x,y]Within a supplement, means with different superscripts differ (*P* < 0.05).

[1]Forage: endophyte-infected tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

[2]Supplement: blood meal and fish meal (BF), and dried distiller's grains with solubles (DDGS).

Table 3.5 Forage type effects on serum metabolites and volatile fatty acid profile of beef heifers during the winter grazing period in Tennessee.

	Forage[1]				
Measurement	TF	BI	SG	SEM	*P*-value
Serum Metabolites					
Glucose, mg/dL	73.2[a]	69.0[a]	84.2[b]	4.06	0.02
NEFA, mmol/L	356.0	343.8	358.8	24.65	0.88
SUN[2], mg/dL	10.03	9.85	9.61	0.59	0.85
Rumen VFA					
Acetate	43.6[a]	42.8[a]	52.6[b]	2.92	0.04
Propionate	10.9	10.8	12.0	0.64	0.32
Butyrate	6.8	5.7	7.5	0.91	0.33
Acetate:Propionate	4.1[a]	4.0[a]	4.5[b]	0.14	0.04

[a,b]Means without a common superscript differ ($P < 0.05$).

[1]Forage: endophyte-infected tall fescue (TF), big bluestem and indiangrass combination (BI), and switchgrass (SG).

[2]SUN = serum urea N.

Table 3.6 Supplement type effects on serum metabolites and volatile fatty acid profile of beef heifers during the winter grazing period in Tennessee.

	Treatment[1]			
Measurement	BF	DDGS	SEM	*P*-value
Serum Metabolites				
Glucose, mg/dL	76.3	74.9	3.26	0.70
NEFA, mmol/L	359.2	346.5	19.75	0.61
SUN[2], mg/dL	10.9	8.7	0.48	< 0.01
Rumen VFA				
Acetate	49.1	43.6	2.19	0.09
Propionate	11.5	10.9	0.50	0.40
Butyrate	8.2	5.2	0.64	< 0.01
Acetate:Propionate	4.3	4.1	0.11	0.15

[1]Supplement: blood meal and fish meal (BF), and dried distiller's grains with solubles (DDGS).

[2]SUN = serum urea N.

CHAPTER IV:

ESTIMATION OF NET PRESENT VALUE, PAYBACK PERIOD, AND BREAKEVEN PRICES OF CALVES FROM HEIFERS DEVELOPED ON STOCKPILED WINTER FORAGES

A version of this chapter is being prepared for publication by: Zachary D. McFarlane, Chris N. Boyer, and J. Travis Mulliniks.

ABSTRACT

We compare a distribution of breakeven prices over an 11-yr productive life for calves born from a heifer that was developed grazing two warm-season grasses and one cool-season grass during the winter months to prices for heifers developed in a drylot system. Data were compiled from a low-input heifer development grazing trial using stockpiled forages and protein supplementation. The range of total cost of producing the first calf from a heifer using the three forage-based systems was $1,079/head to $1,149/head with tall fescue (TF) being the most expensive forage-based heifer development system. The net present value of heifers developed on forage ranged from $264 to $468, while heifers developed in a drylot system had a negative net present value of (-)$876. Payback period was estimated in years of age with heifers in a forage-based system becoming profitable at 3 to 4 years of age, whereas heifers developed in a drylot were 9 to 10 years of age before return on investment. The results indicate that switchgrass was the lowest risk and the most profitable forage species relative to TF. The total cost to produce a calf from heifers developed in a drylot system ranged from $574 to $644/head more expensive than forage-based systems, resulting in an increased breakeven price for the first calf of $1.57 to $1.90/lb greater than the forage-based

development system. These findings suggest low-input, forage-based systems may be more profitable than drylot heifer development systems in the southeastern United States.

INTRODUCTION

Developing heifers to replace cull cows is one of the most expensive management decisions for cow-calf producers, which has major implications on the long-term profitability of the herd. Historically, producers have been encouraged to feed weaned heifer calves to reach 65% of their mature bodyweight before breeding to maximize pregnancy rates (Patterson et al., 1992). Developing heifers in a drylot system, which is feeding confined animals harvested feedstuffs, is common practice to ensure heifers achieve a target bodyweight to maximize pregnancy rates. However, higher feed and production costs have increased the cost of heifer development in drylot systems. Therefore, the additional cost of feeding replacement heifers to maximize pregnancy rates may be greater than returns from producing and selling an additional calf.

Recent studies have shown that developing heifers to a lighter target bodyweight can reduce input costs without impairing reproductive function (Funston and Deutscher, 2004; Clark et al., 2005; Roberts et al., 2009; Funston and Larson, 2011; Mulliniks et al., 2013). Input costs to develop heifers to achieve 50 to 55% of mature bodyweight at breeding were decreased by $19 to $45/heifer when compared with development to 65% of mature body weight (Feuz, 2001; Funston and Deutscher, 2004; Clark et al., 2005; Funston and Larson, 2011). These studies have compared traditional drylot systems with alternative approaches where heifers graze lower-quality forage systems (corn residue and/or winter native range) with additional supplemental protein (Funston and Larson, 2011; Mulliniks et al., 2013; Summers et al., 2014). In addition, these studies determined that reproductive performance was similar across systems while the cost of development in a drylot was more expensive than grazing heifers (Funston and Larson, 2011; Mulliniks et al., 2013; Summers et al., 2014).

While the mentioned research are insightful in making profitable heifer development management decisions, they were conducted in extensive rangelands systems in the western United States and do not go beyond calculating costs. Little is known about how these developmental systems affect reproductive efficiency, calf performance, and economics of heifer development on pasture in the southeastern United States. Beef cattle production in the southeastern United States is centered on forage-based, cow-calf production (McBride and Mathews, 2011). Tall fescue (TF) *(Schedonorus arundinaceus* (Schreb.) Dumort) is a cool-season grass that is adaptable, easy to establish, and persistent under adverse conditions (Stuedemann and Hoveland, 1988; Wolf et al., 1979), which is why cattle producers primarily rely on it for pasture and hay in this region (Keyser et al., 2011). Cool-season grasses grow primarily from early March to May with additional growth from the end of September to November (Keyser et al., 2011).

TF has some physiological characteristics that can cause problems for cattle producers (Volenec and Nelson, 2007). During summer, cattle grazing endophyte-infected TF are likely impacted by fescue toxicity, which can result in elevated body temperature, lower conception rates, reduced average daily gain, and failure to shed winter coat (Looper et al., 2010; Roberts and Andrae, 2004). These biological effects of fescue toxicity result in losses of over $1 billion a year to United States cattle producers (Smith et al., 2012). Thus, some attention has focused on evaluating cattle performance and the net returns to grazing warm-season grasses in the southeastern United States, which primarily grow from May to August (Burns et al. 1984; Burns and Fisher, 2013; Lowe et al., 2015; Lowe et al., 2016). Lowe et al. (2015) reported grazing steers on warm-season grasses in Tennessee had net returns ranging from $99 to $345/acre, depending on species. Similarly, Lowe et al. (2016) analyzed animal performance and economics of grazing bred dairy heifers on warm-season grasses during the summer months. Costs for dairy heifers grazing warm-season grasses were $0.38 and $0.65/head/day and costs for commodity feeds that produced comparable gains were never less than $1.89/head/day (Lowe et al., 2016). Overall, grazing warm-season grasses to complement TF grazing systems in the southeastern United States appears to be an economically viable option.

Since the environment of the southeastern United States allows for multiple forage growing seasons, producers could stockpile cool- and warm-season forages to extend the grazing season in the winter months and reduce the cost of heifer development (Poore et al., 2006; Drewnoski et al., 2009; McFarlane et al., 2017). Poore et al. (2006) and Drewnoski et al. (2009) reported stockpiling endophyte-infected TF for grazing from December to February was a viable opportunity for producers developing beef heifers. Furthermore, McFarlane et al. (2017) reported that heifers grazing low-quality, warm-season grasses during winter development may require a compensatory growth period prior to breeding to be reproductively successful. However, little is known about the economics of developing a heifer in the southeastern United States using stockpiled cool- and warm-season forages during the winter and how the economics of these heifer development systems compare to a drylot system.

The objective of this research was to determine the profitability of retaining a heifer to develop while grazing stockpiled cool- and warm-season grasses during the winter months. Profitability was measured as net present value (NPV) of the developed heifer over an 11-year useful life. We estimated the number of calves a heifer needs to produce over her useful life to be profitable (i.e., payback period) and the breakeven price for each calf over the heifer's production life. Data comes from a grazing experiment in Tennessee where heifers grazed big bluestem (*Andropogon gerardi* Vitman) and indiangrass (*Sorghastrum nutans* L.) combination (BBIG); switchgrass (*Panicum virgatum* L.) (SW); and endophyte-infected TF pastures. Additionally, we estimated NPV, payback period, and breakeven prices for developing a heifer in a traditional drylot system during the same time period to achieve a target bodyweight before breeding. Results will help producers improve long-term profitability of their herd by making profitable heifer development decisions.

MATERIALS AND METHODS

Economic Model

Selection of replacement females is viewed as a long-term investment into the herd (Matthews and Short, 2001; Meek et al., 1999). Beef producers have to invest several years of capital before a heifer produces a calf or generates revenue. Cow-calf producers in the southeastern United States typically follow a spring-calving season, beginning in January (Campbell et al., 2013; Henry et al., 2016). Therefore, the cost of producing a heifer begins when a cow is bred, which is a year before the heifer is born. In January, a heifer calf is born that will be developed to replace a cull cow and is weaned in September. The heifer calf is bred the following April, calves in the following January at two years of age, and her calf is generally weaned in September. Assuming that producers commonly market their calves after a short weaning period, revenue will include the sale of steer and heifer calves as well as the sale of culled cows. The size of the calves at weaning, and the number of cows culled are also components affecting revenue. Therefore, producers incur production costs such as pasture and feed for several years before receiving revenue from heifers. Another important cost to consider in the cow-calf producer's decision to develop a heifer to replace a cull cow is the opportunity cost (Tang et al., 2017). The revenue the producer could receive from selling the heifer calf at weaning is the opportunity cost.

Given the aforementioned factors to consider, partial budgets were used to estimate net returns for heifer developed on forage-based and drylot systems. Partial budgeting approach only considers the costs that are different across the heifer development systems (Kay et al., 2012). Annual net returns can be generally expressed as

(1) $$E[\pi_{it}] = p_{it}^{s} y_{it}^{s} \left(\frac{PR_i}{2}\right) + p_{it}^{h} y_{it}^{h} \left(\frac{PR_i}{2} - RR_i\right) + p_{it}^{c} y_{it}^{c} (RR_i) - p_{it}^{h} y_{it}^{h} \left(\frac{(1-PR_i)}{2} - RR_i\right) - PC_{it} - FC_{it}$$

where π_{it} is the expected annual net returns ($/head) for the *i*th heifer development system (*i* = BBIG, SW, TF, and drylot) in time period *t* (*t* = 1,…,11); p_{it}^{s} is the price of steer calves ($/lb); y_{it}^{s} is the weight of the steer calves (lb/head); PR_i is the pregnancy rate $0 \leq PR_i \leq 1$; p_{it}^{h} is the price of the heifer calves ($/lb); y_{it}^{h} is the weight of heifer calves (lb/head); RR_i is the replacement rate of the cow herd $0 \leq RR_i \leq 1$; p_{it}^{c} is the price of culled cows ($/lb); y_{it}^{c} is the weight of cull cows (lb/head); PC_{it} is the annualized pasture cost for each forage ($/head) in time period *t* (*t* = 1,…, *T*); and FC_{it} is the supplemental or harvested feed costs ($/head) for each heifer development system. The opportunity cost [$p_{it}^{h} y_{it}^{h} \left(\frac{(1-PR_i)}{2} - RR_i\right)$] is discounted back one period because this is a onetime cost that occurs in period one.

Net returns were modeled for a producer that grazes cattle year-round. Therefore, heifers developed on the forages had the cost of pasture and supplemental feed during development heifers developed. In the drylot system, three months of the year (January through March) heifers will be fed harvested feedstuffs and the remaining nine months will be spent grazing. Therefore, pasture costs also was included in the drylot system. With the partial budgeting approach, we only consider the annual cost of pasture and feed during the development months of January through March. Therefore, the total cost of developing a heifer would likely be higher than what is reported in this manuscript.

The annual net returns were discounted to find the NPV of each heifer development system, which is generally expressed as

$$(2)\ E[NPV_i] = \sum_{t=2}^{11}[p_{it}^{s}y_{it}^{s}\left(\frac{PR_i}{2}\right) + p_{it}^{h}y_{it}^{h}\left(\frac{PR_i}{2} - RR_i\right) + p_{it}^{c}y_{it}^{c}(RR_i)]\,/(1+R)^{t} -$$

$$\sum_{t=1}^{11}[(PC_{it} + FC_{it})/(1+R)^{t} - p_{it}^{h}y_{it}^{h}\left(\frac{(1-PR_i)}{2} - RR_i\right)/(1+R)\,]$$

where NPV_i is the sum of the discounted annual net returns; and R is the risk-adjusted discount rate.

Payback period for the heifer was also estimated. This measurement estimates the age when a heifer that was retained and developed becomes profitable (Kay et al., 2012). This calculation was found by dividing the sum of the annual discounted returns by the initial investment cost of developing the heifer (Schultz, 2016). The age at which the revenue annual net returns are greater than the investment cost is when heifers become profitable. Therefore, an investment with the shortest payback period is preferred.

Going beyond payback period, we can determine the price a producer would need to make zero profit for each calf or commonly referred to as a breakeven price (Kay et al., 2012). Equation (1) can be rearranged to show the price (per lb) producers would need to breakeven with each calf produced by the heifer over her useful life, which is expressed as

$$(3) \qquad p_{it}^{BE} = \frac{\left[\sum_{t=0}^{11}(PC_{it}+FC_{it})/(1+R)^{t} - p_i^h y_i^h\left(\frac{(1-PR_i)}{2}+RR_i\right)/(1+R)\right]}{\sum_{t=2}^{11} y_{it}\times[PR_i - RR_i]}$$

where p_{it}^{BE} is the breakeven price ($/lb) for the calf in time period t; and y_{it} is the weight for a given calf. The breakeven price is the same for heifers and steers since the cost of production to raise these calves will be the same. Any price the producer receives above the breakeven price is profitable and if the price received is below the breakeven price, profits will be negative. A greater costs of production will result in a higher breakeven price, thus, limiting the chances of economic profits. However, a lower cost of production will decrease the breakeven price, and the producer would have a greater opportunity of making economic profits. Therefore, minimizing cost of production provides the greatest opportunity for profit.

Simulation and Risk Analysis

Retaining and developing heifers can be a risk investment due to variability in production and prices (Matthews and Short, 2001). A Monte Carlo simulation model was developed to estimate distributions of NPV, payback periods, and breakeven prices for each of the grasses used in the forage-based heifer development as well as on a drylot. Drylot systems closely monitor for heifer feed intake and growth performance, which reduces the production risk (Funston and Larson, 2011; Mulliniks et al., 2013; Summers et al., 2014). However, price risk is an important to consider when using a drylot system. Producers who choose to use a forage-based system for heifer development are potentially taking on greater production risk due to increased variability in growth. Therefore, for the forage-based heifer development systems model considered variability of weaning weights and cattle prices and the drylot system model only considered price variability.

Prices for culled cows, steers, and heifers were randomly drawn from a multivariate empirical distribution derived using historical Tennessee price data from 2000-2017, and calf weights in the forage-based systems were randomly drawn from a GRKS distribution, which is similar to Henry et al. (2016). The GRKS distribution is useful when minimal information is available about the distribution, requiring only minimum, midpoint, and maximum values as the bounds for the distribution (Richardson, 2006). The GRKS distribution is a two-piece normal distribution with 50% of the observations below the midpoint and 2.5% below the minimum value, while 50% of the observations are above the midpoint and 2.5% above the maximum value (Richardson, 2006). Simulation and Econometrics to Analyze Risk (SIMETAR©) was used to develop the distributions and perform the simulations (Richardson et al., 2008). A total of 5,000 breakeven price observations were simulated for each of the forage-based heifer development systems.

Stochastic dominance was used to compare the distributions of NPV for each forage-based system and the drylot system. In first degree stochastic dominance, the scenario with CDF F dominates another scenario with CDF G if $F(\pi) \leq G(\pi)\, \forall\, \pi$ (Chavas, 2004). First degree stochastic dominance often does not find one scenario to clearly be preferred to another; therefore, second degree stochastic dominance adds the restriction that producers are risk averse, which increases the chance of finding a preferable scenario (Chavas, 2004). Second degree stochastic dominance states the scenario with CDF F dominates another scenario with CDF G if G if $\int F(\pi)\, d\pi \leq \int G(\pi)\, d\pi\, \forall\, \pi$ (Chavas, 2004). Stochastic dominance is an effective method of conducting a risk analysis of different production practices (Henry et al., 2016). The distributions of the payback period and breakeven prices are presented but are not analyzed using stochastic dominance. We used NPV distributions for the analysis since this is the measure of profitability.

Drylot System

The primary difference between the forage-based heifer development systems and drylot systems is the cost of feed during the drylot period from January through March (i.e., approximately 100 days). We assume that producers are grazing heifers from April through December on TF pasture and from January to March heifers are fed harvested feedstuffs in a drylot. While the fence, fuel, or equipment costs would likely increase in a drylot system, we only accounted for additional feed and labor costs. The cost of the feed rations for the drylot were estimated for January, February, and, March because adequate nutrition was likely available while grazing TF pastures the remaining months of the year. Rations were generated to meet the pre-determined nutritional needs for heifers using the National Research Council (NRC) Nutrient Requirements of Beef Cattle 2017 program (NRC, 2017). The NRC program determined the minimal nutritional needs for a heifer based on animal description and feed diet evaluation. The animal description variables were age, body weight, and target average daily gain (ADG). In the diet evaluation section, this program focuses on balancing a cow's required dry matter intake (DMI), net energy for maintenance (NEm), net energy for gain (NEg), total digestible nutrients, and crude protein (CP) using the available feed ration ingredients specified in the program. For a growing heifer that is 500 lb with a target ADG of two lb/day, the minimum amount of DMI was 18.4 lb/day, NEm was 3.76 mcal/day, NEg was 2.4 mcal/day, TDN was 13.01 lb/day, and CP was 2.04 lb/day.

Ingredients for feed rations can be selected by producers based on several criteria. The accessibility and price of the ingredients are likely two of the most important criteria for selecting feed rations. Therefore, the least-cost ration was constructed by selecting from five commonly accessible ingredients in Tennessee, including corn gluten feed, corn silage, dried distillers grains with solubles (DDGS), soybean hulls, and whole cottonseed. Since corn silage is the dominant feedstuff used in Tennessee for large beef producers, we restricted the ration to be at least 90% corn silage. Similarly to Henry et al. (2016), a linear programming model was constructed to select across all ingredients to build the least-cost feed rations. The objective was to find the combination and quantity (ϕ_m) of the five ingredients that minimized costs while providing a cow the minimum amount of DMI, NEm, NEg, TDN, and CP per month expressed as:

(4)

$$\min_{\phi_m} FC_m = \sum_{n=1}^{5} \phi_{mn}\bar{d}_{mn}$$

$$s.t.\ \ \phi_{mn} \geq 0\ , \bar{d}_{mn} \geq 0$$

$$DMI_m = \ \sum_{n=1}^{5} \phi_{mn}\delta_n \geq MinDMI_m\ \ \forall\, m's$$

$$NEm_m = \ \sum_{n=1}^{5} \phi_{mn}\lambda_n \geq MinNEm_m\ \ \forall\, m's$$

$$NEg_m = \ \sum_{n=1}^{5} \phi_{mn}\gamma_n \geq MinNEg_m\ \ \forall\, m's$$

$$TDN_m = \ \sum_{n=1}^{5} \phi_{mn}\tau_n \geq MinTDNN_m\ \ \forall\, m's$$

$$CP_m = \ \sum_{n=1}^{5} \phi_{mn}\psi_n \geq MinCP_m\ \ \forall\, m's$$

$$CS_m = \ \sum_{n=1}^{5} \phi_{mn}\kappa_n \geq MinDMI_m \times 0.9\ \ \forall\, m's$$

where FC_m is the feed cost (\$/head) in the *m*th month; $\bar{d}_{mn}$ is average price of the *n*th ingredient (\$/lb); DMI_m is the dry matter intake (lb/day); δ_n is the percentage of ingredient *n* that is dry matter; $MinDMI_m$ is the minimum level of dry matter intake (lb/day) needed by a heifer; NEm_m is the NEm (mcal/day); λ_n is the percentage of ingredient *n* that is NEm; $MinNEm_m$ is the minimal NEm (mcal/day) needed by a heifer; NEg_m is the NEg (mcal/day); γ_n is the percentage of ingredient *n* that is NEg; $MinNEg_m$ is the minimal NEg (mcal/day) needed by a heifer; TDN_m is the TDN in (lb/day); τ_n is the percentage of ingredient *n* that is TDN; CP_m is the CP (grams/day); ψ_n is the percentage of ingredient *n* that is CP; $MinCP_m$ is the minimal CP (grams/day) needed by a heifer; CS_m is the amount of corn silage that is feed in the ration (lb/day); and κ_n is the percentage of ingredient *n* that is corn silage.

DATA

All animal handling and experimental procedures were conducted according to the guidelines of the Institutional Animal Care and Use Committee (IACUC) of the University of Tennessee (IACUC approval number 2146-0116).

Animal Measurements and Treatments

In a 5-yr study, 266 spring-born, crossbred Angus heifers (Initial body weight = 730.36 ± 4.38 lb) were used to assess the effects of winter grazing stockpiled forage types and protein supplementation strategy on heifer growth, reproductive performance, and first calf performance. Heifers were stratified by bodyweight to one of three stockpiled forage types (*n* = 7 replicates per forage treatment) and received either one of two protein supplements at weaning in a 3 × 2 factorial arrangement. Stockpiled forages were BBIG, SW, and endophyte-infected TF. Each forage pasture type was then randomly allocated to receive either 1 of 2 supplement types: (1) 1.5 lb/heifer/day of DDGS (28% CP, 74% RUP, 88% TDN) or (2) 0.48 lb/heifer/day of blood meal and fish meal (BF) (72.5% CP, 67.5% RUP, 69.5% TDN). Therefore, the treatment combinations were BBIG/BF, BBIG/DDGS, SW/BF, SW/DDGS, TF/BF, and TF/DDGS. Heifers were all managed together before and after the grazing period. This research was conducted at the Middle Tennessee Research & Education Center, Spring Hill, TN (35°42'27" N, 86°56'31" W).

The grazing period began in January and was terminated in April at fixed-timed AI (TAI) every year of the study.

Heifers were managed together after termination of the different grazing treatments at the onset of the breeding season. The breeding season began in April every year and all heifers were synchronized utilizing a controlled internal drug-releasing (CIDR) device (Eazi-Breed CIDR, Zoetis Inc., Kalamazoo, MI) with a 7 d CO-Synch protocol. Heifers received a single two mL intramuscular injection of GnRH (Cystorelin, Merial) and a CIDR on -7 d. The CIDR was removed on 0 d and the heifers were administered a 5 mL intramuscular injection of PGF (Lutelyse, Zoetis Inc., Kalamazoo, MI). Intramuscular injections of 2 mL of GnRH (Cystorelin, Merial) were administered to all heifers approximately 66 h after CIDR removal, followed by artificial insemination (TAI). Natural service of heifers was provided by cleanup bulls that were turned out fourteen days after TAI for a 60 d breeding season with a heifer-to-bull ratio of 1:30. Assessment of reception to TAI occurred 30 d after insemination via transrectal ultrasonography. A final pregnancy diagnosis was administered by transrectal ultrasonography in September of every year. Verification of pregnancy diagnosis for reception to TAI or natural service was determined by back-calculating from calving date and subtracting by a 280-d gestation period.

The percentage of heifers that were diagnosed pregnant by forage type were 87% for BBIG/BF, 90% for BBIGDDGS, 92% for SW/BF, 93% for SW/DDGS, 91% for

TF/BF, and 94% TF/DDGS. Since we were unable to track death loss and still born calves because a portion of heifers were sold prior to calving, we assumed a replacement rate of 15%, which is typical for Tennessee producers (Henry et al., 2016). Calf bodyweight was measured at birth and weaning for the first calf of each heifer in the study. For a complete description of the materials and methods see McFarlane et al. (2018). Table 4.1 shows summary statistics of calf weight at weaning from the grazing experiment. In the economic and simulation model, we assumed that calves would have the same distribution of weaning weights in every year of the heifer's 11-year useful life, which is similar to the useful life assumed by Shane et al. (2017).

Economic Data

Enterprise budgets were used to estimate establishment and operational costs for grazing BBIG, SW, and TF. A 10-year production horizon was assumed (Lowe et al., 2015; 2016), with no grazing occurring in the establishment year. Total establishment and production costs of the forages were calculated following Lowe et al. (2015), Lowe et al. (2016), and Keyser et al. (2016). The establishment costs included seed, herbicide, fertilizer, labor, and machinery and were annualized over the life of the pasture using a discount rate of 5.5% (Lowe et al., 2015; 2016). The annualized establishment cost was added with annual operational costs and annual land rent to calculate total annual cost of production over a 10-year useful life. To account for the risk of failed establishment, a 10% re-establishment cost was assumed and in the budget. Estimated total annualized pasture costs are based on 2017 dollars and are shown in Table 4.2. Detailed enterprise budgets for each forage are provided in the appendix.

Livestock budgets were also constructed following the University of Tennessee Extension Livestock Budgets (University of Tennessee, 2017). Annualized pasture costs were multiplied by the stocking density of one cow-calf pair to one and a half acres to get a pasture cost per herd. The forage-based system fed DDGS or a 50:50 mixture of BF in the months of January, February, and March. The cost per head of each of these supplements from January to March was \$10.99 for BF and \$11.56 for DDGS.

The opportunity cost was calculating by multiplying the heifer weaning weight by the average heifer calf price. We selected a heifer weaning weight of 530 lb/head, which was the average weaning weight for heifer calves in the experiment. Prices for Tennessee heifers ranging from 500-600 lb were collected from the United States Department of Agriculture Agricultural Marketing Service (USDA AMS) (2017b) for the last fifteen years and adjusted into 2017 dollars using the United States Bureau of Labor Statistics Consumer Price Index (2017). The average heifer price was 1.26/lb (USDA AMS, 2017b) and opportunity cost was calculated by using a randomly drawn price. To calculate the revenue from cull cows, we also used the randomly drawn price from the Tennessee cull cow price over the last fifteen years (USDA AMS, 2017b) and multiplied the price by average cull cow weight of 1,400 pounds. We made these assumption for both the forage-based system and the drylot system. Production costs were discounted into net present value using the discount rate (*R*) of 5.5%, which is similar to the assumption in Henry et al. (2016).

For the drylot system, monthly prices for the ingredients of the feed rations reported at Memphis, Tennessee and St. Louis, Missouri (nearest locations to Tennessee) were also collected from USDA AMS (2017a). Seasonal prices were only available from 2002-2017 for January, February, and March. All beef and feed ingredient prices were adjusted into 2017 dollar values using the United States Bureau of Labor Statistics Consumer Price Index (2017). Table 4.3 presents the real monthly average and standard deviation for prices of corn gluten feed, corn silage, DDGS, soybean hulls, and whole cottonseed in the months of January, February, and March (USDA AMS, 2017a). Since we do not have data from a drylot system, we assumed a pregnancy rate of 95%, which are similar to previous reports (Patterson et al., 1992; Funston and Larson, 2011; Mulliniks et al., 2013), and calf weaning weight of 543 lb, which is the average of the weaning weight of all the calves in this experiment. The cost of labor for a heifer was assumed to be $80/head higher under a drylot system than a forage-based system. This is because heifers were fed on a daily basis instead of twice weekly in the forage-based treatments.

RESULTS AND DISCUSSION

The cost-minimizing ration formulation was 17.84 lb/day of corn silage and 0.88 lb/day of corn gluten in January and 16.47 lb/day of corn silage and 1.93 lb/day of corn gluten in February and March (Table 4.4). The total ration cost was $36.24/head in January, $38.18/head in February, and $37.40/head in March for a total cost of $111.82/head. With the added feed costs for the drylot system, the total cost of producing a calf from a heifer in a drylot system was $1,723/head, which is from $574 to $644/head more expensive than the forage-based heifer development systems (Table 4.5).

The estimated investment cost of producing a calf using the forage-based systems ranged from $1,079 to $1,149/head (Table 4.5). These estimates include costs from breeding until selling the first calf from the heifer. The most expensive forage treatment to develop heifers was TF/BF, and the least expensive forage treatment was SW/DDGS. Overall, TF had the highest cost of production of the three forage treatments. Switching from developing heifers on TF to BBIG or SW was estimated to reduce development cost from $30 to $62/head. Lowe et al. (2015) and Lowe et al. (2016) reported that summer grazing steers and heifers on warm-season grasses was profitable, which further supports the conclusion that warm-seasons grasses might be an economically viable option to complement TF grazing systems in the southeastern United States.

NPV and payback period for heifers were estimated over an 11-year productive life and presented in Table 4.5. NPV ranged from $264 to $468/head for forage-based heifer development. Heifers grazing SW had the greatest average NPV with $450 and $468/head for SW/BF and SW/DDGS, respectively. The lowest average NPV among forage-based development treatments was determined for heifers grazing TF ($264 and

$289/head for TF/BF and TF/DDGS, respectively). In contrast, heifers developed in a drylot system had a negative average NPV (-$876/head). Similarly, Mulliniks et al. (2013) found that net returns for range-based development were greater ($268.56/heifer developed) when compared with drylot-developed heifers ($168.85/heifer developed). This result is similar to several other studies conducted in the western United States (Feuz, 2001; Funston and Deutscher, 2004; Clark et al., 2005; Funston and Larson, 2011).

The distribution of NPV for each forage-based systems and drylot were compared and the treatment combination of SW/DDGS was found to be dominant over all systems by second degree stochastic dominance (Figure 1). We can conclude that both a risk averse and profit-maximizing producer would select the SW/DDGS heifer development system compared to all other forage-based systems. This results also reinforces the importance of low-cost heifer development on the long-term profitability of the herd.

Heifers developed in forage-based development systems would be approximately 4 years of age before paying back development costs. Approximately 10 years of productivity would be necessary for heifers developed in a drylot system to provide a return on investment. This means using forage-based system for heifer development results in the heifer becoming profitable at a younger age than using a drylot system.

Summary statistics of the breakeven prices over an 11-year productive life of heifers are presented in Table 4.6. The average breakeven price ranged from $2.76/lb to

$3.09/lb for the first calf of heifers developed in a forage-based system. The average breakeven price for the first calf of drylot heifers was $4.66/lb. Confidence intervals were calculated for each treatment at the 95% confidence level. The breakeven price from the drylot system was higher at the 95% confidences than all forage-based treatments. However, there was no difference in the breakeven prices across the forage-based treatments.

Among the forage-based treatments, BBIG/BF had the lowest average breakeven prices and TF/BF had the greatest average breakeven prices. Within treatments supplementing DDGS, SW had the lowest average breakeven prices, and heifers grazing BBIG had the lowest average breakeven price when supplemented BF. With the exception of BBIG/DDGS treatment, the breakeven price for the first calf from a heifer developed on TF was greater on average than for SW and BBIG/BF. First calf weaning weights were greater on average for heifers grazing TF than SW; thus, the lower cost of production for SW resulted in the breakeven price being lower than for TF. While weaning weights are important in analyzing the profitability of herd, the results demonstrate how the cost of production can impact the likelihood of breakeven.

The price of 500 to 600 pound steer and heifer calves in the last fifteen years (2002-2017) has ranged from $0.99 to $2.51/lb with an average price of $1.37/lb (USDA-AMS, 2017b). Thus, 15-year average cattle prices were less than the breakeven prices of the first calf from a heifer in the present study. Therefore, the first calf produced by the heifer will not likely be profitable. However, breakeven prices for calves around three and four years of age were at or below the average cattle price if a forage-based heifer development system was used. In contrast, heifers developed in a drylot would not breakeven until approximately 9 to 10 years of age.

The results show that first-calf heifers and 3-year-old cows are commonly not profitable for cow-calf producers assuming they produce a calf in both years. However, if a heifer or three year old cow does not wean a calf or fails to become pregnant, the long-term profitability of the herd will decreased. Therefore, improper management of the young, 2- and 3-year-old cow could be costly for producers. However, if heifer development costs are low, selling open heifers in a feeder market could be an economically viable enterprise (Clark et al., 2005). Overall, these results illustrate the need for increased selection pressure for heifers that have the ability to remain in the herd longer rather than masking infertility with overfeeding and developing heifers (Roberts et al., 2017).

CONCLUSIONS

Developing heifers to replace cull cows is a complex decision that can have major implications on herd profitability. Several studies have examined ways to reduce the cost of heifer development without impairing reproductive function in the western United States (Funston and Deutscher, 2004; Clark et al., 2005; Roberts et al., 2009; Funston and Larson, 2011; Mulliniks et al., 2013). However, little is known about the economics of heifer development in the southeastern United States. Thus, we calculated breakeven prices over an 11-yr productive life for heifers that were developed grazing BBIG, SW, and TF. We compared these breakeven prices to estimated breakeven prices from heifers developed in a drylot system. In addition, NPV and payback period were estimated for forage-based and drylot-based heifer development systems. This study builds on previous work by focusing on heifers in the southeastern United States, and the results will be helpful to inform producers on more profitable heifer development systems.

A simulation model was established to estimate a distribution of breakeven prices of calves from heifers developed on forage-based systems. The simulation was constructed to account for production risk of using a forage-based system. For the drylot system, a least-cost ration was developed to be fed during the months of January, February, and March.

The average breakeven price for the first calf from a heifer developed on forage-based systems was found to range from $2.76 to $3.09/lb, while the breakeven price under a drylot system was $4.66/lb. The drylot system increased the cost of producing a calf from a heifer in a drylot system to be $574 to $644/head more expensive than the forage-based heifer development systems. Heifers developed in a forage-based system would payback investment at approximately 3 to 4 years of age. Drylot-developed heifers would require a 9 to 10 year payback period. This result also support recent findings that warm-season grasses are an economically viable option to complement TF systems in the southeastern United States. In addition, low-cost, forage-based heifer development systems improve long-term economic efficiency for beef producers.

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APPENDIX

Table 4.1 Summary statistics of calf weaning weight (lb) by forage and supplement type

Pasture	Supplement[1]	Mean	Median	Standard Deviation	Minimum	Maximum
Big Bluestem/ Indiangrass	BF	576.42	568.50	60.30	468.00	737.00
	DDGS	531.15	557.00	75.97	345.00	605.00
Switchgrass	BF	537.33	534.50	73.39	380.00	674.00
	DDGS	548.67	533.00	82.51	405.00	660.00
Tall Fescue	BF	541.13	540.50	67.40	402.00	664.00
	DDGS	557.43	563.00	71.07	380.00	683.00

[1]Supplement: Blood and fish meal (BF) and dried distillers grains and solubles (DDGS).

Table 4.2 Annualized establishment costs and annual operating expenses ($/acre) for each forage type

	Annualized Establishment Cost	Annual Operating Expenses	Total Expense
Big Bluestem/ Indiangrass	$42.88	$185.76	$228.64
Switchgrass	$44.24	$182.78	$227.02
Tall Fescue	$31.95	$193.43	$225.38

Table 4.3 Average monthly real prices ($/dry ton) for feed ration ingredients from 2000 to 2017 in 2017 dollars

Month	Corn Gluten Feed ($/ton)	Corn Silage ($/ton)	Dried Distillers Grains ($/ton)	Soybean Hulls ($/ton)	Cottonseed Whole ($/ton)
January	$145.35	$40.03	$173.60	$133.34	$197.74
February	$138.32	$41.32	$156.47	$128.65	$195.81
March	$134.47	$42.13	$156.27	$119.50	$199.72

Source: USDA-AMS (2017) markets in St. Louis, MO and Memphis, TN as well as BLS-CPI (2017).

Standard Deviations are noted in parentheses.

Table 4.4 Amount of ingredients fed (dry lb/day) and total cost in each of the least-cost feed rations by month

	Month		
Ingredients (dry lb/day)	January	February	March
Corn Silage	17.84	16.47	16.47
Dried Distillers Grains	0.88	1.93	1.93
Total	18.72	18.40	18.40
Total Cost ($/head)	$36.24	$38.18	$37.40

Source: NRC (2017).

Table 4.5 Summary statistics of the simulated distributions of total cost of developing a heifer (in $/head), net present value ($/head), and payback period (years of age) by forage and supplement type

Pasture	Supplement[1]	Investment Cost	Net Present Value	Payback Period
Big Bluestem/ Indiangrass	BF	$1,119 (9.07)	$384 (432.65)	3.61 (0.736)
	DDGS	$1,098 (5.58)	$414 (434.65)	3.70 (0.767)
Switchgrass	BF	$1,087 (5.59)	$450 (434.47)	3.58 (0.751)
	DDGS	$1,079 (4.88)	$468 (437.42)	3.45 (0.716)
Tall Fescue	BF	$1,149 (6.28)	$264 (433.33)	3.91 (0.803)
	DDGS	$1,135 (4.19)	$289 (435.43)	3.51 (0.742)
Drylot	Harvested Feed	$1,723 (3.49)	-$876 (436.15)	9.65 (1.605)

Standard Deviations are noted in parentheses.

[1]Supplement: Blood and fish meal (BF) and dried distillers grains with solubles (DDGS).

Table 4.6 Summary statistics of the distribution of breakeven price for calves (in $/lb) over an 11-year production life by forage and supplement type

	BBIG[1]		SW		TF		
Age (years)	BF[2]	DDGS	BF	DDGS	BF	DDGS	Drylot
2	2.76 (0.313)[a]	3.05 (0.536)[a]	2.96 (0.447)[a]	2.92 (0.367)[a]	3.09 (0.403)[a]	3.00 (0.485)[a]	4.66 (0.021)[b]
3	1.67 (0.135)	1.83 (0.192)	1.79 (0.179)	1.76 (0.152)	1.87 (0.167)	1.81 (0.190)	2.85 (0.012)
4	1.30 (0.087)	1.43 (0.119)	1.40 (0.113)	1.38 (0.096)	1.46 (0.106)	1.42 (0.118)	2.25 (0.007)
5	1.12 (0.066)	1.24 (0.088)	1.21 (0.084)	1.19 (0.072)	1.26 (0.079)	1.22 (0.087)	1.95 (0.006)
6	1.02 (0.053)	1.12 (0.070)	1.09 (0.067)	1.08 (0.059)	1.14 (0.064)	1.11 (0.070)	1.77 (0.006)
7	0.94 (0.045)	1.04 (0.059)	1.01 (0.057)	1.00 (0.050)	1.06 (0.054)	1.03 (0.059)	1.65 (0.005)
8	0.89 (0.039)	0.98 (0.051)	0.96 (0.050)	0.95 (0.044)	1.00 (0.047)	0.97 (0.052)	1.56 (0.005)
9	0.85 (0.035)	0.94 (0.046)	0.92 (0.045)	0.91 (0.039)	0.96 (0.042)	0.93 (0.046)	1.50 (0.005)
10	0.82 (0.032)	0.91 (0.041)	0.89 (0.041)	0.88 (0.035)	0.93 (0.038)	0.90 (0.042)	1.45 (0.005)
11	0.80 (0.030)	0.88 (0.038)	0.86 (0.038)	0.85 (0.033)	0.90 (0.035)	0.87 (0.039)	1.40 (0.005)

Standard Deviations are in parentheses.

[a,b]Means with different superscripts differ ($P < 0.05$).

[1]Pasture: Big bluestem and indian grass (BBIG), switchgrass (SW), and Tall Fescue (TF)

[2]Supplement: Blood and fish meal (BF) and dried distillers grains and solubles (DDGS).

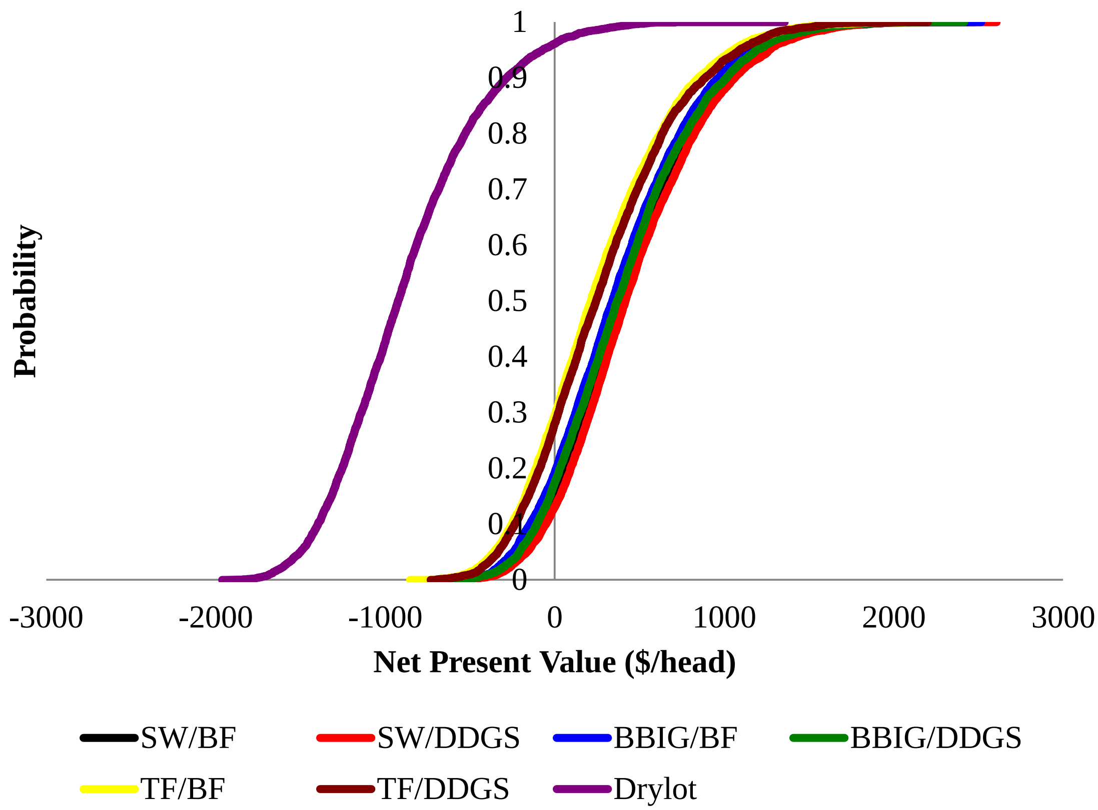

Figure 1. Cumulative distribution function of the breakeven price of the first born calf from a developed heifer ($/lb) by forage type and supplement type

Table 4.7 Switchgrass no-till establishment budget for Tennessee in 2017

Item	Unit	Quantity	Price	Amount
Variable Expenses				
Seed	lb	10.00	$13.50	$135.00
No-Till Drill Rental	acre	1.00	$9.80	$9.80
Nitrogen (NO3[a])	lb	0.00	$0.55	$0.00
Phosphorus (P2O5[b])	lb	30.00	$0.69	$20.70
Potassium (K20[c])	lb	30.00	$0.48	$14.40
Fertilizer Custom Application	acre	1.00	$9.38	$9.38
Lime Custom Application	ton	0.50	$9.38	$4.69
Gramoxone Max	pt	1.50	$4.33	$6.50
Surfactant	pt	0.50	$0.63	$0.32
Herbicide Custom Application	acre	1.00	$8.13	$8.13
Fuel[d]	acre	1.00	$7.94	$7.94
Oil and Filter[d]	acre	1.00	$1.18	$1.18
Repairs and Maintenance[d]	acre	1.00	$4.23	$4.23
Interest on Operating Capital	acre	1.00	8.00%	$12.18
Land Rent	acre	1.00	$20.00	$20.00
Total Variable Cost	acre	1.00		$254.45
Fixed Costs				
Depreciation[d]	acre	1.00	$2.63	$2.63
Interest[d]	acre	1.00	$3.41	$3.41
Insurance[d]	acre	1.00	$0.23	$0.23
Total Fixed Costs	acre	1.00		$6.27
Labor Cost	hour	0.91	$10.07	$9.16
Total Establishment Cost	acre	1.00		$269.88
10% Risk of Re-Establishment	acre	10.00%		$26.99
Total Cost With 10% Risk of Re-establishment	acre	1.00		$296.87
Annualized Total Cost of Establishment With 10% Risk	acre	1.00		$44.24

[a]NO3=Nitrate

[b]P2O5=Potassium Oxide

[c]K2O=Phosphate

[d]Costs are associated with operating a 100hp tractor and 10’ rotary mower.

Table 4.8 Switchgrass, no-till establishment, seeded expenses per acre in 2017

Item	Unit	Quantity	Price	Amount
Variable Expenses				
Nitrogen (NO3[a])	lb	60.00	$0.55	$33.00
Phosphorus (P2O5[b])	lb	30.00	$0.69	$20.70
Potassium (K20[c])	lb	30.00	$0.48	$14.40
Fertilizer Custom Application	acre	2.00	$9.38	$18.77
Lime Custom Application	ton	0.00	$9.38	$0.00
2, 4-D	pt	1.50	$5.15	$7.73
Surfactant	pt	0.20	$0.63	$0.13
Herbicide Custom Application	acre	1.00	$8.13	$8.13
Fuel[d]	acre	1.00	$2.78	$2.78
Oil and Filter[d]	acre	1.00	$0.41	$0.41
Repairs and Maintenance[d]	acre	1.00	$2.16	$2.16
Interest on Operating Capital	acre	1.00	8.00%	$4.33
Land Rent	acre	1.00	$20.00	$20.00
Total Variable Cost	acre	1.00		$132.54
Fixed Costs				
Prorated Establishment Cost	acre	1.00	10 years	$44.24
Depreciation[d]	acre	1.00	$1.13	$1.13
Interest[d]	acre	1.00	$1.53	$1.53
Insurance[d]	acre	1.00	$0.12	$0.12
Total Fixed Costs	acre	1.00		$47.02
Labor Cost	hour	0.32	$10.07	$3.22
Total Maintenance Expenses	acre	1.00		$182.78

[a]NO3=Nitrate

[b]P2O5=Potassium Oxide

[c]K2O=Phosphate

[d]Costs are associated with operating a 100hp tractor and 10’ rotary mower.

Table 4.9 Big bluestem/indiangrass no-till establishment budget for Tennessee in 2017

Item	Unit	Quantity	Price	Amount
Variable Expenses				
Big Bluestem Grass Seed	lb	6.00	$15	$90.00
Indian Grass Seed	lb	3.00	$15	$45.00
No-Till Drill Rental	acre	1.00	$9.80	$9.80
Nitrogen (NO3[a])	lb	0.00	$0.55	$0.00
Phosphorus (P2O5[b])	lb	30.00	$0.69	$20.70
Potassium (K20[c])	lb	30.00	$0.48	$14.40
Fertilizer Custom Application	acre	1.00	$9.38	$9.38
Lime Custom Application	ton	0.00	$9.38	$0.00
Gramoxone Max	pt	1.50	$4.33	$6.50
Surfactant	pt	0.50	$0.63	$0.32
Herbicide Custom Application	acre	1.00	$8.13	$8.13
Fuel[d]	acre	1.00	$7.94	$7.94
Oil and Filter[d]	acre	1.00	$1.18	$1.18
Repairs and Maintenance[d]	acre	1.00	$4.23	$4.23
Interest on Operating Capital	acre	1.00	8.00%	$8.59
Land Rent	acre	1.00	$20.00	$20.00
Total Variable Cost	acre	1.00		$246.17
Fixed Costs				
Depreciation[d]	acre	1.00	$2.63	$2.63
Interest[d]	acre	1.00	$3.41	$3.41
Insurance[d]	acre	1.00	$0.23	$0.23
Total Fixed Costs	acre	1.00		$6.27
Labor Cost	hour	0.91	$10.07	$9.16
Total Establishment Cost	acre	1.00		$261.60
10% Risk of Re-Establishment	acre	10.00%		$26.16
Total Cost With 10% Risk of Re-establishment	acre	1.00		$287.76
Annualized Total Cost of Establishment With 10% Risk	acre	1.00		$42.88

[a]NO3=Nitrate

[b]P2O5=Potassium Oxide

[c]K2O=Phosphate

[d]Costs are associated with operating a 100hp tractor and 10’ rotary mower.

Table 4.10 Big bluestem/indiangrass, no-till establishment, seeded expenses per acre in 2017

Item	Unit	Quantity	Price	Amount
Variable Expenses				
Nitrogen (NO3[a])	lb	60.00	$0.55	$33.00
Phosphorus (P2O5[b])	lb	30.00	$0.69	$20.70
Potassium (K20[c])	lb	30.00	$0.48	$14.40
Fertilizer Custom Application	acre	2.00	$9.38	$18.77
Lime Custom Application	ton	0.00	$9.38	$0.00
Plateau	pt	0.75	$15.93	$11.95
Surfactant	pt	0.125	$0.63	0.08
Herbicide Custom Application	acre	1.00	$8.13	$8.13
Fuel[d]	acre	1.00	$2.78	$2.78
Oil and Filter[d]	acre	1.00	$0.41	$0.41
Repairs and Maintenance[d]	acre	1.00	$2.16	$2.16
Interest on Operating Capital	acre	1.00	8.00%	$4.50
Land Rent	acre	1.00	$20.00	$20.00
Total Variable Cost	acre	1.00		$136.88
Fixed Costs				
Prorated Establishment Cost	acre	1.00	10 years	$42.88
Depreciation[d]	acre	1.00	$1.13	$1.13
Interest[d]	acre	1.00	$1.53	$1.53
Insurance[d]	acre	1.00	$0.12	$0.12
Total Fixed Costs	acre	1.00		$45.66
Labor Cost	hour	0.32	$10.07	$3.22
Total Maintenance Expenses	acre	1.00		$185.76

[a]NO3=Nitrate

[b]P2O5=Potassium Oxide

[c]K2O=Phosphate

[d]Costs are associated with operating a 100hp tractor and 10’ rotary mower.

Table 4.11 Endophyte-infected tall fescue no-till establishment budget for Tennessee in 2017

Item	Unit	Quantity	Price	Amount
Variable Expenses				
Kentucky 31 Tall Fescue Seed	lb	15.00	$1.32	$19.80
No-Till Drill Rental	acre	1.00	$9.80	$9.80
Nitrogen (NO3[a])	lb	30.00	$0.55	$16.50
Phosphorus (P2O5[b])	lb	60.00	$0.69	$41.40
Potassium (K20[c])	lb	60.00	$0.48	$28.80
Fertilizer Custom Application	acre	1.00	$9.38	$9.38
Lime Custom Application	ton	0.50	$9.38	$4.69
Gramoxone Max	pt	1.50	$4.33	$6.50
Surfactant	pt	0.50	$0.63	$0.32
Herbicide Custom Application	acre	1.00	$8.13	$8.13
Fuel[d]	acre	1.00	$7.94	$7.94
Oil and Filter[d]	acre	1.00	$1.18	$1.18
Repairs and Maintenance[d]	acre	1.00	$4.23	$4.23
Interest on Operating Capital	acre	1.00	8.00%	$5.27
Land Rent	acre	1.00	$20.00	$20.00
Total Variable Cost	acre	1.00		$183.93
Fixed Costs				
Depreciation[d]	acre	1.00	$2.63	$2.63
Interest[d]	acre	1.00	$3.41	$3.41
Insurance[d]	acre	1.00	$0.23	$0.23
Total Fixed Costs	acre	1.00		$6.27
Labor Cost	hour	0.91	$10.07	$9.16
Total Establishment Cost	acre	1.00		$194.92
10% Risk of Re-Establishment	acre	10.00%		$19.49
Total Cost With 10% Risk of Re-establishment	acre	1.00		$214.41
Annualized Total Cost of Establishment With 10% Risk	acre	1.00		$31.95

[a]NO3=Nitrate

[b]P2O5=Potassium Oxide

[c]K2O=Phosphate

[d]Costs are associated with operating a 100hp tractor and 10’ rotary mower.

Table 4.12 Endophyte-infected tall fescue, no-till establishment, seeded expenses per acre in 2017

Item	Unit	Quantity	Price	Amount
Variable Expenses				
Nitrogen (NO3[a])	lb	30.00	$0.55	$16.50
Phosphorus (P2O5[b])	lb	60.00	$0.69	$41.40
Potassium (K20[c])	lb	60.00	$0.48	$28.80
Fertilizer Custom Application	acre	2.00	$9.38	$18.77
Lime Custom Application	ton	0.00	$9.38	$0.00
Plateau	pt	0.75	$15.93	$11.95
Surfactant	pt	0.125	$0.63	0.08
Herbicide Custom Application	acre	1.00	$8.13	$8.13
Fuel[d]	acre	1.00	$2.78	$2.78
Oil and Filter[d]	acre	1.00	$0.41	$0.41
Repairs and Maintenance[d]	acre	1.00	$2.16	$2.16
Interest on Operating Capital	acre	1.00	8.00%	$4.50
Land Rent	acre	1.00	$20.00	$20.00
Total Variable Cost	acre	1.00		$155.48
Fixed Costs				
Prorated Establishment Cost	acre	1.00	10 years	$31.95
Depreciation[d]	acre	1.00	$1.13	$1.13
Interest[d]	acre	1.00	$1.53	$1.53
Insurance[d]	acre	1.00	$0.12	$0.12
Total Fixed Costs	acre	1.00		$34.73
Labor Cost	hour	0.32	$10.07	$3.22
Total Maintenance Expenses	acre	1.00		$193.43

[a]NO3=Nitrate

[b]P2O5=Potassium Oxide

[c]K2O=Phosphate

[d]Costs are associated with operating a 100hp tractor and 10' rotary mower.

CHAPTER V:

CONCLUSION

Low-input heifer development utilizing stockpiled forages is an alternative strategy for development of replacement females in the southeastern United States. Although heifers grazing native warm-season grasses initially lost body weight prior to breeding, a subsequent compensatory growth period began post-breeding, resulting in similar reproductive performance. Stockpiling switchgrass pastures altered ruminal fermentation by increasing ruminal acetate and acetate:propionate ratio when compared with heifers grazing tall fescue and big bluestem/indiangrass combination pastures. Heifers grazing tall fescue had the most expensive total cost of production for their first calf when compared with their warm-season forage counterparts. Due to production costs and revenue, this dissertation would suggest that a risk averse and profit-maximizing producer would select a switchgrass development system compared to all other forage-based systems. If compared to a traditional, high average daily gain dry lot heifer development system, heifer development cost would be estimated to be $574 to $644/head more expensive when compared with forage-based development using stockpiled pastures. Ultimately, stockpiled native warm-season forages can be used effectively to lower production costs by extending the grazing season in the southeastern United States for heifer development. In addition, these studies suggest that stockpiled warm-season forages may be utilized as a strategic heifer development opportunity to increase production and economic efficiency.

VITA

Zachary David McFarlane was born in Yuba City, CA on May 26, 1990. He graduated in May 2008 from Gridley High School in Gridley, CA. He then earned his B.S. and M.S. degrees at the University of Arizona in 2013 and 2015, respectively. He then pursued his Ph.D. at the University of Tennessee under the guidance of Dr. Travis Mulliniks and Dr. Neal Schrick. His Ph.D. in Animal Science was conferred in May 2018.