

Nutritional strategies to improve performance of cattle in fescue forage-based systems

Keri Nicole Hardin

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
In
Animal and Poultry Sciences

Dr. T. Bain Wilson, Chair
Scott P. Greiner
Robin R. White

April 25, 2018
Blacksburg, Virginia

Keywords: forage, supplementation, production, beef cattle

Nutritional strategies to improve performance of cattle in fescue forage-based systems

Keri N Hardin

SCHOLARLY ABSTRACT

Two experiments were conducted to determine the efficacy of supplemented feedstuffs to improve the performance of cattle consuming fescue-based rations. The objective of the first experiment was to evaluate growth and reproductive characteristics of heifers consuming endophyte-infected (**EI**) fescue seed with or without sodium bicarbonate supplementation. Forty-eight heifers (8 mo; BW = 268 ± 24 kg) were utilized in a 2 x 2 factorial design. Treatments were either high-EI fescue seed without sodium bicarbonate (**E+B-**), high-EI fescue seed with sodium bicarbonate supplementation (**E+B+**), low-EI fescue seed without sodium bicarbonate (**E-B-**), or low-EI fescue seed with sodium bicarbonate supplementation (**E-B+**). At d 56, G:F ($P = 0.084$) and ADG ($P = 0.071$) tended to be improved for heifers fed E+B+. By d 84 bicarbonate supplementation tended to decrease ADG ($P = 0.087$). Bicarbonate supplementation ameliorated the negative effects of E+ at 28 d, but by d 84 negatively impacted animal performance. The objective of the second experiment was to determine the energy content of corn gluten feed (**CGF**) relative to corn in forage-based beef rations. Forty-two steers (13.8 ± 0.4 mo; BW = 382 ± 8 kg) were supplemented with either corn or CGF at 0.15% (**L**), 0.54% (**M**) or 0.96% (**H**) BW for 63 d. Steer ADG was greater for steers supplemented with CGF relative to steers supplemented with corn ($P = 0.034$). Energy value of CGF relative to corn was calculated by adjusting supplement TDN in the 2016 Nutrient Requirements of Beef

Cattle Model. The energy values of CGF relative to corn were 106%, 107%, and 112% for L, M, and H.

Nutritional strategies to improve performance of cattle in fescue forage-based systems

Keri N. Hardin

GENERAL AUDIENCE ABSTRACT

Tall fescue is the predominant forage in the southeast United States, and has a symbiotic relationship with an endophytic fungus, providing drought and pest resistance to the plant. However, the fungal endophytes produce toxic ergot alkaloids which can result in decreased performance when cattle consume tall fescue. Performance losses, resulting from the consumption of these ergot alkaloids, are costly and economical strategies to reduce the negative impact of endophyte-infected fescue consumption on animal performance are needed. Previous research indicates that ruminal buffering capacity and nutrient uptake may be impaired in cattle consuming endophyte-infected fescue seed. Providing a dietary buffer is a low-cost strategy that may help to improve nutrient utilization in cattle, resulting in improved animal performance. Aside from reduced performance resulting from the consumption of ergot alkaloids, forage nutrient content can vary throughout the year, resulting in situations where the animals' nutrient requirements are not met by the forage alone. Historically, corn has been the major energy supplement used, but recent data suggest that co-products of the corn sweetener and ethanol industries have greater energy compared to corn in both feedlot and forage-based beef rations. Supplementing corn gluten feed at low levels may improve performance of cattle consuming forage-based rations without driving up the cost of production. The objective of this thesis is to evaluate two strategies to mitigate the

negative effects of endophyte-infected fescue consumption on animal performance. The first experiment was conducted to evaluate the efficacy of sodium bicarbonate to mitigate the negative effects of endophyte-infected fescue on replacement heifers. Heifers were fed a basal corn silage diet. Fescue seed and bicarbonate were supplemented at 1.5 kg/day and 0.25 kg/day, respectively. After a 56 d treatment period, bicarbonate supplementation tended to improve performance of heifers fed endophyte-infected seed with bicarbonate relative to those fed un-infected seed without bicarbonate supplementation. However, by d 84 of the experiment, the benefits of bicarbonate supplementation were no longer observed. More research is needed to understand why the benefits of sodium bicarbonate supplementation were not sustained over the full experimental period. The second experiment was conducted to evaluate the feeding value of corn gluten feed relative to corn when fed to steers consuming a forage-based ration. Steers had free-choice access to fescue hay, and individual hay and supplement intake were recorded daily. Steers supplemented with corn gluten feed had greater average daily gain than steers supplemented corn. This translated to a greater energy value relative to corn for all inclusion levels, exceeding model predictions. These experiments help to shed light on low-cost solutions to improve performance and profitability for fescue forage-based beef production systems.

ACKNOWLEDGEMENTS

Thank you to my committee members, Drs. Wilson, White, and Greiner. I would not have been able to complete this degree without each of your contributions and dedication to mentoring me. Thank you, Dr. Wilson for the guidance and support you have given me throughout the past two years—you've always gone above and beyond to help me and I am thankful for that.

Thank you to our VT Agricultural Program Coordinator, Dave Linker, and Agricultural Supervisor, Chad Joines for all of your help coordinating my projects. David Fiske, Colby Sheets, Brian Brooks, Chris Beard, and Drew Mackey: thank you for feeding and caring for my cattle on a daily basis and helping me sample every week—I would not have been able to complete this degree without your help.

Thank you to Taylor Langford, Chuck Zumbaugh, Linda Beckett, Adam Murray, Andrew Weaver, Dr. Nicholas Dias, Claire Timlin, Dr. Andrea Bedford, Devan Powers, Grace Barry, Wil Sims, Sandra Krone, Kendra Phipps, and Felipe Vieira Santilli for your help with data collection and analysis.

The Virginia Agricultural Council funded the experiments described herein and I am grateful for their contributions to my research projects.

To all of the students in my office, thank you for making graduate school enjoyable. Thanks for listening on the bad days and making me laugh on the good ones!

Last, but not least, thank you to my parents, Steve and Teresa, and brother, Tyler, for your support. Completing this degree would have been impossible without your encouragement.

TABLE OF CONTENTS

CHAPTER I: Literature Review	1
Introduction.....	1
Fungal endophyte infection and associated agronomic and animal health concerns	3
Supplementation with novel feedstuffs or corn co-products.....	14
Inclusion of corn co-products in forage-based beef rations	17
Effects of supplemental corn gluten feed in forage-based beef production systems.....	24
Conclusions	24
Literature cited.....	26
CHAPTER II: Growth and reproductive responses of heifers consuming endophyte- infected tall fescue seed with or without sodium bicarbonate supplementation	36
Abstract.....	36
Introduction.....	37
Materials and Methods.....	38
Results	44
Discussion.....	46
Systematic Responses and Study Limitations	56
Literature Cited	58
Chapter III: Determining the energy value of dried corn gluten feed in forage-based beef rations	
Abstract.....	69
Introduction.....	70
Materials and Methods.....	72
Results and Discussion	77
Literature Cited	86

LIST OF TABLES

Chapter II:

Table 2.1. Nutrient composition of corn silage, high endophyte (E+) seed, and low endophyte (E-) seed.....65

Table 2.2. Description of reproductive tract scores in heifers based on uterine and ovarian characteristics.....66

Table 2.3. Growth performance of heifers consuming high (E+) or low (E-) endophyte-infected fescue seed with (E+B+, E-B+) or without (E+B-, E-B-) sodium bicarbonate supplementation67

Table 2.4 Reproductive performance of heifers consuming high (E+) or low (E-) endophyte-infected fescue seed with (E+B+, E-B+) or without (E+B-, E-B-) sodium bicarbonate supplementation68

Chapter III:

Table 3.1 Nutrient composition of feedstuffs included in treatment rations.....91

Table 3.2. Description of treatment rations fed to growing steers to determine the energy value of corn gluten feed in forage-based rations92

Table 3.3. Effects of supplementing steers with corn or corn gluten feed (CGF) in forage-based rations.....93

Table 3.4. Energy value of treatment supplements fed to growing steers94

Table 3.5 Return on supplementation cost for steers supplemented corn or corn gluten feed (CGF) in forage-based rations95

CHAPTER I

REVIEW OF LITERATURE

Introduction

Tall fescue is the predominant forage throughout the Southeastern United States (U.S.). A symbiotic relationship with a fungal endophyte improves drought and pest tolerance, allowing tall fescue to be widely adapted to a variety of climates (Strickland et al., 2011). Beneficial agronomic traits enabled endophyte-infected (EI) fescue to be widely adapted as a forage crop throughout the eastern U.S. The ability to withstand drought, pest infestations, and animal herbivory made tall fescue a popular forage among livestock producers (Hoveland, 1993). Tall fescue is the predominant forage crop on over 35 million acres of pastureland throughout the southeastern U.S., equating to over one third of pasture land in Virginia (Smith et al., 2009). Siegel et al. (1985) reported an estimated 90% of tall fescue in the U.S. is EI. Consumption of EI fescue results in ergot toxicity in grazing livestock and leads to reduced growth and reproductive performance. The causative agent of reduced performance in grazing livestock has been identified as ergot alkaloids that are produced by a fungal endophyte living within the plant. Reductions in animal performance are well documented when animals are fed EI fescue (Strickland et al., 2011). The negative impacts on animal health and economic losses incurred as a result of reduced performance warrant development of long term solutions to improve performance of animals produced in endophyte-infected fescue forage systems.

Tall fescue was likely introduced into the United States as a contaminant in grass seed imported from Europe (Hoveland, 1993). After its release in 1942, 'Kentucky 31' tall fescue pastures were widely established by producers and KY31 is now the most commonly grown tall fescue cultivar in the U.S. Producers noted reduced animal performance when livestock grazed EI

fescue pastures, and the symptoms in cattle resembled those of humans suffering from ergot toxicity (Strickland et al., 2011). The causative agent of fescue toxicosis in livestock was not characterized until long after observations of reduced growth and reproductive performance in livestock (Lyons et al., 1986; Strickland et al., 2011). General symptoms of fescue toxicity in cattle include poor thrift, lameness, reduced BW gain, reduced grazing time, reduced milk production, and extended time spent in shade, mud holes, or surface waters (Strickland et al., 2011). Ergovaline was identified as the primary ergot alkaloid present in EI fescue, and as such, was determined the chemical responsible for fescue toxicity (Lyons et al., 1986).

Economic impact of tall fescue on animal agriculture

The prevalence of tall fescue within the U.S., coupled with reduced animal performance, makes fescue toxicosis the largest health-related cost for the grazing livestock industries (Hoveland, 1993), with current economic losses exceeding \$1 billion annually (Strickland et al., 2011). Much of the fescue-related economic losses to beef producers occur in the cow-calf segment of the beef industry, because most cow-calf production systems are forage based and rely on EI fescue pasture systems (Hoveland, 1993). Many feeder cattle raised in fescue-based cow-calf operations ultimately end up in Midwestern feedlots, making fescue toxicity a nationwide concern. This is especially true if negative effects of EI consumption have lasting negative impacts on finishing performance. Fescue toxicosis directly impacts animal health and profitability of beef systems in Virginia because EI tall fescue is the predominant forage on over one million acres of hay and pastureland in cow-calf operations (Smith et al., 2009). Reductions in animal performance and associated economic losses make finding strategies to improve animal performance a primary concern for beef producers.

Fungal endophyte infection and associated agronomic and animal health concerns

The fungal endophyte responsible for symptoms of endophyte toxicity is observed in livestock grazing tall fescue pasture is *Epichloë coenophiala*, formerly known as *Neotyphodium coenophialum* (Leuchtman et al., 2014). Production of ergot alkaloids by fungal endophytes are a means to deter insect and mammalian herbivory; benefiting both plant and fungus (Malinowski and Belesky, 2000). The fungal endophyte present in EI fescue is transferred efficiently from parent plant to offspring through the seed, directly impacting the infection rates and persistence of tall fescue stands (Leuchtman et al., 2014). Because the fungal endophyte relies on host seeds for reproduction, maximizing host growth by endophyte infection is in the interest of both plant and endophyte (Malinowski and Belesky, 2000). Finding a strategy to improve performance of animals consuming EI fescue without negatively impacting plant production and yield has been a challenge for scientist and producers. Persistence of an existing stand, infection rates, and ergot alkaloid production are dependent on genetic, environmental, and management strategies.

Mode of action for fescue toxicity

Although beneficial to the plant, endophyte infection is deleterious to host health when the plant is consumed. General symptoms of ergot alkaloid consumption include elevated rectal temperature, increased respiration rate, extended time spent in shade or surface water, reduced body weight gain, reduced time spent grazing, reduced serum prolactin concentrations, rough hair coat, and reduced milk production (Strickland et al., 2011). Fescue toxicosis is defined as the moderate to extreme production loss observed in livestock consuming EI fescue, and may be difficult to diagnose because reductions in animal performance may be less obvious to producers.

Symptoms indicating severe fescue toxicosis include loss of hooves, loss of tail switch, dry gangrene of the ear, tail tips, or teats, and lameness in combination with reduced animal performance (Strickland et al., 2011). General symptoms, particularly behavioral changes among cattle, are common throughout the Southeastern U.S., are easily dismissed, and often go unnoticed. It is also possible that beef producers located in regions where EI is the predominate forage have selected for tolerant cattle; potentially reducing the severity of negative effects of consumption (Smith and Cassady, 2015). A multitude of genes are involved in EI fescue response, and genotype by environment interactions also influence animal response to EI fescue consumption (Campbell, 2012).

Ergot alkaloids are grouped into two broad categories: ergoline alkaloids and ergopeptine alkaloids (Ayers, 2003). Each group of ergot alkaloids contains a common lysergic acid ring moiety, with varied functional groups (Ayers, 2003). Recent arguments suggest that ergoline alkaloids are more likely to be absorbed and result in toxicity than ergopeptine alkaloids (Hill, 2008). The primary site of ergot alkaloid digestion in ruminants is proposed to be in the rumen, primarily by microbial fermentation (Strickland et al., 2011). Microorganisms detoxify a variety of different compounds and, perhaps more importantly, absorption from the gastrointestinal tract of ruminants is more extensive than other species (Strickland et al., 2011). Much of the research surrounding ergot alkaloids has been conducted in monogastric models for human biomedical research, and because of differences in absorption and metabolism, these data are of limited usefulness to livestock researchers (Hill, 2008).

Regardless of the causative agent responsible for fescue toxicosis, the exact mechanism of action is poorly understood. Structural similarities to dopamine allow ergot alkaloids to have dopamine agonist effects within the animal, but it is likely that ergot alkaloids negatively impact

a multitude of reproductive tissues and hormonal balances (Schillo et al., 1988; Jones et al., 2003; Hill, 2008; Strickland et al., 2011). Schillo et al. (1988) found that EI fescue consumption decreased prolactin synthesis and release, as evidenced by reduced prolactin concentrations in the serum and anterior pituitary of heifers fed EI fescue. Jones et al. (2003) fed EI, endophyte-free (E-), and EI fescue seed plus domperidone, a dopamine antagonist, to replacement heifers to investigate the effect of EI fescue consumption on replacement heifer growth and reproductive development. Heifers consuming EI fescue had shorter estrous cycles and lower mid-cycle progesterone concentrations than heifers receiving E- fescue or EI fescue dosed with domperidone (Jones et al., 2003). Heifers fed EI fescue seed and administered domperidone had greater BW gain than heifers fed EI seed without domperidone (Jones et al., 2003). The results from Jones et al. (2003) indicate that growth and reproductive performance of replacement heifers consuming EI fescue is improved by domperidone administration, suggesting that ergot alkaloids in EI fescue act as a dopamine agonists. Interactions between EI fescue, the environment, and the animal, combined with differences in experimental methods makes comparing data across ruminant studies difficult. The current body of knowledge regarding the causative agent and mode of action responsible for fescue toxicity in ruminants and the complex nature of fescue toxicity prevent scientists from making definitive statements related to the manifestations and severity of fescue toxicity symptoms.

Fescue Toxicosis Effects on Growth

Endophyte-infected fescue intake results in animals having difficulty dissipating body heat, as evident by elevated rectal temperatures, increased respiration rates, excessive salivation, rough hair coats, and extended time in shade (Strickland et al., 2011). Previous research concerning rectal temperatures of cattle consuming EI fescue are contradictory. Under heat stress conditions, rectal temperature and respiration rate were significantly elevated in cattle consuming a toxic ryegrass-fescue hybrid compared to cattle consuming a diet free of EI fescue (Hemken et al., 1981). In contrast to these findings, rectal temperatures were lower for heifers consuming EI than those consuming E- tall fescue (Aldrich et al., 1993; Jones et al., 2003). It is likely that differences in rectal temperature and respiration rate are most notable when animals are exposed to elevated ambient temperature and relative humidity. Research has shown when cattle are exposed to EI and environmental heat stress, rectal temperatures are more extreme and exhibit varied fluctuations compared to cattle fed diets that do not contain EI fescue (Spiers et al., 2012). Heifers consuming EI had increased rectal temperatures compared with heifers fed E- fescue seed under heat stress conditions, indicating heifers exposed to EI could not effectively cool core temperatures (Burke et al., 2001). Spiers et al. (2012) reported no difference in the rectal temperature of steers consuming EI and E- under thermoneutral or heat stress conditions. Although differences in rectal temperature were not statistically significant, steers receiving EI fescue seed exhibited more rapid elevations and more rapid reduction in rectal temperatures over time in response to heat stress when compared to controls (Spiers et al., 2012). Sheep consuming EI fescue had elevated rectal temperatures during the afternoon, but not in the morning, when compared with sheep consuming E- fescue, indicating diurnal regulation of body temperature is impacted in animals consuming EI fescue (Bouton et al., 2002). Environmental factors, such as

ambient temperature and relative humidity negatively impact thermoregulatory ability in cattle consuming EI fescue.

Concentration of ergot alkaloids also impacts the thermoregulatory efficiency of cattle. In diets containing 0, 0.61, 1.2, or 1.8 g/d of total pyrrolizidine (N-acetyl and N-formyl loline alkaloids) from EI fescue seed, steers consuming either 1.2 or 1.8 g/d exhibited increased rectal temperatures compared with steers consuming 0 or 0.61 g/d total pyrrolizidine alkaloid (Jackson et al., 1984). Similarly, Westendorf et al. (1993) reported wethers consuming 2346 mg/d pyrrolizidine alkaloid had elevated rectal temperatures when compared to wethers receiving 945 mg/d. Diets containing 945 mg/g and 2346 mg/g pyrrolizidine alkaloid also had 1.4 and 1.6 µg/g total ergot alkaloid, potentially confounding data observed because ergot alkaloids are absorbed at a much slower rate compared with pyrrolizidine alkaloids (Westendorf et al., 1993).

Regardless of which alkaloid compound was responsible for the observed animal response, concentration of toxic compounds influences observed thermoregulatory status (Westendorf et al., 1993). These results suggest factors such as ambient environmental conditions and time of day, combined with concentration of toxic compounds may be important in detection of impaired thermoregulatory ability in cattle (Westendorf et al., 1993). Furthermore, rectal temperature and respiratory rate measurements alone may not be a reliable method in determining cases of suspected fescue toxicity in cattle.

The most notable impact of EI fescue consumption on animal growth performance is reduced body weight gain. Steers consuming EI fescue had reduced ADG compared to steers fed low endophyte (**LE**) tall fescue (Bond et al., 1984; Paterson et al., 1995). Steers consuming endophyte-infected fescue had 30 to 100% reductions in ADG compared with steers grazing LE fescue pasture (Paterson et al., 1995). Reductions in ADG are not limited to steers. Heifers

consuming EI fescue had reduced BW compared to E- fed heifers (Mahmood et al., 1994; Jones et al., 2003). Heifers fed a pelleted EI fescue seed exhibited depressed ADG when compared to heifers fed E- or endophyte-infected plus domperidone (Jones et al., 2003). It is hypothesized that the reduction in ADG is because of reduced digestibility or reductions in gastrointestinal tract (**GIT**) motility that is induced by ergot alkaloid intake (Jones et al., 2003). Lambs grazing EI forage showed lower ADG than those consuming E- or LE fescue cultivars (Bouton et al., 2002). Changes in GIT motility may also impact digestibility in livestock consuming EI fescue. Fiber and crude protein digestibilities were reduced in wethers fed EI fescue seed compared to wethers consuming E- fescue seed (Westendorf et al., 1993). A study designed to equalize intake of EI and E- hay reported total tract DM, NDF and ADF digestibilities were lower in wether lambs consuming EI (Fiorito et al., 1991). Similarly, in vivo digestibility in steers was substantially lower for EI than for E- or novel endophyte-infected (**NE**) hay, despite similar in vitro true dry matter digestibility among hays (Matthews et al., 2005). Other data suggest there are no differences between in vivo dry matter or crude protein digestibility when comparing EI with E- fescue hay when intake is restricted, indicating reduced performance in animals consuming endophyte-infected fescue may be an effect of reduced feed intake as opposed to reduced digestibility (Harmon et al., 1991). Although the exact mechanisms behind reductions in ADG are not fully understood, the most likely causes for reduced animal growth are reduced DMI, reductions in digestibility and impaired GIT motility (Strickland et al., 2011).

Animals consuming EI fescue have reduced DMI compared with animals consuming E- or LE. Lambs fed EI had lower voluntary DMI of ground hay compared to those fed E- hay (Fiorito et al., 1991). Spiers et al. (2012) utilized a ground fescue seed model for cattle consuming EI fescue. Steers were fed a forage-based diet and supplemented with high EI (40

$\mu\text{g ergovaline/kg}^{-1}/\text{d}^{-1}$), low EI ($20 \mu\text{g ergovaline/kg}^{-1}/\text{d}^{-1}$, or E- ($0 \mu\text{g ergovaline/kg}^{-1}/\text{d}^{-1}$) ground fescue seed (Spiers et al., 2012). Steers consuming high levels of ground EI seed at thermoneutral conditions had reduced feed intake compared to steers consuming E- seeds (Spiers et al., 2012). Steers fed ground low EI seed had similar feed intake to high EI and control groups, indicating that ergovaline produces dose-dependent responses in cattle (Spiers et al., 2012). Spiers et al. (2012) found that steers maintained at thermoneutral conditions showed no differences in rectal temperature, skin temperature, or respiration rate, indicating the effects of EI consumption on feed intake are ergot alkaloid driven, not an effect of reduced thermoregulatory ability. Studies utilizing EI fescue seed have been criticized because this method does not fully represent EI consumption in vivo. Endophytes are present in tissues other than the seed head of the plant, and cattle select more palatable plant tissues. Measuring EI fescue consumption in more natural circumstances can make quantifying actual DMI and concentration of ergot alkaloids difficult to determine in an experimental setting. Despite these difficulties, some data utilizing more relevant feeding methods exist. In growing beef steers, ad libitum DMI was lower in steers consuming EI fescue hay compared to those consuming E- and nontoxic endophyte-infected hay (Matthews et al., 2005). Differences in ergot alkaloid concentration may differ in EI hay compared with pasture, but quantifying DMI and ergot alkaloid consumption of hay-based diets is easier to measure than pasture consumption under experimental conditions.

In addition to reduced DMI, cattle consuming endophyte-infected fescue often show changes in grazing behavior. Disruptions in grazing behavior pattern can be indicative of environmental stress. Steers grazing EI fescue spent less time during the day grazing compared to steers grazing LE fescue (Howard et al., 1992). Reductions in digestibility of multiple nutrients have been reported in livestock consuming endophyte-infected fescue, suggesting a

direct effect of ergot alkaloid consumption (Strickland et al., 2011). Hannah et al. (1990) reported decreased OM, NDF, and cellulose digestibilities and increased ruminal fluid dilution rate and fluid outflow for sheep consuming 3 ppm ergovaline compared to diets containing 0 ppm ergovaline.

Effects of fescue toxicosis on reproduction

Although much of the research concerning animal performance of cattle consuming endophyte-infected fescue is focused on steer performance, much of the fescue pastures in the United States are grazed by cow-calf pairs (Paterson et al., 1995). Reproductive efficiency is crucial for the profitability of cow-calf systems. It is unclear whether reductions in reproductive performance are a direct or indirect effect of consumption of EI fescue. Reductions in DMI and subsequent reductions in BW gain could partially explain reproductive failure or delayed puberty in heifers consuming ergot alkaloids.

Reductions in serum prolactin concentration are often observed for ruminants grazing EI fescue (Elsasser and Bolt, 1987; Bouton et al., 2002; Shoup et al., 2016). Serum prolactin concentration was dramatically reduced in lambs grazing EI fescue compared to those grazing E-fescue (Bouton et al., 2002). A similar effect was noted in ewes grazing EI fescue (Elsasser and Bolt, 1987). Steers consuming EI fescue had serum prolactin concentrations that were significantly lower than steers consuming LE fescue (Schillo et al., 1988). Cows consuming EI fescue had reduced prolactin concentrations compared to cows that were not exposed to toxic fescue (Looper et al., 2010; Shoup et al., 2016). Similar to other markers of fescue toxicity, ambient temperature may affect serum prolactin response in cattle consuming EI. Burke et al.

(2001) observed reduced serum prolactin concentrations in EI heifers under heat stress conditions, but no difference in prolactin concentrations at thermoneutral conditions.

Although it is well accepted that cattle in adequate body condition have greater reproductive success than cattle in low body condition, the interaction of EI consumption and body condition and breeding efficiency are not well understood. Cows with low body condition score (BCS) at the beginning of the breeding season lost more body fat stores when grazing EI fescue compared with cows of adequate BCS grazing EI fescue (Looper et al., 2010). Serum prolactin concentrations were significantly lower for thin cows grazing EI compared with cows in good body condition grazing E- pasture. These findings suggest thinner cows are more affected by EI consumption than cows with ideal BCS. It is possible that reductions in adipose stores in cattle grazing EI may be related to the hypothalamic-pituitary axis by metabolic hormones, such as prolactin (Strickland et al., 2011).

Progesterone is necessary for establishment and maintenance of pregnancy in cattle (Strickland et al., 2011). Heifers consuming EI fescue seed had lower circulating progesterone concentrations than their E- fed counterparts (Jones et al., 2003). Elevated environmental conditions amplify the effects of EI fescue consumption. Serum progesterone concentrations were decreased in heifers exposed to heat stress, and to a greater extent in heifers consuming EI under heat stress conditions (Burke et al., 2001). Heifers grazing EI fescue had decreased incidences of normal ovarian function as defined by repeated serum progesterone concentration measurements, however this effect was not sustained by the end of the study (Mahmood et al., 1994). It is possible that instances of reproductive failure may only be evident during periods when ergot alkaloid concentrations within EI fescue are highest, such as the summer months. Poole et al. (2016) reported that circulating progesterone concentrations tended to be decreased

in heifers consuming EI fescue seed. One factor that regulates circulating progesterone concentrations is the rate of blood flow and metabolism of the liver (Wiltbank et al., 2014). The vasoconstrictive effects of EI consumption could impact hepatic blood flow, potentially explaining observed reductions in circulating progesterone concentrations. Reduced concentrations of circulating cholesterol has been observed in cattle consuming EI, suggesting ergot alkaloid consumption may alter formation of steroid hormones (Bond et al., 1984; Burke et al., 2001; Strickland et al., 2011). Jones et al. (2003) reported similar progesterone concentrations in luteal tissues of heifers consuming EI fescue compared to those fed E- fescue, suggesting the impact on progesterone concentration may not be a result of progesterone production. Jones et al. (2003) recognized the potential for localized vasoconstriction of blood flow to either the ovary or corpus luteum (CL) was responsible for inhibiting the release of progesterone into circulation.

Heifers consuming EI had lower preovulatory dominant follicle size (Burke et al., 2001). Recent findings indicate that prolactin receptors are present on the bovine CL throughout the mid- and regressed luteal stages (Shibaya et al., 2006). These findings suggest the bovine CL as a potential site of prolactin production (Shibaya et al., 2006). Vasoconstriction of the uterine and ovarian arteries and uterine and ovarian veins were observed in heifers consuming EI fescue seed from d 10 to d 17 of the estrous cycle (Poole et al., 2016). In combination, these findings provide evidence that EI fescue consumption could directly impact reproductive tissues in cattle. Uncertainty regarding nature of the relationship between ergot alkaloid consumption and reduced reproductive performance in cattle still challenges researchers to articulate management strategies, largely because it is unclear whether the negative impact on reproduction is a direct or indirect effect of alkaloid consumption.

Younger heifers may be more susceptible to reproductive failure induced by EI fescue consumption than older heifers and cows. Estrus response following synchronization of replacement heifer calves grazing EI fescue was less than those grazing LE pastures (Mahmood et al., 1994). This effect was not observed in yearling heifers, suggesting negative effects of EI consumption on reproductive traits may be affected by age. Regardless of the age at which a heifer is no longer at risk for impaired reproductive development, data indicate early life events can impact long term fertility of cattle (Fortune et al., 2013; Wathes et al., 2014). It is hypothesized that follicle formation and initiation of follicle growth occur before birth in cattle and the possibility of EI consumption in utero could alter fetal reproductive development (Fortune et al., 2013). Developing effective management strategies to mitigate negative effects of EI consumption on animal performance will improve animal health and economic profitability of beef production systems throughout the southeastern U.S.

Strategies to mitigate negative associative effects of endophyte-infected fescue intake

Management strategies have been investigated to improve performance of animals consuming EI fescue. Some strategies that have been utilized include providing supplemental nutrition through grain or grain coproducts, use of pharmacological compounds, and renovation of tall fescue pastures with alternative forages (Gadberry et al., 2015). The most economical and easily adapted of these management techniques to alleviate fescue toxicity is supplemental nutrients because alternative strategies are often expensive. Renovating pastures is expensive because of seed, equipment, and lost opportunity costs. Use of pharmacological compounds is not ideal from a producer standpoint because these techniques often require handling cattle frequently in order to administer treatment, adding additional time, labor, and input costs for

producers. Providing supplemental nutrients remains one of the most economically feasible and practical strategies to mitigate negative associative effects of EI intake.

Supplementation with novel feedstuffs or corn co-products

Although the exact mode of action of fescue toxicosis remains unclear, researchers have used dietary supplementation as a tool for improving performance of cattle consuming EI. Dietary supplementation can reduce the negative production responses in cattle consuming EI fescue by reducing ergot alkaloid concentration in the diet and by potentially altering the rumen environment to enhance digestibility. Reductions in fiber digestibility may result in decreased ADG when cattle are grazed on EI fescue (Hannah et al., 1990). Recent findings indicate EI fescue seed intake results in reduced production of several proteins responsible for volatile fatty acid (VFA) and sodium bicarbonate buffer exchange within the rumen (Kim et al., 2014). These data indicate EI fescue consumption negatively impacts VFA transport, altering the energy supply to the bloodstream. From these data, it is possible that reduced fiber digestibility observed in animals consuming EI is a function of reduced buffering capacity. One strategy to improve buffering capacity is to supplement a feedstuff capable of supplying buffering agents, such as calcium carbonate or sodium bicarbonate, to the diet of animals consuming EI forage or seed to maintain a more desirable rumen pH. Dietary supplementation of sodium bicarbonate could improve whole body buffering capacity by providing an additional source of bicarbonate ions in the rumen; thus, replenishing the sodium bicarbonate lost through fermentation and improving VFA absorption from the rumen to the bloodstream. Improving fiber digestibility in cattle could positively impact whole-animal health by improving energy supply and pH balance within the rumen.

Dietary supplementation has been adapted as a strategy to dilute EI content in the diet of cattle consuming tall fescue. Supplementing nutrients into the diet is also effective in extending hay supplies for cattle producers. Supplementing a soybean hull and corn gluten feed (CGF) blend has been shown to decrease fescue hay intake in steers (Richards et al., 2006; Drewnoski et al., 2011; Drewnoski and Poore, 2012). Supplementation also improves diet digestibility of steers fed medium-quality, tall fescue hay and a soybean meal and corn gluten feed blend supplement (Drewnoski and Poore, 2012). In a meta-analysis conducted by Gadberry et al. (2015), CGF and soybean hulls supplemented to cattle fed EI fescue exhibited the greatest improvements to ADG compared to cattle fed energy in the form of high starch and sugar content, as found in corn, grain sorghum, and molasses. Supplementing a protein and fibrous energy source could improve digestibility and reduce DMI of EI fescue hay, while diluting dietary ergot alkaloid concentrations. Utilizing corn co-products as a source of energy and protein in fescue-based rations is an economical alternative to corn grain and protein supplements, such as soybean meal, but poses some challenges to producers.

Reduced animal performance and greater economic losses associated with EI consumption led to the development of various LE and NE fescue cultivars. Initially, replacing pastures with highly EI fescue with strains of low-EI fescue seemed to be a promising strategy to improve animal performance and maintain adequate forage production (Roberts and Andrae, 2004). Endophyte-free fescue cultivars were developed to improve ADG of grazing livestock, but E- pastures had reduced forage yield compared with EI fescue pasture (Pedersen and Sleper, 1988). Endophyte-free cultivars were produced by exposing seed to either long-term storage, short-term heat treatment, or use of fungicides to reduce viability of the endophyte (Pedersen and Sleper, 1988). Infecting E- strains with non-ergot alkaloid-producing, or “novel” endophytes, is

an effective strategy to maintaining forage production and persistence while improving animal performance (Bouton et al., 2002). Stand persistence of E- and NE fescue cultivars relative to EI cultivars is often a concern for cattle producers. Hopkins and Alison (2006) report reduced botanical composition of E- and NE fescue cultivars compared with EI fescue cultivars between the third and fourth year after establishment, but no differences in botanical composition in the fifth year after establishment.

Persistence of low-endophyte cultivars was poor when either infrequently, mechanically defoliated or grazed in pastures; suggesting that the removal of the fungal endophyte may reduce the plant's ability to adapt and survive to climates in the deep south (Gates and Wyatt, 1989).

Another strategy utilized to improve the performance of livestock grazed on EI fescue is to replace toxic endophyte strains with non-toxic ones. Bouton et al. (2002) evaluated the stand persistence of Georgia (E-) and Jesup (EI) cultivars when E- and EI were infected with 5 different non-toxic ergot-alkaloid producing NE strains or removing the endophyte from the Jesup cultivar completely. Animal performance and desirable agronomic performance were achieved by infecting E- cultivars with the AR542 NE into both Georgia and Jesup fescue cultivars (Bouton et al., 2002). Stand persistence between Jesup AR542 NE (MaxQ™, Pennington Seed, Madison, Georgia) was improved compared with E- Jesup and was not different from EI Jesup (Bouton et al., 2002). Lamb ADG and serum prolactin concentration were greater for lambs grazing E- and AR542 (a NE fescue) cultivars compared with lambs grazing EI cultivars, indicating the AR542 endophyte is non-toxic to livestock (Bouton et al., 2002). Despite improvements in animal performance, renovating pastures is expensive and often takes the renovated land out of forage production for the first year. Producers must also consider the possibility of drought or soil erosion when determining the best strategy to mitigate

symptoms of fescue toxicity in their herd. Other strategies to mitigate the negative effects of grazing EI fescue may be more cost effective.

Renovating pastures is not always an economical strategy for producers. Cost of removing old cultivars and establishing new ones is expensive and labor intensive. Renovated pastures are often sensitive to grazing pressures, therefore, newly established pastures should not be grazed for one to two years to allow adequate establishment, resulting in lost opportunity cost to producers. Rotational grazing can improve performance of cattle consuming EI fescue, however, developing and implementing rotational grazing strategies require intensive management. Gates and Wyatt (1989) compared the productivity and persistence of 13 LE fescue cultivars to annual ryegrass in the southern U.S. Annual ryegrass had greater yield in the spring than any of the fescue cultivars evaluated; suggesting that use of alternative species may be ideal if forage yield is a major concern, depending on geographic location (Gates and Wyatt, 1989).

Inclusion of corn co-products in forage-based beef rations

Traditionally, corn has been supplemented to forage-based beef rations to increase energy concentration in the diet. With the expansion of the ethanol industry in the mid-2000's and the subsequent increase in corn prices, producers began searching for more affordable alternatives to supplementing corn. Corn co-products, such as distillers grains with solubles (**DGS**) and CGF were utilized in beef rations as supplemental energy sources prior to the expansion of the ethanol industry, however, use of corn co-products as protein and energy supplements became more popular as corn prices continued to rise (Blasi et al., 2001; Klopfenstein et al., 2008). Removal of starch from corn grain further concentrates other nutrients in co-products, such as protein and digestible fiber. Economical supplementation strategies to mitigate the negative effects of EI

consumption need to be investigated. Supplementation of co-products to cattle fed EI fescue has potential to be a cost-effective strategy to improve cattle performance.

Corn gluten feed production: An overview of the wet-milling process

The wet milling process is utilized in corn sweetener and ethanol production and ultimately results in CGF production. Upon arrival to the processing facility, corn grain is steeped in water and sulfur dioxide for 40 hours to separate the starch component from other constituents of the corn kernel, such as the encapsulating protein matrix (Singh and Eckhoff, 1996). The addition of enzymes in the steeping process has increased starch yield; however, CGF yield has been reduced with increasing amounts of enzyme because of improved availability of starch from the surrounding protein matrix (Johnston and Singh, 2004). The steepwater is then removed and the germ fraction of the kernel is separated from the steepwater and remaining slurry, and oil is removed creating a higher value primary product than corn co-products. The starch is separated and fermented to produce ethanol or condensed to form corn sweetener products (Singh and Eckhoff, 1996). The steepwater, germ, bran, and gluten fractions are separated into a variety of corn co-products, specifically; condensed fermented extractives, corn germ meal, and CGF, respectively (Blasi et al., 2001). Wet milling allows for greater fractionation of the corn kernel than traditional dry-milling processes; adding diversified products and financial incentive for the processing plant to implement a wet milling infrastructure.

Distillers grains production: An overview of the dry-grind process

The dry-grind process is utilized in ethanol production. Traditionally, dry-grinding corn grain has produced ethanol, and DGS. Recent advancements have allowed dry-grind facilities to further fractionate corn grain by removing the oil and fiber fractions and allowing for greater fermentative capacity; thus, improving efficiency of ethanol production (Singh et al., 2005). In the modified dry-grind process, corn grain is soaked in water to remove starch from the protein matrix. The germ and fiber are separated, and the remaining mixture is finely ground, cooked, and enzymes are added to aid in fermentation of starches. After fermentation, the ethanol is removed and the remainder of the mixture is marketed as DGS.

Nutritional value of corn co-products

Once the starch component has been removed for ethanol or sweetener production, nutrients are concentrated approximately 3 fold in DGS (Klopfenstein et al., 2008). Energy in DGS and CGF is primarily in the form of highly digestible NDF (Klopfenstein et al., 2008). Dried distillers grains plus solubles (**DDGS**) contains moderate quantities of rumen undegradable protein (31% CP; 68% RUP; National Academies of Sciences, Engineering, and Medicine, 2016). Estimates indicate that only 40% of zein, the primary protein in corn, is utilized for microbial protein synthesis in the rumen (McDonald, 1954). High levels of dietary fat negatively affect microbial symbiosis and fiber digestibility in the rumen (Zinn, 1989). Specifically, dietary fat that is highly rumen degradable negatively impacts NDF digestion (Zinn et al., 2000). Corn gluten feed provides a high energy, moderate protein source to beef rations (37% RUP; National Academies of Sciences and Medicine, 2016). Energy supplements high in

non-structural carbohydrates, such as starch, negatively impact the rumen environment. Corn co-products are remnant fractions of the kernel after the starch and germ have been removed, concentrating the remaining protein, fat, and highly-digestible fiber. The low starch content and combination of highly digestible fiber, crude protein, and fat content of corn co-products may contribute to improved animal performance (Jolly 2008).

One challenge of utilizing corn co-products in beef rations is the different energy values predicted by analysis obtained via laboratory analysis and observed feeding value in feeding trials. Additionally, in forage-based beef production systems, nutrient requirement models underestimate animal performance when co-products are supplemented at low levels (Loy et al., 2008). It is hypothesized that the unique nutrient profile of corn co-products enables the remaining fiber, protein, and fat to be utilized without negatively impacting the rumen environment. The feeding value of corn co-products also varies with inclusion rate and basal diet formulation (Ham et al., 1995; Klopfenstein et al., 2008; Loy et al., 2008). Research evaluating the feeding value of co-products in forage-based rations is limited.

Effects of distillers grains inclusion on animal performance in grain-based rations

The proximity of ethanol plants to Midwestern feedlots has influenced DGS research within the beef industry. Much of the data available regarding DGS has been collected in feedlot studies in the Midwestern Region of the U.S. and has focused on the use of wet DGS in feedlot rations. Because transportation of wet feedstuffs to the Eastern U.S. cost prohibitive, the use of DDGS in feedlot studies will be discussed because results are more pertinent to cow-calf production in Virginia.

In a meta-analysis conducted by Klopfenstein et al. (2008), the feeding value of DDGS was 153% and 100% that of corn when inclusion was 10% and 40% diet DM, respectively. Although the feeding value of DDGS is greater than that of corn when inclusion of DDGS is 10% diet DM, feeding DDGS at higher inclusion rates does not negatively impact animal efficiency or product palatability; and may be more economical depending on relative feed prices of corn and DDGS (Klopfenstein et al., 2008). Reasons for differences in feeding value of DDGS at various inclusion levels are unclear. It is hypothesized that observed fluctuations in feeding value of DDGS, and similar co-products, occur as a result of synergistic interactions between highly digestible fiber, moderate fat content, and low starch content (Jolly, 2008).

Effects of corn gluten feed inclusion on animal performance in grain-based rations

Wet corn gluten feed (**WCGF**) is another commonly utilized ingredient in feedlot rations. Few experiments have evaluated the energy content of WCGF in forage-based beef rations. Ham et al. (1995) evaluated the energy value of WCGF in alfalfa hay-based growing beef rations. In the growing trial, treatment diets consisted of 44% dry rolled corn (**DRC**), 50% alfalfa hay, 5% molasses; 49% WCGF, 50% alfalfa hay; 65% WCGF, 33% alfalfa hay; 33% DRC, 33% corn silage, 33% alfalfa hay; and 61% WCGF, 37% ground cornstalks (**CS**). Calves fed 49% WCGF, 50% alfalfa hay gained 14% faster and 11% more efficiently than calves fed DRC and CS (Ham et al., 1995). Based on calf performance in the growing trial, the average estimated NE_g of WCGF was 13% higher than DRC, exceeding NRBC predictions (Ham et al., 1995; National Academies of Sciences and Medicine, 2016).

Ham et al. (1995) also investigated the energy value of WCGF in dry DRC based finishing rations by replacing either 20%, 40%, 60%, 80% or 100% DM of DRC and molasses.

Average daily gain and DMI exhibited a quadratic response as inclusion of WCGF increased, with optimum ADG and DMI occurring when WCGF replaced 40% DRC (Ham et al., 1995). In a second finishing trial, steers were fed concentrate-based rations containing 79% DRC, a combination of DRC and 35% or 70% WCGF, a combination of DRC and 70% dry CGF with or without added water, or a combination of high-moisture corn and 70% WCGGF (Ham et al., 1995). Steers fed 35% or 70% WCGF in combination with DRC or high-moisture corn had similar ADG and G:F to steers fed DRC (Ham et al., 1995). Additionally, the average NE_g of WCGF was 10% less than the NE_g of corn, exceeding the Nutrient Requirements of Beef Cattle Model (**NRBCM**) predicted energy content of WCGF (Ham et al., 1995; National Academies of Sciences and Medicine, 2016). Average daily gain of steers consuming WCGF at varied levels of inclusion was improved compared to finishing steers receiving a steam flaked corn control, with a predicted optimal ADG at 23% WCGF inclusion (Block et al., 2005). In a review by Stock et al. (2000), the NE value of CGF was reported to be 93 to 100% that of corn, depending on source of WCGF. These data, in combination with the nature of CGF production, suggest the energy value of CGF in feedlot rations exceeds that predicted by nutrient analysis and varies considerably with inclusion rate. Additionally, nutrient composition of CGF should be analyzed on a load or source basis rather than depending solely on book values, because of variation in nutrient content among different sources. While data regarding the feeding value of CGF and DDGS in feedlot rations are applicable to beef production throughout the Midwestern region of the U.S., most cow-calf production systems are forage based. The nature of cow-calf production systems throughout the Southeastern U.S. make data regarding the use of corn co-products in fescue forage-based beef rations valuable to both producers and researchers.

Effects of dried distillers grains supplementation on animal performance in forage-based production systems

Limited data regarding the energy value of DDGS in forage-based beef rations are available. Loy et al. (2008) evaluated the energy value of DDGS in high-forage diets. Treatments were arranged in a 3 x 2 x 2 factorial arrangement with 3 supplements, 2 concentrations, and 2 frequencies of supplementation (Loy et al., 2008). Supplements were DRC, DRC with corn gluten meal, and DDGS and supplement concentrations were 0.21% or 0.81% of BW, with supplements fed either daily or 3 times weekly (Loy et al., 2008). At 0.21% and 0.81% BW heifers fed DDGS gained faster and more efficiently than those supplemented DRC (Loy et al., 2008). DDGS provided greater energy value than corn in forage-based rations. Total digestible nutrient content of DDGS varied with inclusion rate (Loy et al., 2008). When supplemented at 0.21% of BW, TDN of DDGS was 130% that of corn; and when supplemented at 0.81% of BW, TDN of DDGS was 118% that of corn (Loy et al., 2008). The greater energy value of DDGS relative to corn is hypothesized to be the result of the fat and rumen undergradable protein content found in co-products (Loy et al. 2008). This data provides evidence that other corn co-products, such as CGF, may also have greater energy value than corn and that the energy value may vary based on inclusion rate when supplemented in forage-based diets.

Effects of supplemental corn gluten feed in forage-based beef production systems

Based on evidence gathered from experiments that evaluated energy value of corn co-products in feedlot and grain-based beef rations, it is likely animal performance will exceed that predicted by laboratory feed analysis and nutrient requirement models when beef cattle fed forage-based rations are supplemented with CGF. Despite this hypothesis, there are currently no data supporting this hypothesis. Quantifying the feeding value of CGF in forage-based rations will allow for more precise ration formulation and more predictable animal performance in forage-based production systems throughout the beef industry. Utilizing CGF in beef rations in Virginia is often cheaper than sourcing DDGS for producers because of proximity of sweetener plants in neighboring states and relative feed prices. Research regarding the use of CGF as an energy and protein supplement to forage-based rations has the potential to positively impact producers throughout the Southeastern United States.

Conclusions

The negative associative effects of EI intake continue to affect cattle throughout the Southeastern United States. Symptoms of EI consumption may go unnoticed, particularly if a majority of the herd is affected. The multitude of factors influencing manifestation of symptoms associated with EI intake complicate making clinical or observational diagnoses. Literature regarding the effects of EI intake on animal performance is inconclusive. Environmental conditions, ambient temperature, geographic location, and genetic factors for tolerance influence manifestation of fescue toxicosis. A variety of strategies have been evaluated as methods to alleviate symptoms of fescue toxicosis; however, because of variability among experimental methodologies, geographic locations, and genetic variation among animal models, there is no universal solution to improve

performance of cattle across different production systems and management styles. Providing sodium bicarbonate to diets of cattle fed EI may improve VFA uptake and fiber digestion in the rumen. These improvements in diet digestibility may result in improved animal growth and reproductive performance. Providing supplemental dietary crude protein and energy in the form of highly digestible fiber improves the growth performance of cattle fed forage-based diets. Providing supplemental dietary crude protein and energy in the form of highly digestible fiber may improve growth performance of cattle consuming EI fescue by diluting the dietary concentration of ergot alkaloids.

Literature Cited

- Aldrich, C. G., J. A. Paterson, J. L. Tate, and M. S. Kerley. 1993. The effects of endophyte-infected tall fescue consumption on diet utilization and thermal regulation in cattle. *J. Anim. Sci.* 71:164-170. doi: 10.2527/1993.711164x
- Ayers, A. W. 2003. Ruminal metabolism and transport of tall fescue ergot alkaloids. M.S. Thesis. Univ. Georgia, Athens.
- Blasi, D. A., M. J. Brouk, J. Drouillard, and S. P. Montgomery. 2001. Corn gluten feed: composition and feeding value for beef and dairy cattle. Kansas St. Univ, Manhattan. MF-2488.
- Block, H. C., C. N. Macken, T. J. Klopfenstein, G. E. Erickson, and R. A. Stock. 2005. Optimal wet corn gluten and protein levels in steam-flaked corn-based finishing diets for steer calves. *J. Anim. Sci.* 83:2798-2805. doi:10.2527/2005.83122798x
- Bond, J., J. B. Powell, D. J. Undersander, P. W. Moe, H. F. Tyrrell, and R. R. Oltjen. 1984. Forage composition and growth and physiological characteristics of cattle grazing several varieties of tall fescue during summer conditions. *J. Anim. Sci.* 59:584-593. doi: 10.2527/jas1984.593584x
- Bouton, J. H., G.C.M. Latch, N.S. Hill, C.S. Hoveland, M.A. McCann, R. H. Watson, J.A. Parish, L.L. Hawkins, and F. N. Thompson. 2002. Reinfection of tall fescue cultivars with non-ergot alkaloid-producing endophytes. *Agron. J.* 94:567-574. doi:10.2134/agronj2002.5670
- Burke, J. M., D. E. Spiers, F. N. Kojima, G. A. Perry, B. E. Salfen, S. L. Wood, D. J. Patterson, M. F. Smith, M. C. Lucy, W. G. Jackson, and E. L. Piper. 2001. Interaction of endophyte-

- infected fescue and heat stress on ovarian function in the beef heifer. *Biol. Reprod.* 65:260-268. doi: 10.1095/biolreprod65.1.260
- Campbell, B. T. 2012. Improving beef cattle performance on tall fescue. PhD Dis. Univ. Tennessee, Knoxville
- Drewnoski, M. E., and M. H. Poore. 2012. Effects of supplementation frequency on ruminal fermentation and digestion by steers fed medium-quality hay and supplemented with a soybean hull and corn gluten feed blend. *J. Anim. Sci.* 90:881-891. doi: 10.2527/jas.2010-3807
- Drewnoski, M. E., M. H. Poore, and G. A. Benson. 2011. Effect of frequency of supplementation of a soyhulls and corn gluten feed blend on hay intake and performance of growing steers. *Anim. Feed Sci. Technol.* 164(1):38-44. doi: 10.1016/j.anifeeds.2010.11.022
- Elsasser, T. H., and D. J. Bolt. 1987. Dopaminergic-like activity in toxic fescue alters prolactin but not growth hormone or thyroid stimulating hormone in ewes. *Domest. Anim. Endocrinol.* 4:259-269. doi: 10.1016/0739-7240(87)90022-1
- Fiorito, I. M., L. D. Bunting, G. M. Davenport, and J. A. Boling. 1991. Metabolic and endocrine responses of lambs fed *Acremonium coenophialum*-infected or noninfected tall fescue hay at equivalent nutrient intake. *J. Anim. Sci.* 69:2108-2114. doi: 10.2527/1991.6952108x
- Fortune, J. E., M. Y. Yang, J. J. Allen, and S. L. Herrick. 2013. Triennial Reproduction Symposium: The ovarian follicular reserve in cattle: what regulates its formation and size? *J. Anim. Sci.* 91:3041-3050. doi: 10.2527/jas.2013-6233

- Gadberry, M. S., J. Hawley, P. A. Beck, J. A. Jennings, E. B. Kegley, and K. P. Coffey. 2015. BILL E. KUNKLE INTERDISCIPLINARY BEEF SYMPOSIUM: A meta-analysis of research efforts aimed at reducing the impact of fescue toxicosis on cattle weight gain and feed intake. *J. Anim. Sci.* 93:5496-5505. doi: 10.2527/jas.2015-9245
- Gates, R. N., and W. E. Wyatt. 1989. Evaluation of low-endophyte tall fescue for cool-season forage in the lower south. *J. Prod. Agric.* 2:241-245.
- Ham, G. A., R. A. Stock, T. J. Klopfenstein, and R. P. Huffman. 1995. Determining the net energy value of wet and dry corn gluten feed in beef growing and finishing diets. *J. Anim. Sci.* 73:353-359. doi: 10.2527/1995.732353x
- Hannah, S. M., J. A. Paterson, J. E. Williams, M. S. Kerley, and J. L. Miner. 1990. Effects of increasing dietary levels of endophyte-infected tall fescue seed on diet digestibility and ruminal kinetics in sheep. *J. Anim. Sci.* 68:1693-1701. doi: 10.2527/1990.6861693x
- Harmon, D. L., K. L. Gross, K. K. Kreikemeier, K. P. Coffey, T. B. Avery, and J. Klindt. 1991. Effects of feeding endophyte-infected fescue hay on portal and hepatic nutrient flux in steers. *J. Anim. Sci.* 69:1223-1231. doi: 10.2527/1991.6931223x
- Helander, M., T. Phillips, S. H. Faeth, L. P. Bush, R. McCulley, I. Saloniemi, and K. Saikkonen. 2016. Alkaloid quantities in endophyte-infected tall fescue are affected by the plant-fungus combination and environment. *J. Chem. Ecol.* 42:118-126. doi: 10.1007/s10886-016-0667-1
- Hemken, R. W., J. A. Boling, L. S. Bull, R. H. Hatton, R. C. Buckner, and L. P. Bush. 1981. Interaction of environmental temperature and anti-quality factors on the severity of summer fescue toxicosis. *J. Anim. Sci.* 52:710-714. doi: 10.2527/jas1981.524710x

- Hill, N. S. 2008. Absorption of Ergot Alkaloids in the Ruminant. In *Neotyphodium in Cool-Season Grasses*. Blackwell Publishing Ltd. p. 271-290. doi:
10.1002/9780470384916.ch12
- Hopkins, A. A., and M. W. Alison. 2006. Stand persistence and animal performance for tall fescue endophyte combinations in the south central USA. *Agron. J.* 98:1221-1226. doi:10.2134/agronj2006.0007
- Hoveland, C. S. 1993. Importance and economic significance of the *Acremonium* endophytes to performance of animals and grass plant. *Agric. Ecosyst. Environ.* 44:3-12. doi:
10.1016/0167-8809(93)90036-O
- Howard, M. D., R. B. Muntifering, N. W. Bradley, G. E. Mitchell, and S. R. Lowry. 1992. Voluntary intake and ingestive behavior of steers grazing Johnstone or endophyte-infected Kentucky-31 tall fescue. *J. Anim. Sci.* 70:1227-1237. doi:
10.2527/1992.7041227x
- Jackson, J. A., R. W. Hemken, J. A. Boling, R. J. Harmon, R. C. Buckner, and L. P. Bush. 1984. Summer fescue toxicity in dairy steers fed tall fescue seed. *J. Anim. Sci.* 58:1057-1061. doi: 10.2527/jas1984.5851057x
- Johnston, D. B., and V. Singh. 2004. Enzymatic milling of corn: Optimization of soaking, grinding, and enzyme incubation steps. *Cereal Chem.* 81:626-632.
- Jolly, M. L. 2008. Evaluation of oil extraction on corn dry-milling byproducts in growing and finishing cattle diets. M.S. Thesis Univ. Nebraska., Lincoln

- Jones, K. L., S. S. King, K. E. Griswold, D. Cazac, and D. L. Cross. 2003. Domperidone can ameliorate deleterious reproductive effects and reduced weight gain associated with fescue toxicosis in heifers. *J. Anim. Sci.* 81:2568-2574. doi: 10.2527/2003.81102568x
- Kim, D., J. L. Klotz, and D. L. Harmon. 2014. Effects of fescue toxicosis induced by endophyte-infected tall fescue seed on forestomach epithelial gene expression in Angus steers. *J. Anim. Sci.* 92(E.Suppl.2):898.
- Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. *J. Anim. Sci.* 86:1223-1231. doi: 10.2527/jas.2007-0550
- Leuchtman, A., C. W. Bacon, C. L. Schardl, J. F. White, and M. Tadych. 2014. Nomenclatural realignment of *Neotyphodium* species with genus *Epichloë*. *Mycologia* 106:202-215. doi: 10.3852/13-251
- Looper, M. L., S. T. Reiter, B. C. Williamson, M. A. Sales, D. M. Hallford, and C. F. Rosenkrans. 2010. Effects of body condition on measures of intramuscular and rump fat, endocrine factors, and calving rate of beef cows grazing common bermudagrass or endophyte-infected tall fescue. *J. Anim. Sci.* 88:4133-4141. doi: 10.2527/jas.2010-3192
- Loy, T. W., T. J. Klopfenstein, G. E. Erickson, C. N. Macken, and J. C. MacDonald. 2008. Effect of supplemental energy source and frequency on growing calf performance. *J. Anim. Sci.* 86:3504-3510. doi: 10.2527/jas.2008-0924
- Lyons, P. C., R. D. Plattner, and C. W. Bacon. 1986. Occurrence of peptide and clavine ergot alkaloids in tall fescue grass. *Science* 232:487-489. doi: 10.1126/science.3008328
- McDonald, I. W. 1954. The extent of conversion of food protein to microbial protein in the rumen of the sheep. *Biochem J.* 56:120-125.

- Mahmood, T., R. S. Ott, G. L. Foley, G. M. Zinn, D. J. Schaeffer, and D. J. Kesler. 1994. Growth and ovarian function of weanling and yearling beef heifers grazing endophyte-infected tall fescue pastures. *Theriogenology*. 42:1149-1158. doi: 10.1016/0093-691X(94)90863-X
- Malinowski, D. P., G. A. Alloush, and D. P. Belesky. 1998. Evidence for chemical changes on the root surface of tall fescue in response to infection with the fungal endophyte *Neotyphodium coenophialum*. *Plant Soil* 205:1-12. doi: 10.1023/a:1004331932018
- Malinowski, D. P., and D. P. Belesky. 2000. Adaptations of endophyte-infected cool-season grasses to environmental stresses: mechanisms of drought and mineral stress tolerance. *Crop Sci.* 40:923. doi: 10.2135/cropsci2000.404923x
- Malinowski, D. P., D. P. Belesky, and G. C. Lewis. 2008. Abiotic stresses in endophytic grasses. In *Neotyphodium in Cool-Season Grasses* (eds C. A. Roberts, C. P. West, and D.E. Spiers). doi:10.1002/9780470384916.ch8
- Matthews, A. K., M. H. Poore, G. B. Huntington, and J. T. Green. 2005. Intake, digestion, and N metabolism in steers fed endophyte-free, ergot alkaloid-producing endophyte-infected, or nonergot alkaloid-producing endophyte-infected fescue hay. *J. Anim. Sci.* 83:1179-1185. doi: 10.2527/2005.8351179x
- National Academies of Sciences, E., and Medicine. 2016. *Nutrient requirements of beef cattle: Eighth Revised Edition*. The National Academies Press, Washington, DC.

- Newman, J. A., M. L. Abner, R. G. Dado, D. J. Gibson, A. Brookings, and A. J. Parsons. 2003. Effects of elevated CO₂, nitrogen and fungal endophyte-infection on tall fescue: growth, photosynthesis, chemical composition and digestibility. *Global Change Biol.* 9:425-437. doi: 10.1046/j.1365-2486.2003.00601.x
- Paterson, J., C. Forcherio, B. Larson, M. Samford, and M. Kerley. 1995. The effects of fescue toxicosis on beef cattle productivity. *J. Anim. Sci.* 73:889-898. doi:10.2527/1995.733889x
- Pedersen, J. F., and D. A. Sleper. 1988. Considerations in breeding endophyte-free tall fescue forage cultivars. *J. Prod. Agric.* 1:127-132.
- Poole, D. H., S. E. Lyons, J. C. Mackey, A. M. Tyson, G. Shaeffer, and M. H. Poore. 2016. Ergot alkaloid induced vasoconstriction of bovine uterine and ovarian blood vessels. *J. Anim. Sci.* 94:29-30. doi:10.2527/ssasas2015-060
- Richards, C. J., R. B. Pugh, and J. C. Waller. 2006. Influence of soybean hull supplementation on rumen fermentation and digestibility in steers consuming freshly clipped, endophyte-infected tall fescue. *J. Anim. Sci.* 84:678-685. doi: 10.2527/2006.843678x
- Roberts, C., and J. Andrae. 2004. Tall fescue toxiosis and management. *Crop Management* 3: doi: 10.1094/cm-2004-0427-01-MG
- Ryan, G. D., S. Rasmussen, H. Xue, A. J. Parsons, and J. A. Newman. 2014. Metabolite analysis of the effects of elevated CO₂ and nitrogen fertilization on the association between tall fescue (*Schedonorus arundinaceus*) and its fungal symbiont *Neotyphodium coenophialum*. *Plant Cell Environ.* 37:204-212. doi: 10.1111/pce.12146
- Schillo, K. K., L. S. Leshin, J. A. Boling, and N. Gay. 1988. Effects of endophyte-infected fescue on concentrations of prolactin in blood sera and the anterior pituitary and

- concentrations of dopamine and dopamine metabolites in brains of steers. *J. Anim. Sci.* 66:713-718. doi: 10.2527/jas1988.663713x
- Shibaya, M., S. Murakami, Y. Tatsukawa, D. J. Skarzynski, T. J. Acosta, and K. Okuda. 2006. Bovine corpus luteum is an extrapituitary site of prolactin production. *Mol. Reprod. Dev.* 73:512-519. doi: 10.1002/mrd.20445
- Shoup, L. M., L. M. Miller, M. Srinivasan, F. A. Ireland, and D. W. Shike. 2016. Effects of cows grazing toxic endophyte-infected tall fescue or novel endophyte-infected tall fescue in late gestation on cow performance, reproduction, and progeny growth performance and carcass characteristics. *J. Anim. Sci.* 94:5105. doi: 10.2527/jas2016-0819
- Siegel, M. R., G. C. M. Latch, and M. C. Johnson. 1985. Acremonium fungal endophytes of tall fescue and perennial ryegrass: significance and control. *Plant Dis.* 69:179-183.
- Singh, N., and S. R. Eckhoff. 1996. Wet milling of corn—a review of laboratory-scale and pilot plant-scale procedures. *Cereal Chem.* 73:659-657.
- Singh, V., D. B. Johnston, K. Naidu, K. D. Rausch, R. L. Belyea, and M. E. Tumbleson. 2005. Comparison of modified dry-grind corn processes for fermentation characteristics and DDGS composition. *Cereal Chem.* 82:187-190. doi:10.1094/CC-82-0187
- Smith, S. R., J.B. Hall, G. D. Johnson, and P. R. Peterson. 2009. Making the most of tall fescue in Virginia. VCE, Blacksburg. #418-050.
- Smith, T. and J. P. Cassady. 2015. BILL E. KNUCKLE INTERDISCIPLINARY BEEF SYMPOSIUM: Genetic resistance to the effects of grazing endophyte-infected tall fescue. *J. Anim. Sci.* 93:5506-5511. doi:10.2527/jas2015-9285

- Spiers, D. E., L. E. Wax, P. A. Eichen, G. E. Rottinghaus, T. J. Evans, D. H. Keisler, and M. R. Ellersieck. 2012. Use of different levels of ground endophyte-infected tall fescue seed during heat stress to separate characteristics of fescue toxicosis. *J. Anim. Sci.* 90:3457-3467. doi: 10.2527/jas.2012-5099
- Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. *J. Anim. Sci.* 77(E-Suppl):1-12. doi: 10.2527/jas2000.77E-Suppl1w
- Strickland, J. R., M. L. Looper, J. C. Matthews, C. F. Rosenkrans, M. D. Flythe, and K. R. Brown. 2011. BOARD-INVITED REVIEW: St. Anthony's Fire in livestock: Causes, mechanisms, and potential solutions. *J. Anim. Sci.* 89:1603-1626. doi: 10.2527/jas.2010-3478
- Wathes, D. C., G. E. Pollott, K. F. Johnson, H. Richardson, and J. S. Cooke. 2014. Heifer fertility and carry over consequences for life time production in dairy and beef cattle. *Animal.* 8(s1):91-104. doi: 10.1017/S1751731114000755
- Westendorf, M. L., G. E. Mitchell, Jr., R. E. Tucker, L. P. Bush, R. J. Petroski, and R. G. Powell. 1993. In vitro and in vivo ruminal and physiological responses to endophyte-infected tall fescue. *J. Dairy Sci.* 76:555. doi:10.1368/jds.S0022-0302(93)77375-0
- Wiltbank, M. C., A. H. Souza, P. D. Carvalho, A. P. Cunha, J. O. Giordano, P. M. Fricke, G. M. Baez, and M. G. Diskin. 2014. Physiological and practical effects of progesterone on reproduction in dairy cattle. *Animal* 8:70-81. doi:10.1017/S1751731114000585
- Zinn, R. A. 1989. Influence of level and source of dietary fat on its comparative feeding value in finishing diets for feedlot steers: metabolism. *J. Anim. Sci.* 67:1038-1049. doi:10.2527/jas1989.6741038x

Zinn, R. A., S. K. Gulati, A. Plascencia, and J. Salinas. 2000. Influence of ruminal biohydrogenation on the feeding value of fat in finishing diets for feedlot cattle. *J. Anim. Sci.* 78:1738-1746. doi: 10.2527/2000.787138x

CHAPTER II

Growth and reproductive responses of heifers consuming endophyte-infected tall fescue with or without sodium bicarbonate supplementation

ABSTRACT

Endophyte-infected (**EI**) tall fescue occupies a majority of the grazing land in the Southeastern U.S. and is associated with poor growth and reproductive performance. Supplementing bicarbonate to cattle grazing EI tall fescue was hypothesized to be a strategy to alleviate these negative performance outcomes by improving fiber digestibility and buffering capacity in the rumen. The objective of this study was to evaluate growth and reproductive characteristics of heifers consuming EI tall fescue seed with or without sodium bicarbonate supplementation. Commercial beef heifers ($n = 48$ total; 8 ± 1.2 mo; $BW = 268 \pm 24$ kg) were blocked by BW and assigned to treatments. Heifers were group-housed in 4 pens and fed individually using Calan gates. Treatments were arranged in a 2×2 factorial design with heifers fed either high EI fescue seed without sodium bicarbonate (**E+B-**), high EI fescue seed with sodium bicarbonate supplementation (**E+B+**), low EI fescue seed without sodium bicarbonate (**E-B-**), or low EI fescue seed with sodium bicarbonate supplementation (**E-B+**). Heifers were fed a basal corn silage diet; seed and bicarbonate were supplemented at 1.5 kg/day and 0.25 kg/day, respectively. Heifer BW was recorded on sequential days at the beginning and end of the 84 d experiment and every 14 d. Feed intake and refusals were measured daily. Reproductive tract scores (**RTS**) were assigned on a 1 to 5 scale and every 28 d via transrectal palpation and ultrasonography. Antral follicle count (**AFC**), anti-Müllerian Hormone (**AMH**), and mean age at puberty (**AAP**) were assessed at d 84. Results were analyzed after the 2nd ultrasound (d 56) and

at the end of the experiment (d 84). There tended to be an interaction between seed type and bicarbonate supplementation at d 56 for G:F ($P = 0.084$) and ADG ($P = 0.071$). Neither fescue seed type or bicarbonate supplementation affected DMI at d 56 ($P \geq 0.739$). By d 84, bicarbonate supplementation tended to decrease ADG ($P = 0.087$); and endophyte-infected seed intake tended to decrease DMI ($P = 0.074$). On d 56, bicarbonate supplementation showed promise as a strategy to ameliorate the negative effects of endophyte-infected seed intake; however, by the end of the study, no effects of fescue seed type were observed for ADG or G:F. Additional research is needed to fully understand why the influences of bicarbonate supplementation and endophyte-infected seed intake were not sustained over the full experimental period.

Key words: fescue toxicosis, replacement heifer, sodium bicarbonate, endophyte, supplementation

INTRODUCTION

Endophyte-infected fescue accounts for approximately 33% of pastureland in the southeastern United States (Smith et al., 2009). A symbiotic relationship with a fungal endophyte protects the plant from environmental stressors (Strickland et al., 2011). The fungal endophyte infecting EI, *Epichloë coenophiala* (Leuchtman et al., 2014), produces toxic ergot alkaloids to deter insect and mammalian herbivory (Malinowski and Belesky, 2000). Cattle consuming EI typically have reduced growth and reproductive performance relative to cattle consuming low endophyte-infected fescue (Porter and Thompson, 1992; Paterson et al., 1995; Strickland et al., 2011). Certain dietary and pharmaceutical interventions have been demonstrated to improve BW gain and improve reproductive performance of cattle fed EI (Jones et al., 2003). However, it is unclear if impaired reproductive performance is a direct or indirect effect of reduced growth

caused by EI intake. It has been hypothesized that impaired nutrient digestion limits metabolizable nutrient supply and can partially explain the negative effects of EI intake on growth and reproduction (Strickland et al., 2011). Intake of EI has been shown to reduce fiber digestibility in ruminants (Hannah et al., 1990; Matthews et al., 2005). A common cause of impaired fiber digestibility is dysregulated rumen pH. Cattle consuming EI show similar shifts in rumen epithelial VFA-bicarbonate transporters (Kim, 2014) as those seen in acidotic animals (Metzler-Zebeli et al., 2013); supporting the idea that pH may be dysregulated by EI intake. Supplementing sodium bicarbonate to increase buffering capacity of the rumen and enhance fiber digestibility may help stabilize the rumen environment, increase metabolizable nutrient supply, and improve growth and reproduction of cattle consuming EI. The objective of this experiment was to evaluate sodium bicarbonate supplementation as a strategy to mitigate negative effects of high EI seed (**E+**) intake on heifer growth and reproductive performance. We hypothesized that supplemental bicarbonate will improve performance of heifers consuming E+.

MATERIALS AND METHODS

Animals, Experimental Design and Treatments

All experimental procedures and protocols were approved by the Virginia Tech Institutional Animal Care and Use Committee (IACUC Protocol Number 16-086). A cohort of 48 Angus x Simmental heifers (589 ± 53.1 kg; 8 ± 1.2 mo of age) were blocked by body weight and assigned to treatments. Heifers were assigned to 1 of 6 blocks by body weight to equalize body weights across treatments. Cattle were housed in a dry lot at the Shenandoah Valley Agricultural Research and Extension Center in Raphine, VA from November 2016 through

February 2017. The experiment utilized a randomized complete block design with a 2×2 factorial arrangement of treatments. Fescue seed type and sodium bicarbonate supplementation strategy served as experimental factors. Treatments diets were either high EI fescue seed without sodium bicarbonate (**E+B-**), high EI fescue seed with sodium bicarbonate supplementation (**E+B+**), low EI fescue seed without sodium bicarbonate (**E-B-**), or low EI fescue seed with sodium bicarbonate supplementation (**E-B+**). Fescue seed supplementation consisted of either E+ seed (1,320 $\mu\text{g}/\text{kg}$ total ergot alkaloid) or low endophyte-infected (**E-**) seed (11 $\mu\text{g}/\text{kg}$ total ergot alkaloid) fed at 1.5 kg/d. Sodium bicarbonate was fed at a rate of 0.25 kg/d to heifers in E+B+ and E-B+ treatments. Level of fescue seed intake was formulated to target 20% dietary inclusion. Diets containing 20% endophyte-infected seed have been shown to induce hyperthermia in cattle by Burke et al. (2001). Nutrient analysis and diet composition of the silage and fescue seed and rations are detailed in Table 2.1. The resulting ration was expected to contain approximately 261 $\mu\text{g}/\text{kg}$ ergot alkaloid, which was also above the threshold for negative performance outcomes identified in a meta-analysis (Liebe and White, 2018). Bicarbonate supplementation rate assumed 4.5 g bicarbonate-C/kg $\text{BW}^{0.75}$ were irreversibly lost each day due to blood conversion to CO_2 , and 15% of that loss must be replaced in the diet (Abdullah et al., 1992).

Cattle were fed once daily at 0800 h. The basal ration consisted of corn silage, fescue seed, and a commercial vitamin and mineral premix with or without supplemental sodium bicarbonate. Silage was offered ad libitum with daily feeding levels adjusted to target 10% feed refusals. Corn silage and fescue seed basal diets were formulated to target ME and MP allowable gains of 0.80 kg (National Academies of Sciences, Engineering, and Medicine, 2016). Fescue seed, sodium bicarbonate, and vitamin/mineral premix were top-dressed within 30 min of feed

delivery by mixing into the top 1/3 of the silage in the feed bunk. Composition of the commercial vitamin/mineral premix (Southern States Cooperative, Richmond, VA) was: 12% Ca (ground limestone, monocalcium phosphate, dicalcium phosphate), 4.0% P (monocalcium phosphate, dicalcium phosphate), 20% Na (salt, sodium selenite), 10% Mg (magnesium oxide, magnesium sulfate), 0.32% S (potassium sulfate, magnesium sulfate, zinc sulfate, ferrous sulfate, copper sulfate), 1.0% K (potassium chloride, potassium sulfate), 65 mg/kg I (ferrous sulfate, ethylenediamine dihydroiodide), 1,000 mg/kg Cu (copper sulfate), 30 mg/kg Co (cobalt carbonate), 100 mg/kg Se (sodium selenite), 5,000 mg/kg Zn (zinc oxide), 1,500 mg/kg Mn (manganous oxide), 451,000 IU/kg Vitamin A (vitamin A supplement), 123,000 IU/kg Vitamin D (vitamin D supplement), and 495 IU/kg Vitamin E (vitamin E supplement).

Heifer Management and Performance Measures

Rations were fed using Calan gates (American Calan, Northwood, NH) gates to measure individual feed intake. Daily feed offerings were delivered using a Data Ranger (American Calan) and feed refusals collected and weighed daily at 0700 h. A 28 d pre-trial acclimation period was implemented to train heifers to consume feed from the Calan gates in a series of steps. Initially, gates were tied open from d -28 to d -15 to allow unrestricted access to feed. Gates were closed and solenoids deactivated to train heifers to open gates for d -14 through d 0 of the adaptation period. Trained personnel observed animals daily while eating and assigned Calan gates according to each heifer's perceived bunk preference during the 28 d period. At d 0 of the adaptation period, solenoids were activated and heifers were assigned transponders that would allow access to only one bunk. Heifers were monitored closely for 72 h after assigning transponders to ensure heifers were successful in opening gates to eat. Once the majority of

heifers were observed successfully opening and eating from the Calan gates, adaptation to the feeding system was recognized as complete. Data is reported for 44 heifers and excludes heifers that failed to adapt to the Calan gate system (n = 3) or learned to steal feed from other Calan gates assigned to other animals (n = 1). Cattle were fed individually and housed in 4 pens that were covered on 3 sides with concrete floors (9.75 m × 9.14 m, open to the east) containing 10 to 12 animals each. Feeding behavior was observed each day immediately after feeding to identify heifers eating from the wrong bunk and or sorting fescue seed from their ration. Daily feed intake estimates suspected to be affected by heifers stealing feed or sorting their rations, were removed prior to analysis of feed intake data.

Heifer BW was recorded on 2 consecutive days at the start and end of the 84 d experiment and interim BW was recorded every 14 d. Heifer BW was recorded between 4 and 6 h post-feeding with cattle weighed in a squeeze chute in the same pen order. Heifer ADG was calculated for the entire experimental period and from beginning of the experimental period to each interim BW recorded every 14 d. Heifer DMI was averaged for each 14 d period. Heifer ADG and DMI were used to calculate G:F.

Reproductive tract scores (**RTS**) were evaluated on d 0 and every 28 d thereafter via transrectal palpation and ultrasonography by the same technician. Descriptions of each RTS are listed in Table 2.2. Change in RTS was analyzed for differences between d 0 and d 28 and d 28 and d 56. Reproductive tract score change from d 56 to d 84 was not analyzed because the model failed to converge due to an insufficient number of animals having changes in RTS. Video and still images were obtained during transrectal palpation every 28 d and utilized to measure ovarian diameter, area, and antral follicle counts (**AFC**). Ovarian measurements were determined by

utilizing ImageJ software (National Institutes of Health, Bethesda, MD) by trained personnel to estimate ovarian diameter and area to obtain AFC. Follicle count and ovarian reserve are correlated with fertility and can be assessed by AFC independent of stage of the estrous cycle and concentration of AMH (Fortune et al., 2013).

Blood Sampling and Analysis

Blood plasma samples were collected weekly via jugular venipuncture into 10 ml sodium heparin vacutainer vials (Becton Dickinson, Franklin Lakes, NJ) and stored on ice for no more than 4 h until plasma was isolated via centrifuge (Sorvall RC-3B, Thermo Scientific, Langensfeld, Germany) at 2,300 x g at 4°C for 15 minutes. Isolated plasma was stored at -20°C until further analysis. Blood samples were collected on alternate sides of the animal's neck each week. Plasma samples were analyzed for concentrations of progesterone with an immunoassay system (Immulite 2000 XPI Immunoassay System, Siemens Healthcare, CA, USA). Plasma progesterone concentration was utilized as a measure of attainment of puberty. Age at puberty (**AAP**) was determined as the earliest d where plasma progesterone concentration was ≥ 1 pg/ml. An aliquot of plasma from each heifer was also analyzed for serum anti-Müllerian hormone (**AMH**) concentration utilizing the AMH GenII ELISA kit (Beckman Coulter, Brea, CA). Anti-Müllerian hormone is a predictor of follicular reserve of heifers and can be utilized as an indicator of productive lifespan and long-term fecundity in cattle (Jimenez-Krassel et al., 2015).

Feed analysis

One sample of corn silage was commercially analyzed for nutrient composition (Cumberland Valley Analytical Services, Hagerstown, MD). One sample of each seed type was dried at 55°C and ground to pass through a 1 mm screen (Wiley Mill, Thomas Scientific). Crude protein, ADF, and EE of E+ and E- were analyzed using Association of Official Analytical Chemists (1990) methods 990.03, 973.18, and 920.39, respectively. The methods described by Goering and Van Soest (1970) was used for analysis of E+ and E- NDF. Total digestible nutrients were calculated based on re-derived digestibility equations in White et al. (2017a) and White et al. (2017b).

Statistical Analysis

Data were analyzed with R statistical software (R Foundation for Statistical Computing, Vienna, Austria). Data were analyzed using a linear mixed effects model with fixed effects for fescue seed type, sodium bicarbonate supplementation, and the interaction between fescue seed type and sodium bicarbonate supplementation. Pen and BW block were included as random effects in the statistical model. Heifer BW, DMI, ADG, RTS, and progesterone concentrations were analyzed at d 28, d 56, and d 84 of the experimental period and by d 56 heifers were assumed to be acclimated to treatment diets. Treatment means are reported as least-square means. Treatment effects were considered significant at $P \leq 0.05$ and trends at $0.05 \leq P \leq 0.10$.

RESULTS

Animal growth parameters are presented in Table 2.3. Fescue seed type affected ($P = 0.018$) DMI at d 28, with heifers consuming E+ seed having reduced ($P = 0.010$) DMI compared to heifers consuming E- seed. Heifer DMI was not affected by fescue seed type ($P = 0.132$) or sodium bicarbonate supplementation ($P = 0.392$) at d 56. At d 84, there was a tendency ($P = 0.103$) for fescue seed type to have an effect on heifer DMI. Heifers fed E+ seed tended ($P = 0.074$) to have reduced DMI compared to those consuming E- seed.

Initial BW was not different ($P = 0.162$) among treatments. There tended ($P = 0.058$) to be a fescue seed type by sodium bicarbonate supplementation interaction for heifer BW at d 28. Heifers in the E+B- treatment had decreased ($P = 0.049$) BW at d 28 relative to heifers fed the other treatment rations. At d 56, the fescue seed type by sodium bicarbonate interaction significantly impacted heifer BW ($P = 0.021$). Heifers fed E+B- had decreased ($P = 0.030$) BW relative to heifers in E-B- treatments. Heifers fed E+B+ and E-B+ treatment rations had BW intermediate ($P \geq 0.189$) to E+B- and E-B-. Neither fescue seed type ($P = 0.877$) nor sodium bicarbonate supplementation ($P = 0.835$) affected heifer BW at d 84.

Heifer ADG was not affected by fescue seed type ($P = 0.683$) or sodium bicarbonate supplementation ($P = 0.416$) at d 28. The fescue seed type by sodium bicarbonate supplementation interaction tended ($P = 0.071$) to affect ADG at d 56. No treatment comparisons were significant ($P \geq 0.205$) for the fescue seed type by sodium bicarbonate supplementation interaction for ADG at d 56; however, heifers fed E+B- had numerically lower ADG relative to heifers fed E+B+ and E-B-. Sodium bicarbonate supplementation tended ($P = 0.087$) to affect ADG at d 84. Heifers supplemented sodium bicarbonate tended to have reduced ($P = 0.089$) ADG at d 84 relative to heifers that did not receive sodium bicarbonate supplementation.

There were no significant effects of fescue seed type ($P = 0.954$) or sodium bicarbonate supplementation ($P = 0.413$) treatment on G:F at d 28. At d 56, there was a tendency ($P = 0.053$) for the fescue by sodium bicarbonate interaction to have an effect on G:F; however, there were no differences among treatment means. There was a tendency for sodium bicarbonate supplementation to reduce ($P = 0.091$) G:F at d 84. Heifers supplemented sodium bicarbonate tended ($P = 0.086$) to have reduced feed efficiency relative to those not fed sodium bicarbonate.

Data regarding reproductive parameters are presented in Table 4. Heifer RTS was affected by the fescue seed type by sodium bicarbonate interaction at d 28 ($P = 0.031$). Heifers fed E+B- had lower ($P = 0.040$) RTS at d 28 relative to heifers fed E-B-. At d 56, heifer RTS was affected by the fescue seed type by sodium bicarbonate supplementation interaction ($P = 0.026$). Heifers fed E+B- had lower ($P = 0.048$) RTS relative to heifers fed E-B-. At d 84, heifer RTS were not affected by fescue seed type, sodium bicarbonate supplementation, or their interaction ($P \geq 0.121$). Change in RTS was not affected ($P \geq 0.439$) fescue seed type or sodium bicarbonate supplementation. There were also no significant differences in AAP among treatment groups ($P \geq 0.150$). Antral follicle count was measured and analyzed at d 84. There was no effect of fescue, sodium bicarbonate supplementation, or their interaction ($P = 0.291$) on AFC. Anti Müllerian hormone concentrations at d 84 were also not affected by fescue seed type, sodium bicarbonate supplementation, or their interaction ($P \geq 0.158$).

DISCUSSION

Intake and Growth Outcomes

At day 28 of the experiment heifers consuming E+ seed had significantly reduced DMI compared with heifers fed E- ($P = 0.018$), however, this observation was not maintained throughout the current experiment. Treatment did not affect DMI at d 56 ($P = 0.739$). There was a noticeable trend for E+ consumption to reduce ($P = 0.103$) DMI at d 84. It appears that heifers adapted to E+ seed intake, as evidenced by the fact that there were no differences in DMI at d 56 and a weak trend for E+ to reduce DMI at d 84. Previous research documents reduced DMI for ruminants consuming EI (Fiorito et al., 1991; Matthews et al., 2005, Spiers et al., 2012). A major difference between the current experiment and previous research is the feeding of fescue seed as a model for grazing fescue forage. Most previous research either uses hay or pasture for long-term experiments, or seed feeding for indoor, short-term, intensive experiments. A previous short-term experiment utilized a seed feeding as model for fescue toxicity and found steers fed ground EI seed had reduced DMI relative to those fed endophyte-free seed at thermoneutral conditions (Spiers et al., 2012). Spiers et al. (2012) also reported no difference in serum prolactin concentration between treatments. This is important because elevated ambient temperature is well acknowledged to reduce DMI in ruminants, and serum prolactin concentration is often utilized as a marker for fescue toxicity in cattle (Koontz et al., 2012; Spiers et al., 2012; Strickland et al., 2011). There is some debate as to whether animals consuming EI during summer months (Hemken et al., 1981; Hannah et al., 1990) have reduced DMI as a result of EI consumption or elevated ambient temperature. Koontz et al. (2012) also found that heat stress reduced DMI but did not fully account for reductions in intake associated with endophyte-

infected seed consumption; suggesting elevated ambient temperatures may compound the reduction in DMI observed for cattle consuming EI. Cattle housed in temperature controlled rooms with diurnal cycling from 22 to 33°C showed no difference in DMI between E+ and E- groups (Aldrich et al., 1993). However, when temperatures were held constant at either 22 or 33°C, an interaction between increased environmental temperature and E+ consumption is observed for DMI (Aldrich et al., 1993).

The current experiment was conducted in Virginia from late fall through early spring with an average temperature of $6.84^{\circ}\text{C} \pm 2.13^{\circ}\text{C}$. The significant reduction in DMI for E+ treatments at d 28 ($P = 0.018$) and tendency for depressed DMI for E+ groups at d 84 ($P = 0.074$) supports the assertion of Koontz et al. (2012) and Spiers et al. (2012) that EI seed has a direct regulatory effect on feed intake because the ambient temperature range during the current experiment would be insufficient to lead to thermally-associated intake depression. What data in the current experiment do not support is a constant, long-term effect of E+ on DMI; suggesting that duration of exposure, E+ feeding level, and thermal environment may all compound to drive DMI responses. The magnitude of differences in DMI among heifers fed E+ over time from d 28 to d 84 suggests physiological adaptation to E+ seed occurred.

Heifer ADG was not affected by treatment at d 28 ($P \geq 0.416$). At d 56, there was a tendency for the fescue seed type by bicarbonate supplementation interaction to have an effect on ADG ($P = 0.071$). Heifers fed E-B- had numerically greater ADG relative to heifers fed E+B- and E-B+, with heifers fed E+B+ having intermediate ADG. At d 56, sodium bicarbonate supplementation improved ADG of heifers fed E+, but this improvement was not statistically significant. At d 84 fescue seed type no longer affected heifer ADG ($P = 0.579$). Depressed ADG was expected for the cattle fed E+ seed because reduced growth rate is commonly associated

with EI consumption (Bond et al., 1984; Mahmood et al., 1994; Paterson et al., 1995; Jones et al., 2003; Parish et al., 2013). Indeed, a recent meta-analysis by Liebe and White (2018) suggests that EI consumption typically reduces growth rates by 33 g/d for each increase of 100 µg/kg in ergovaline concentration. In the current experiment, the E-B- and E+B- group ADG differed by only 142 g/d (10.8 g ADG per 100 µg/kg ergovaline), which is a response less than would be expected by Liebe and White (2018). If the meta-analysis by Liebe and White (2018) represents the mean response of cattle to ergovaline within the literature, heifers in the current experiment may have adapted to E+ seed intake by d 84. At d 84 sodium bicarbonate supplementation tended to reduce ($P = 0.089$) heifer ADG.

There are several potential reasons for this unexpected response to E+ feeding. It is hypothesized that cattle fed EI have depressed ADG because of decreased DMI, impaired blood flow to the gastrointestinal tract, depressed nutrient digestibility, or a direct toxic effect of EI on cellular function. Of these, dysregulated blood flows and depressed nutrient digestibility also occur when cattle are thermally stressed (Beede and Collier, 1986); and thus may depend on thermal environment. The results of the current experiment suggest the effects of EI and thermal environment are additive because heifers did not have a static response to E+ consumption.

Another potential reason for the limited ADG response in the current experiment is the method of EI delivery. Seed feeding has historically been used in short-term intensive studies. In the current experiment, seed was fed for a long duration. In the current experiment there was a trend for fescue seed type to affect ADG ($P = 0.071$); however, by d 84 that difference was no longer detectable ($P = 0.579$). This suggests that performance of animals fed E+ is dependent on the duration the seed is fed. A potential reason for the reduced E+ effect over time is that animals learned to sort out the E+ seed. However, intake and refusals were monitored daily and no

evidence of sorting E+ seed was identified. Another potential reason for the limited E+ effect over time is some adaptation of the animal to the E+ seed. Kohl and Dearing (2012) identified that exposure to plant-based toxins enhanced microbial diversity in the herbivore gut. Those results suggest that time-dependent adaptation of the digestive tract to toxins like ergot alkaloids produced by endophyte is possible. Additionally, a recent experiment quantified plasma and urine ergot alkaloid metabolites of steers grazing EI and demonstrated clear time-of-exposure dependent responses between exposure d 1 and 28 in steers grazing EI compared with steers grazing fescue infected with a non-toxic endophyte (Mote et al., 2017). Although it is difficult to compare the results of Mote et al. (2017) with the current experiment due to differences in experimental timeline and feeding strategies, the adaptation of the post-absorptive digestive system to EI supports the idea that animals in the current experiment may have adapted to the E+ intake by d 84.

There are two primary reasons why sodium bicarbonate supplementation may help ameliorate the effects of EI consumption on ADG in the short-term. A potential reason is related to decreased nutrient digestibility. A buildup of volatile fatty acids (VFA) in the rumen may negatively impact digestion in ruminants consuming EI, as a result of altered ruminal digestion kinetics. Hannah et al. (1990) reported a tendency for impaired fiber digestibility in wethers fed ground EI seed compared to wethers consuming uninfected fescue seed. In another experiment wethers consuming EI seed exhibited reduced fiber digestibility compared with those consuming endophyte-free seed (Westendorf et al., 1993). Cattle consuming E+ had reduced DM and OM digestibilities compared with E- fed cattle (Aldrich et al., 1993). The observed positive effect of sodium bicarbonate supplementation on ADG in heifers fed the E+B+ treatment ration relative to those fed the E+B- treatment ration at d 56 in the current experiment supports the idea that E+

consumption negatively impacts buffering capacity in the rumen. Providing supplemental dietary buffers may improve growth of heifers transitioning to a EI diet.

Although the exact mechanism through which EI influences buffering capacity is not clear, reduced expression of proteins responsible for the exchange of sodium bicarbonate for VFA has been observed in cattle fed EI (Kim et al., 2014). Acidotic goats show similar reductions in VFA transport proteins (Metzler-Zebeli et al., 2013). However, other data report no difference in gene expression for acidotic and control animals (Penner et al., 2009).

Discrepancies in data regarding the modifications in gene expression of acidotic ruminants may be because of differences in methodology and specific transporters evaluated. Interestingly, Schlau et al. (2012) report differences in expression of genes within ruminal epithelium responsible for maintaining intracellular pH in acidosis-susceptible steers compared with acidosis-resistant steers. Differences in gene expression related to VFA metabolism may contribute to an animal's ability to adapt to EI treatment diets; possibly explaining the impact of EI and bicarbonate treatment observed in the current experiment. Steers fed EI had greater molar proportions of butyrate; suggesting a shift in fermentation kinetics of cattle consuming EI (Harmon et al., 1991). Foote et al (2013) evaluated the effects of ergot alkaloids on ruminal blood flow by dosing steers with EI seed. Steers dosed with EI seed had impaired reticuloruminal epithelial blood flow relative to steers fed endophyte-free seed (Foote et al., 2013). Because protein-mediated uptake of VFA from the rumen is mediated by bicarbonate co-transport (Dijkstra et al. 1993), ruminal bicarbonate buffering is implicitly related to VFA dynamics. Collectively, these findings suggest that changes in expression and efficacy of rumen VFA transporters, or differences in nutrient flux may impair buffering capacity during EI consumption. Impaired VFA absorption, either due to impaired digestibility or impaired

epithelial function, supports previous research findings that heifers consuming EI pasture had lower ADG and BCS compared with heifers grazing endophyte-free and novel endophyte-infected pasture (Drewnoski et al., 2009). It also provides a potential mechanism for why the E+B+ treatment showed improved performance compared with the E+B- treatment in the current experiment.

It should also be noted that at d 56 heifers in the E-B+ treatment group had ADG numerically equivalent to that of heifers in E+B+. Both of these groups had numerically lower ADG than E+B- and E-B- fed heifers; suggesting that the level of sodium bicarbonate supplementation utilized in the current experiment may negatively impact growth of cattle as they adapt to sodium bicarbonate supplementation. By d 84 there was a tendency for bicarbonate supplementation to reduce ($P = 0.087$) ADG. We hypothesize that this negative influence is due to altering long-term fluid passage rate in the rumen. Sodium bicarbonate supplementation has been associated with changes in digestion kinetics in cattle (Haaland and Tyrell, 1982; Okeke et al., 1983). A linear decrease in mean retention time has been observed in cattle with increasing sodium bicarbonate in the diet (Okeke et al., 1983). Haaland and Tyrell (1982) observed a 7% numerical increase in liquid disappearance rate when cattle received ruminal buffer treatments. Changes in rate of disappearance of liquid from the rumen may alter the site and extent of digestion (Haaland and Tyrell, 1982). Although we did not measure digestion kinetics or take fecal samples in the current experiment, anecdotal differences in fecal output consistency were observed for several heifers receiving sodium bicarbonate supplementation. Interestingly, EI intake has also been related to dysregulated fluid dynamics. Ruminal fluid dilution rate (%/h) and fluid outflow (liters/hour) were greater when diets contained 3 mg/kg ergovaline compared to control groups (Hannah et al., 1990). Ergot alkaloid consumption is acknowledged to increase

vasoconstriction in the gastrointestinal system of cattle. Estimates of blood flow restriction to the gastrointestinal tract of cattle dosed with ergovaline indicate blood flow to the reticulorumen epithelium is reduced by at least 50% compared with baseline measurements under thermoneutral conditions (Foote et al., 2013). Vasoconstriction of mesenteric arteries has been observed in steers consuming EI seed; suggesting that impaired blood flow is associated with EI consumption (Egert et al., 2014). The compounding effects of EI and bicarbonate regulation of fluid dynamics may provide some explanation for the bicarbonate by seed type interaction on ADG observed at day 56 and for the negative bicarbonate effect on ADG observed by d 84.

Feed efficiency was not affected by the fescue seed type and sodium bicarbonate interaction at d 28 ($P \geq 0.333$). The fescue seed type and sodium bicarbonate interaction tended to have an effect on G:F at d 56 ($P = 0.053$) however, there were no significant treatment comparisons. At d 56, heifers fed E-B- had numerically greater G:F relative to heifers fed E+B- and E-B+, with heifers fed E+B+ having intermediate G:F. At d 84, bicarbonate supplementation tended to decrease G:F ($P = 0.087$). It appears sodium bicarbonate may have been overfed. In the current experiment, heifers did not have the ability to self-select the level of sodium bicarbonate supplementation and level of sodium bicarbonate supplementation may have been excessive; negatively affecting fluid passage rates and nutrient digestibility. Allowing cattle to self-select sodium bicarbonate supplementation may prevent reductions in growth performance and may improve feed efficiency. Previous research suggests that beef cattle can effectively self-select component-fed feedlot rations to maintain similar pH to that observed in cattle consuming a TMR (Moya et al., 2011). This ability to regulate feeding behavior to modulate pH suggests that allowing cattle to self-select sodium bicarbonate intake may be a more promising method to evaluate whether impacts of EI on growth performance can be alleviated by sodium bicarbonate.

Reproductive Outcomes

There was a tendency for the fescue seed type by sodium bicarbonate supplementation interaction to affect RTS at d 0 ($P = 0.080$). At d 28, heifers consuming E-B- had higher RTS compared with heifers consuming E+B- ($P = 0.040$). At d 56, heifer RTS was affected by the fescue seed type by sodium bicarbonate supplementation interaction ($P = 0.026$). Heifers fed E-B- had higher ($P = 0.048$) RTS than heifers fed E+B-. Treatment did not affect RTS at d 84 ($P \geq 0.121$). There were no significant main effects for change in RTS from d 0 to d 28 or from d 28 to d 56 ($P \geq 0.439$), and this suggests that differences in RTS at d 28 and d 56 were because of inherent differences in RTS at d 0. Change in RTS from d 56 to d 84 is not presented because the model would not converge. Heifer AAP ($P \geq 0.150$), and AMH concentrations ($P \geq 0.354$) were not affected by treatment. Therefore, results for the reproductive outcomes measured in the current experiment are mixed and largely fail to support a negative influence of EI on reproductive performance indicators. Follicle formation and initiation of follicular growth begins in utero (Fortune et al., 2013), and perhaps fetal programming in utero would be a more effective strategy than supplementing dietary ingredients to influence AFC or AMH concentration in heifers.

Previous research supports the theory that ergot alkaloid intake directly affects reproductive performance of cattle consuming EI fescue. Separating negative effects of EI consumption on reproduction from animal growth performance is difficult (Strickland et al., 2011). Heifers consuming EI seed have been shown to have lower circulating progesterone concentrations relative to heifers fed endophyte-free fescue seed (Jones et al., 2003). Additionally, vasoconstriction of the uterine and ovarian arteries and veins has been observed in heifers during the mid- to late stages of the estrous cycle (Poole et al., 2016). Vasoconstriction of

the lateral saphenous vein is observed in cattle grazed on EI is often sustained immediately after removal from endophyte-infected fescue pasture (Klotz, 2015). Vasoconstriction of the lateral saphenous vein shows improvement within 5 to 6 wk after removal from EI pasture (Klotz, 2015). If vasoconstriction of the uterine and ovarian veins is sustained for several wk after exposure to ergot alkaloids, EI intake early in development could negatively impact future reproductive success of developing heifers.

As noted previously, ambient temperature may play a role in manifestation of fescue toxicosis symptoms in cattle. For example, heifers grazing EI pasture in April through June in Butner, North Carolina had lower ADG than heifers grazing endophyte-free or novel-endophyte pasture, but there were no differences in response to estrous synchronization, conception to synchronized estrous, or overall pregnancy rates (Drewnoski et al., 2009). One reason for lack of negative reproductive response among treatments in the current experiment could be that thermoneutral conditions in late winter and early spring were insufficient to compound with the effect of EI intake to influence reproduction. The current experiment was conducted during a similar season and geographical region as Drewnoski et al (2009) and climatic conditions may have been insufficient in eliciting a significant reproductive response.

Mahmood et al. (2014) evaluated the effects of EI pasture consumption on reproductive performance of weanling (6 to 8 mo) and yearling (11 to 13 mo) heifers grazed on EI or low endophyte-infected fescue pastures for 112 d in southern Illinois. Heifers were determined acyclic or pre-pubertal if serum progesterone concentrations were less than 1.5 ng/ml for two serum samples taken 7 d apart (Mahmood et al., 1994). Heifers were categorized as abnormal if they began acyclic and remained acyclic over the duration of the experiment, those that were cyclic and became acyclic, and those that were acyclic became cyclic and then became acyclic

again (Mahmood et al., 2014). Mahmood et al. (1994) observed that weanling heifers grazing EI pastures had decreased instances of normal ovarian function relative to weanling heifers grazing low endophyte-infected pastures. Yearling heifers grazing EI pastures had similar ovarian activity to heifers grazing low endophyte-infected fescue (Mahmood et al., 1994); suggesting younger heifers may be more susceptible to the negative effects of EI intake on reproductive function. Jones et al. (2003) evaluated the efficacy of domperidone, a dopamine agonist, as a treatment for fescue toxicosis in 18 to 24 mo old heifers. Jones et al. (2003) reported greater progesterone concentrations for heifers fed endophyte-free fescue seed in the mid-to-late luteal phase compared with heifers fed EI fescue seed. Progesterone concentrations were elevated in heifers fed EI fescue seed and treated with domperidone on d 10, 9, and 6 before ovulation relative to heifers fed EI seed without domperidone treatment; suggesting that domperidone may ameliorate some of the negative effects of EI consumption in heifers (Jones et al., 2003). Despite reduced serum progesterone concentration for heifers fed EI, incubated corpora lutea tissue from heifers fed either EI, low endophyte-infected seed, or EI infected seed and treated with domperidone secreted similar levels of progesterone (Jones et al., 2003). Collectively, the results from Jones et al. (2003) suggest that reduced serum progesterone may not enter the peripheral blood supply in heifers fed EI without treatment because reduced serum progesterone was detected for heifers fed EI seed, but there were no differences in progesterone secreted from luteal tissues of heifers fed EI. Another experiment reported reduced growth performance in heifers consuming EI, but no observable differences in ovarian activity, synchronized estrous response, or pregnancy rate (Fanning et al., 1992). Heifers in the current experiment were similar in age to the weaned heifers utilized by Mahmood et al. (1994), but were considerably younger than heifers utilized by Jones et al. (2013). Further research is needed to make definitive

conclusions regarding the effects of EI fescue consumption on reproductive performance of heifers and how this relationship may differ with thermal environment and heifer age.

Additional consideration should also be given to including a wider variety of reproductive parameters in future studies evaluating the effects of EI intake in beef cattle because different metrics of reproductive success rarely agree within a study. Ten to 18 mo old heifers fed EI seed while being exposed to heat stress had reduced pre-ovulatory dominant follicle size and reduced serum prolactin concentrations relative to heifers fed endophyte-free seed exposed to heat stress, but no differences in follicle size or serum prolactin concentration were detected for heifers fed EI under thermoneutral conditions (Burke et al., 2001). Heifer age and ambient environment may have an additive negative effect on reproductive measurements when cattle consume EI. Estrus response following synchronization was reduced for weanling heifers grazed on EI than for heifers grazed on endophyte-free pastures, but this difference did not impact pregnancy rate (Mahmood et al., 1994). Evaluating a broader range of reproductive parameters over a longer experimental period may help to detect differences among treatments in the future. Heifers in the current experiment were young (8 ± 1.2 mo age) at the beginning of the experiment, and it is possible that a sufficient number of heifers did not attain puberty during the duration of the experiment.

Systemic Responses and Study Limitations

Collectively, the results of the current experiment suggest long-term seed feeding during winter does not replicate EI growth responses observed in pasture or hay feeding experiments conducted during the spring, summer, and fall. Although seed feeding is an appropriate model for evaluating short-term responses to ergovaline intake, it is likely an inappropriate

experimental approach for evaluating long-term growth and reproductive responses. It is possible that the efficacy of the seed feeding model used in the current experiment was decreased by low environmental temperatures more than anticipated. Additional research is needed to understand whether the lack of growth response at d 84 in the current experiment was because of the fescue toxicosis model or environmental conditions of the experiment.

Acknowledgements

The authors of the current experiment express their gratitude to the Virginia Agricultural Council for funding this research.

LITERATURE CITED

- Aldrich, C. G., J. A. Paterson, J. L. Tate, and M. S. Kerley. 1993. The effects of endophyte-infected tall fescue consumption on diet utilization and thermal regulation in cattle. *J. Anim. Sci.* 71:164-170. doi:10.2527/1993.711164x
- Abdullah, N., J. V. Nolan, M. Mahyuddin, and S. Jalaludin. 1992. Digestion and nitrogen conservation in cattle and buffaloes given rice straw with or without molasses. *J. Agric. Sci.* 119:255-263. doi:10.1017/S0021859600014180
- Anderson, K. J., D. G. Lefever, J. S. Brinks, and K. G. Odde. 1991. The use of reproductive tract scoring in beef heifers. *Agri-Practice* 12:19-26.
- Beede, D. K. and R. J. Collier. 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. *J. Anim. Sci.* 62:543-554. doi:10.2527/jas1986.622543x
- Bond, J., J. B. Powell, D. J. Undersander, P. W. Moe, H. F. Tyrrell, and R. R. Oltjen. 1984. Forage composition and growth and physiological characteristics of cattle grazing several varieties of tall fescue during summer conditions. *J. Anim. Sci.* 59:584-593. doi:10.2527/jas1984.593584x
- Burke, J. M., D. E. Spiers, F. N. Kojima, G. A. Perry, B. E. Salfen, S. L. Wood, D. J. Patterson, M. F. Smith, M. C. Lucy, W. G. Jackson, and E. L. Piper. 2001. Interaction of endophyte-infected fescue and heat stress on ovarian function in the beef heifer. *Biol. Reprod.* 65:260-268. doi:10.1095/biolreprod65.1.260
- Drewnoski, M. E., E. J. Oliphant, M. H. Poore, J. T. Green, and M. E. Hockett. 2009. Growth and reproductive performance of beef heifers grazing endophyte-free, endophyte-infected and novel endophyte-infected tall fescue. *Livest. Sci.* 125:254-260. doi:10.1016/j.livsci.2009.05.003

- Egert, A. M., D. H. Kim, F. N. Schrick, D. L. Harmon, and J. L. Klotz. 2014. Dietary exposure to ergot alkaloids decreases contractility of bovine mesenteric vasculature. *J. Anim. Sci.* 92:1768-1779. doi:10.2527/jas.2013-7141
- Fanning, M. D., J. C. Spitzer, D. L. Cross, and F. N. Thompson. 1992. A preliminary study of growth, serum prolactin, and reproductive performance of beef heifers grazing *Acremonium coenophialum*-infected tall fescue. *Theriogenology*. 38:375-384. doi:10.1016/0093-691X(92)90058-Y
- Fiorito, I. M., L. D. Bunting, G. M. Davenport, and J. A. Boling. 1991. Metabolic and endocrine responses of lambs fed *Acremonium coenophialum*-infected or noninfected tall fescue hay at equivalent nutrient intake. *J. Anim. Sci.* 69:2108-2114. doi:10.2527/1991.6952108x
- Foote, A. P., N. B. Kristensen, J. L. Klotz, D. H. Kim, A. F. Koontz, K. R. McLeod, L. P. Bush, F. N. Schrick, and D. L. Harmon. 2013. Ergot alkaloids from endophyte-infected tall fescue decrease reticuloruminal epithelial blood flow and volatile fatty acid absorption from the washed reticulorumen. *J. Anim. Sci.* 91:5366-5378. doi:10.2527/jas.2013-6517
- Fortune, J. E., M. Y. Yang, J. J. Allen, and S. L. Herrick. 2013. Triennial Reproduction Symposium: The ovarian follicular reserve in cattle: What regulates its formation and size? *J. Anim. Sci.* 91:3041-3050. doi:10.2527/jas.2013-6233
- Haaland, G. L., and a. H. F. Tyrell. 1982. Effects of limestone and sodium bicarbonate buffers on rumen measurements and rate of passage in cattle. *J. Anim. Sci.* 55:935-942. doi:10.2527/jas1982.554935x

- Hannah, S. M., J. A. Paterson, J. E. Williams, M. S. Kerley, and J. L. Miner. 1990. Effects of increasing dietary levels of endophyte-infected tall fescue seed on diet digestibility and ruminal kinetics in sheep. *J. Anim. Sci.* 68:1693-1701. doi:10.2527/1990.6861693x
- Harmon, D. L., K. L. Gross, K. K. Kreikemeier, K. P. Coffey, T. B. Avery, and J. Klindt. 1991. Effects of feeding endophyte-infected fescue hay on portal and hepatic nutrient flux in steers. *J. Anim. Sci.* 69:1223-1231. doi:10.2527/1991.6931223x
- Hemken, R. W., J. A. Boling, L. S. Bull, R. H. Hatton, R. C. Buckner, and L. P. Bush. 1981. Interaction of environmental temperature and anti-quality factors on the severity of summer fescue toxicosis. *J. Anim. Sci.* 52:710-714. doi:10.2527/jas1981.524710x
- Jimenez-Krassel, F., D. M. Scheetz, L. M. Neuder, J. L. Ireland, J. R. Pursley, G. W. Smith, R. J. Tempelman, T. Ferris, W. E. Roudebush, F. Mossa, P. Lonergan, A. C. O. Evans, and J. J. Ireland. 2015. Concentration of anti-Müllerian hormone in dairy heifers is positively associated with productive herd life. *J. Dairy Sci.* 98:3036-3045. doi:10.3168/jds.2014-8130
- Jones, K. L., S. S. King, K. E. Griswold, D. Cazac, and D. L. Cross. 2003. Domperidone can ameliorate deleterious reproductive effects and reduced weight gain associated with fescue toxicosis in heifers. *J. Anim. Sci.* 81:2568-2574. doi:10.2527/2003.81102568x
- Kim, D., J. L. Klotz, and D. L. Harmon. 2014. Effects of fescue toxicosis induced by endophyte-infected tall fescue seed on forestomach epithelial gene expression in Angus steers. *J. Anim. Sci.* 92(E.Suppl.2):898.
- Klotz, J. L. 2015. BILL E. KUNKLE INTERDISCIPLINARY BEEF SYMPOSIUM: Physiologic effects of ergot alkaloids: What happens when excretion does not equal consumption? *J. Anim. Sci.* 93:5512. doi:10.2527/jas.2015-9261

- Kohl, K. D., and M. D. Dearing. 2012. Experience matters: prior exposure to plant toxins enhances diversity of gut microbes in herbivores. *Ecol. Lett.* 15:1008-1015.
doi:10.1111/j.1461-0248.2012.01822.x
- Koontz, A. F., L. P. Bush, J. L. Klotz, K. R. McLeod, F. N. Schrick, and D. L. Harmon. 2012. Evaluation of a ruminally dosed tall fescue seed extract as a model for fescue toxicosis in steers. *J. Anim. Sci.* 90:914-921. doi:10.2527/jas.2011-4292
- Leuchtman, A., C. W. Bacon, C. L. Schardl, J. F. White, and M. Tadych. 2014. Nomenclatural realignment of *Neotyphodium* species with genus *Epichloë*. *Mycologia* 106:202-215. doi: 10.3852/13-251
- Liebe, D.M. and R.R. White. 2018. Meta-analysis of endophyte-infected Tall Fescue effects on cattle growth rates. *J. Anim. Sci.* 96(Suppl. 1):34-35. (Abstr.)
doi:10.1093/jas/sky0.27.064
- Mahmood, T., R. S. Ott, G. L. Foley, G. M. Zinn, D. J. Schaeffer, and D. J. Kesler. 1994. Growth and ovarian function of weanling and yearling beef heifers grazing endophyte-infected tall fescue pastures. *Theriogenology*. 42:1149-1158. doi:10.1016/0093-691X(94)90863-X
- Malinowski, D. P., and D. P. Belesky. 2000. Adaptations of endophyte-infected cool-season grasses to environmental stresses: mechanisms of drought and mineral stress tolerance. *Crop Sci.* 40:923. doi: 10.2135/cropsci2000.404923x
- Matthews, A. K., M. H. Poore, G. B. Huntington, and J. T. Green. 2005. Intake, digestion, and N metabolism in steers fed endophyte-free, ergot alkaloid-producing endophyte-infected, or non-ergot alkaloid-producing endophyte-infected fescue hay. *J. Anim. Sci.* 83:1179-1185. doi:10.2527/2005.8351179x

- Metzler-Zebeli, B. U., M. Hollmann, S. Sabitzer, L. Podstatzky-Lichtenstein, D. Klein, and Q. Zebeli. 2013. Epithelial response to high-grain diets involves alteration in nutrient transporters and Na⁺/K⁺-ATPase mRNA expression in rumen and colon of goats. *J. Anim. Sci.* 91:4256-4266. doi:10.2527/jas.2012-5570
- Mote, R. S., N. S. Hill, K. Uppal, V. T. Tran, D. P. Jones, and N. M. Filipov. 2017. Metabolomics of fescue toxicosis in grazing beef steers. *Food Chem. Toxicol.* 105(Suppl. C):285-299. doi:10.1016/j.fct.2017.04.020
- Moya, D., A. Mazzenga, L. Holtshausen, G. Cozzi, L. A. González, S. Calsamigla, D. G. Gibb, T. A. McAllister, K.A. Beauchemin, and K. Schwartzkopf-Genswein. 2010. Feeding behavior and ruminal acidosis in beef cattle offered a total mixed ration or dietary components separately. *J. Anim. Sci.* 89:520-530. doi:10.2527/jas.2010-3045
- Okeke, G. C., J. G. Buchanan-Smith, and D. G. Grieve. 1983. Effect of sodium bicarbonate on rate of passage and degradation of soybean meal in postpartum dairy cows. *J. Dairy Sci.* 66:1023-1031. doi:10.3168/jds.S0022-0302(83)81897-9
- Parish, J. A., J. R. Parish, T. F. Best, H. T. Boland, and C. A. Young. 2013. Effects of selected endophyte and tall fescue cultivar combinations on steer grazing performance, indicators of fescue toxicosis, feedlot performance, and carcass traits. *J. Anim. Sci.* 91:342-355. doi:10.2527/jas.2011-4725
- Paterson, J., C. Forcherio, B. Larson, M. Samford, and M. Kerley. 1995. The effects of fescue toxicosis on beef cattle productivity. *J. Anim. Sci.* 73:889-898. doi:10.2527/1995.73389x

- Penner, G. B., M. Taniguchi, L. L. Guan, K. A. Beauchemin, and M. Oba. 2009. Effect of dietary forage to concentrate ration on volatile fatty acid absorption and the expression of genes related to volatile fatty acid absorption and metabolism in ruminal tissue. *J. Dairy Sci.* 92:2767-2781. doi:10.3168/jds.2008-1716
- Poole, D. H., S. E. Lyons, J. C. Mackey, A. M. Tyson, G. Shaeffer, and M. H. Poore. 2016. Ergot alkaloid induced vasoconstriction of bovine uterine and ovarian blood vessels. *J. Anim. Sci.* 94:29-30. (Abstr.) doi:10.2527/ssasas2015-060
- Porter, J. K., and F. N. Thompson, Jr. 1992. Effects of fescue toxicosis on reproduction in livestock. *J. Anim. Sci.* 70:1594-1603. doi:10.2527/1992.7051594x
- Schlau, N., L. L. Guan, and M. Oba. The relationship between rumen acidosis resistance and expression of genes involved in regulation of intracellular pH and butyrate metabolism of ruminal epithelial cells in steers. *J. Dairy Sci.* 95:5866-5875. doi:10.3168/jds.2011-5167
- Smith, S. R., J.B. Hall, G.D. Johnson, and a. P. R. Peterson. 2009. Making the Most of Tall Fescue in Virginia. Virginia Coop. Ext. Pub.418-050. Virginia Tech. Blacksburg, VA.
- Spiers, D. E., L. E. Wax, P. A. Eichen, G. E. Rottinghaus, T. J. Evans, D. H. Keisler, and M. R. Ellersieck. 2012. Use of different levels of ground endophyte-infected tall fescue seed during heat stress to separate characteristics of fescue toxicosis. *J. Anim. Sci.* 90(10):3457-3467. doi:10.2527/jas.2012-5099
- Strickland, J. R., M. L. Looper, J. C. Matthews, C. F. Rosenkrans, M. D. Flythe, and K. R. Brown. 2011. BOARD-INVITED REVIEW: St. Anthony's Fire in livestock: Causes, mechanisms, and potential solutions. *J. Anim. Sci.* 89(5):1603-1626. doi:10.2527/jas.2010-3478

- Wathes, D. C., G. E. Pollott, K. F. Johnson, H. Richardson, and J. S. Cooke. 2014. Heifer fertility and carry over consequences for life time production in dairy and beef cattle. *Animal*. 8(Suppl. 1):91-104. doi:10.1017/S1751731114000755
- Westendorf, M. L., G. E. Mitchell, Jr., R. E. Tucker, L. P. Bush, R. J. Petroski, and R. G. Powell. 1993. In vitro and In vivo ruminal and physiological responses to endophyte-infected tall fescue. *J. Dairy Sci.* 76:555-563. doi:10.3168/jds.S0022-0302(93)77375-0
- White, R. R., Y. Roman-Garcia, J. L. Firkins, M. J. VandeHaar, L. E. Armentano, W. P. Weiss, T. McGill, R. Garnett, and M. D. Hanigan. 2017a. Evaluation of the National Research Council (2001) dairy model and derivation of new prediction equations. 1. Digestibility of fiber, fat, protein, and non-fiber carbohydrate. *J. Dairy Sci.* 100:3591-3610. doi:10.3168/jds.2015-10800.
- White, R. R., Y. Roman-Garcia, J. L. Firkins, P. Kononoff, M. J. VandeHaar, H. Tran, T. McGill, R. Garnett, and M. D. Hanigan. 2017b. Evaluation of the National Research Council (2001) dairy model and derivation of new prediction equations. 2. Rumen degradable and undegradable protein. *J. Dairy Sci.* 100:3611-3627. doi:10.3168/jds.2015-10801

TABLES

Table 2.1. Nutrient composition of corn silage, high endophyte (E⁺) seed, and low (E⁻) endophyte seed

Component	Nutrient Composition of Feedstuffs			Basal Diet Composition ¹	
	Corn Silage	E ⁺ Seed	E ⁻ Seed	E+ Diet	E- Diet
DM, % AF	44.7	97.3	96.7	50.0	50.0
OM, % DM	97.0	95.5	95.6	96.7	96.7
TDN ² , % DM	80.6	77.7	76.6	80.0	79.78
NE _g , Mcal/kg	1.359	1.047	1.043	1.298	1.339
CP, % DM	7.3	15.1	12.3	8.8	8.3
ADF, % DM	21.2	12.5	15.5	24.5	20.1
NDF, % DM	35.9	38.0	38.3	36.4	36.4
Starch, % DM	40.4	--	--	32.8	32.8
Crude Fat, % DM	3.5	2.0	0.9	3.0	2.8
Ash, % DM	3.1	4.5	4.4	3.3	3.3
Total Ergot					
Alkaloids, µg/kg	--	1,320	11	261	2

¹ Nutrient composition of corn silage and fescue seed diets. Sodium bicarbonate was top dressed into the top one third of corn silage in each bunk.

²TDN values calculated using re-derived equations in White et al. (2017a) and White et al. (2017b). Diet composition calculated using calculated TDN.

Table 2.2. Description of reproductive tract scores in heifers based on uterine and ovarian characteristics

Score ¹	Uterine Horns	Ovaries
1	Immature; < 20 mm diameter; no tone	No palpable structures
2	20 - 25 mm diameter; no tone	8 mm follicles
3	20 - 25 mm diameter; slight tone	8 - 10 mm follicles
4	30 mm diameter; no, slight, or good tone	> 10 mm follicles; possible CL
5	> 30 mm diameter; no tone	CL present

¹Assessed by transrectal palpation. Adapted from (Anderson et al., 1991).

Table 2.3. Growth performance of heifers consuming high (E+) or low (E-) endophyte fescue seed with (E+B+, E-B+) or without (E+B-, E-B-) sodium bicarbonate supplementation

Item	Treatment ¹				SEM	Seed	<i>P</i> -Values ²	
	E+B-	E+B+	E-B-	E-B+			Bicarb	Seed x Bicarb
BW, kg								
Initial	269	264	269	271	4	0.342	0.141	0.162
d 28	285 ^x	297 ^y	295 ^y	296 ^y	4	0.066	0.027	0.058
d 56	305 ^a	314 ^{ab}	318 ^b	311 ^{ab}	4	0.175	0.855	0.021
d 84	317	322	324	318	5	0.877	0.835	0.120
DMI, kg/d								
d 28	12.17 ^a	11.64 ^a	12.36 ^b	12.65 ^b	0.14	0.018	0.867	0.534
d 56	13.12	13.05	13.83	13.53	0.35	0.132	0.392	0.739
d 84	12.89	13.31	14.24	13.66	0.44	0.103	0.625	0.372
ADG, kg/d								
d 28	0.822	0.937	0.890	0.924	0.084	0.683	0.416	0.654
d 56	0.737	0.783	0.880	0.737	0.045	0.528	0.404	0.071
d 84	0.647 ^x	0.601 ^y	0.655 ^x	0.565 ^y	0.037	0.579	0.087	0.579
G:F								
d 28	0.15	0.18	0.16	0.16	0.01	0.954	0.413	0.333
d 56	0.12	0.14	0.14	0.12	0.01	0.973	0.689	0.053
d 84	0.25	0.21	0.22	0.19	0.14	0.120	0.091	0.887

¹Heifers receiving E+B- treatment received 1.5 kg/d of endophyte-infected fescue seed and no sodium bicarbonate, heifers receiving E+B+ received 1.5 kg/d of endophyte-infected fescue seed and 0.25 kg/d sodium bicarbonate, heifers receiving E- B- received 1.5 kg/d of low-endophyte fescue seed and no sodium bicarbonate, and heifers receiving E-B+ received 1.5 kg/d of low-endophyte fescue seed and 0.25 kg/d sodium bicarbonate.

²Seed = main effect of fescue seed type; Bicarb = main effect of sodium bicarbonate supplementation; Seed x Bicarb = interaction between fescue seed type and sodium bicarbonate supplementation

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

^{x,y} Means with different superscripts tend to differ $0.05 \leq P < 0.10$.

Table 2.4. Reproductive performance of heifers consuming high (E+) or low (E-) endophyte fescue seed with (E+B+, E-B+) or without (E+B-, E-B-) sodium bicarbonate supplementation

Item	Treatment ¹				SEM	P-Values ²		
	E+B-	E+B+	E-B-	E-B+		Seed	Bicarb	Seed x Bicarb
RTS³								
d 0	2.11	2.40	2.98	2.42	0.24	0.824	0.690	0.080
d 28	2.48 ^a	2.87 ^{ab}	3.40 ^b	2.75 ^{ab}	0.22	0.157	0.555	0.031
d 56	3.18 ^a	3.55 ^{ab}	3.95 ^b	3.43 ^{ab}	0.23	0.155	0.700	0.026
d 84	3.69	3.67	4.25	3.88	0.24	0.121	0.372	0.461
Change in RTS								
d 0 to 28	0.47	0.49	0.23	0.34	0.15	0.439	0.614	0.794
d 26 to 56	0.63	0.71	0.64	0.73	0.16	0.801	0.960	1.000
AAP, days⁴	378	366	348	362	14	0.150	0.475	0.365
AFC⁵	21	23	21	23	2	0.763	0.291	0.954
AMH, pg/mL⁶	866	1151	537	829	259	0.354	0.407	0.986

¹ Heifers receiving E+B- treatment received 1.5 kg/d of endophyte-infected fescue seed and no sodium bicarbonate, heifers receiving E+B+ received 1.5 kg/d of endophyte-infected fescue seed and 0.25 kg/d sodium bicarbonate, heifers receiving E- B- received 1.5 kg/d of low-endophyte fescue seed and no sodium bicarbonate, and heifers receiving E-B+ received 1.5 kg/d of low-endophyte fescue seed and 0.25 kg/d sodium bicarbonate.

² Seed = main effect of fescue seed type; Bicarb = main effect of sodium bicarbonate supplementation; Seed x Bicarb = interaction between fescue seed type and sodium bicarbonate supplementation

³Mean reproductive tract score assessed on d 56 and d 84

⁴Mean age at puberty

⁵Mean antral follicle count measured on d 84

⁶Mean anti-Müllerian Hormone concentration measured on d 84

^{a,b} Means with different superscripts differ $P \leq 0.05$.

CHAPTER III:

Determining the energy value of dried corn gluten feed in forage-based beef rations

ABSTRACT

Forty-two Angus × Simmental steers (382 ± 8 kg; 13.8 ± 0.4 mo) were individually fed to quantify the energy value of corn gluten feed (CGF) relative to corn in forage-based beef rations at 3 levels of supplement DMI. Treatments were arranged in a 2×3 factorial design with 2 supplement types and 3 levels of supplement DMI. Either cracked corn or pelleted CGF was supplemented at 0.15% (L), 0.54% (M), or 0.96% (H) of BW daily to steers fed ad libitum mixed grass hay for 63 d. Steers were housed in a dry lot facility equipped with Calan gates. Steer BW and flesh scores (FS) were recorded on 2 consecutive d at the beginning and end of the experiment. Supplement DMI was adjusted after an interim BW was recorded every 14 d. There were no interactions ($P \geq 0.103$) between supplement type and level. Initial BW, final BW, and FS were not different ($P \geq 0.226$) by supplement type or level. Steer ADG was greater ($P = 0.034$, 0.13 kg/d) with CGF supplementation and increased ($P < 0.001$) as level of supplementation increased. Steers supplemented CGF tended to have greater ($P = 0.090$) hay DM disappearance than steers supplemented corn. Supplement type did not affect supplemental G:F ($P = 0.305$). Supplemental G:F decreased ($P < 0.001$) as level of supplementation increased. Observed BW and DMI were entered into the 2016 Beef Cattle Nutrient Requirements Model (BCNRM). The TDN values of corn and CGF were adjusted until observed ADG was correctly predicted by the 2016 BCNRM. The resulting TDN values of corn-L, corn-M, corn-H, CGF-L, CGF-M, and CGF-H were 226%, 113%, 82%, 239%, 120%, and 92%, respectively. The energy value of CGF relative to corn were 106%, 107%, and 112% for L, M, and H, respectively.

INTRODUCTION

The demand for corn grain for ethanol production drove corn grain prices higher, creating additional incentive to find substitutes for corn in beef rations. Corn grain prices have since plateaued; however, beef producers have continued to seek alternatives to corn grain in rations. The expansion of the ethanol industry has increased the supply of corn co-products available as alternative protein and energy supplements in beef rations. Utilizing co-products as energy and protein supplements is a major paradigm shift from the use of co-products as protein supplements in traditional beef ration formulations (Klopfenstein et al., 2008). Many grains are too expensive to be included in beef rations. Additionally, high rates of corn grain inclusion in beef rations can negatively impact fiber digestion, with optimal levels of corn inclusion ranging between 0.2% and 0.5% BW (Anderson et al., 1988; Russell et al., 2016). In a forage-based production system, cattle supplemented with soybean hulls gained faster than cattle supplemented with dry rolled corn, suggesting that fibrous energy supplements may prevent negative associative effects associated with grain supplementation (Anderson et al., 1988). The nutritive value of co-products in forage-based production systems is not accurately represented by ration modeling software because chemical analyses do not represent the nutritive value of many co-product feeds. Reasons for under-predicted energy value and animal performance parameters may be a result of basal diet type and inclusion rate of corn co-products. The feeding value of co-products varies with basal diet type and inclusion rate of co-product (Ham et al., 1995; Klopfenstein et al., 2008; Loy et al., 2008). In a meta-analysis conducted by Klopfenstein et al. (2008), the feeding value of dried distillers grains plus solubles (**DDGS**) relative to corn in feedlot rations was 153% and 100% when DDGS inclusion was 10% and 40% of diet DM. The feeding value of corn gluten feed (**CGF**) in a feedlot ration had 90% to 100% the energy value of

corn when CGF replaced 44% and 70% of dry rolled corn in a grain-based finishing ration, exceeding model predictions (Ham et al., 1995). In a low quality grass hay-based ration, DDGS provided greater energy value than corn when DDGS were supplemented at 0.21% BW and 95% the energy value of corn when DDGS were supplemented at 0.81% BW (Loy et al., 2008). While DDGS is readily available and economically viable in the Midwestern U.S., dried CGF is often a more economical feedstuff for most producers in the Southeastern U.S., where corn sweetener production facilities are nearby. A substantial portion of beef cattle operations in the Southeastern U.S. are cow-calf operations that rely heavily on forage as the primary source of nutrients. Endophyte-infected (EI) tall fescue is the predominant forage throughout most grazing livestock operations in the southeastern United States (Hoveland, 1993). Tall fescue has a symbiotic relationship with a fungal endophyte, *Epichloë coenophiala*, that enhances the drought tolerance and pest resistance of the plant (Leuchtman et al., 2014). The fungal endophyte in EI fescue produces toxic ergot alkaloids to deter grazing livestock (Malinowski and Belesky, 2000). Cattle consuming EI tall fescue often exhibit reduced growth and reproductive performance (Strickland et al., 2011). A strategy to mitigate the symptoms of EI fescue on animal performance includes providing supplemental feedstuffs to dilute ergot alkaloid intake (Gadberry et al., 2015). Dilution of dietary concentrations of ergot alkaloids have been proposed as one potential strategy to reduce the impact of endophyte-infected fescue consumption on animal performance (Aiken and Strickland, 2013), and providing supplemental feedstuffs increases the plane of nutrition. The objectives of this experiment were to quantify the energy value of CGF relative to corn grain in fescue-forage based rations and to determine the changes in energy value of CGF as supplement inclusion rate increases. We hypothesize that the energy value of CGF will exceed that predicted by nutrient analysis and that as inclusion rate increases, the energy

value of the supplement will decrease. The effects of supplement type and supplement inclusion rate on steer hair shedding score (**HSS**) and flesh score (**FS**) were also evaluated in order to determine if supplementation improved markers of fescue toxicity.

MATERIALS AND METHODS

All animal-use procedures were reviewed and approved by the Institutional Animal Care and Use Committee at Virginia Tech (# 17-073).

Animals, Diet, and Management

Forty-two Angus x Simmental steers (382 ± 8 kg; 13.8 ± 0.04 mo) were stratified by body weight and sire and randomly allotted to treatments in a randomized block design with a 2 x 3 factorial treatment arrangement. Factors included 2 supplement types, either cracked corn or CGF, and 3 levels of supplementation. Treatment rations consisted of mixed grass fescue hay fed *ad libitum* with either cracked corn or pelleted CGF fed at 0.15% BW (**L**), 0.54% BW (**M**), or 0.96% BW (**H**). Supplement inclusion levels were formulated to meet a NE allowable gain of 0.36, 0.80, or 1.27, kg/d, for L, M, and H, respectively, for cattle using the Beef Cattle Nutrient Requirements Model (BCNRM; National Academies of Sciences, Engineering, and Medicine, 2016; Table 3.1). Level of supplementation was expressed as % BW and steers receiving CGF supplement were fed at the same % BW throughout the experiment. Nutrient composition of supplements and hay are listed in Table 3.2. Steers were housed in 1 of 4 pens measuring 9.14 by 9.75 meters in a barn open to the east with automatic waterers and concrete flooring in each pen. Bunks were equipped with Calan gates (American Calan, Northwood, NH) to measure individual supplement dry matter intake and hay dry matter disappearance (**DMD**). Daily feed offerings

were measured and recorded manually, and feed refusals were collected and weighed every 7 d. Supplements were hand fed at 0800 daily throughout the trial. Mixed fescue and orchardgrass hay was fed *ad libitum* following observation of a clean bunk after supplement feeding to ensure consumption of the entire supplement. Formulated and actual diet composition for each treatment group is presented in Table 3.1.

A 30 d acclimation period was implemented to train steers to Calan gates. Gates were tied open for 14 d, allowing free access to feed. For the next 14 d, solenoids were deactivated, allowing the gates to close but not lock to train steers to push gates open. Throughout the acclimation period, trained personnel observed steers eating and noted each steer's perceived preferred bunk space. At the end of the 28 d acclimation period, solenoids were activated and steers were assigned transponders allowing access to a single gate. For 72 h after assignment of transponders, steers were closely monitored to ensure each steer could successfully open and eat from the gates. Two steers were removed for failure to consume supplements. Beginning 7 d prior to the start of the treatment diet, all steers received approximately 1.81 kg CGF to acclimate cattle to CGF supplementation.

A commercially available vitamin premix (Sothern States Cooperative, Richmond, VA) was top dressed in bunks following supplement feeding. Composition of the commercial vitamin/mineral premix was: 12.0% Ca (ground limestone, monocalcium phosphate, dicalcium phosphate), 4.0% P (monocalcium phosphate, dicalcium phosphate), 20.0% Na (salt, sodium selenite), 10% Mg (magnesium oxide, magnesium sulfate), 0.32% S (potassium sulfate, magnesium sulfate, zinc sulfate, ferrous sulfate, copper sulfate), 1.0% K (potassium chloride, potassium sulfate), 65 mg/kg I (ferrous sulfate, ethylenediamine dihydroiodide), 1,000 mg/kg Cu (copper sulfate), 30 mg/kg Co (cobalt carbonate), 100 mg/kg Se (sodium selenite), 5,000 mg/kg

Zn (zinc oxide), 1,500 mg/kg Mn (manganous oxide), 451,000 IU/kg Vitamin A, 123,000 IU/kg Vitamin D, and 495 IU/kg Vitamin E.

Measures of Animal Performance

Animals were weighed once every 14 d. Pen order through the chute was maintained throughout the experiment. Steers were restrained in a squeeze chute. Additionally, steer HSS assigned initially and every 14 d thereafter as an external marker of ergot alkaloid toxicity. Steer HSS was assigned visually utilizing a 1 to 5 scale. A HSS of 1 indicated an animal with a healthy coat appearance appropriate to season. A HSS of 3 indicated an animal with a hair coat that exhibited slight variations in color and was slightly slow to shed, compared to what would be expected in the season. A hair shedding score of 5 indicated an animal with a coat of mostly dead, brittle hair that was uncharacteristic of the season.

Flesh scores (**FS**) were evaluated visually and assigned numerically to the 0.5 score utilizing a 1 to 9 scale. A score of 1 indicated a severely emaciated animal, whereas a score of 9 indicated an animal with an excessive fat deposits. Feeder cattle with excessive finish or fleshy appearance are often sold at a discount due to expected weight loss as a result of change in environment and reduced profitability associated with feeding heavier cattle (Troxel and Barham, 2007).

Overall G:F was calculated by 63 d ADG divided by total intake. Total intake included hay dry matter disappearance and supplement DMI. Supplement G:F was calculated by 63 d ADG divided by supplement DMI.

Feed and Forage Analysis

Feed, hay, and feed refusal samples were collected weekly to form a composite for determination of DM, ash, NDF, ADF, ether extract, and nitrogen analysis. Samples were composited and analyzed for nutrient composition. Individual loads of CGF were analyzed separately in addition to composite analysis to evaluate load-to-load variation. Feed 100°C DM was determined weekly and supplement intake was updated every 7 d to account for changes in moisture content. Samples were analyzed for ADF and NDF using an ANKOM Fiber Analyzer (ANKOM, Macedon, NY). Ether extract was determined using an ANKOM XT10 Extraction System (ANKOM, Macedon, NY). Nitrogen content was obtained using the Rapid MICRO N Cube Analyzer (Elementar, Elementar Americas, Ronkonkoma, NY) and procedures provided by manufacturer. Crude protein, ADF, and EE were analyzed using Association of Official Analytical Chemists (1990) methods 990.03, 973.18, and 920.39, respectively. The methods described by Goering and Van Soest (1970) was used for analysis of NDF. Analyzed nutrient composition of feedstuffs are presented in Table 3.2.

Determination of Feeding Value of Corn and Corn Gluten Feed

The feeding value of CGF and corn in the current experiment were quantified using the Beef Cattle Nutrient Requirements Model (Version 1.0.37.10, National Academies of Sciences, Engineering, and Medicine, 2016). Breed type was entered as a 3-way cross (Angus, Simmental, and Angus) to achieve a $\frac{3}{4}$ Angus $\frac{1}{4}$ Simmental breed to reflect the breed composition of steers. Ambient temperature, environmental conditions, feed intake, and animal age were consistent across treatments. Animal age is reported as the average age across all treatments. Average animal initial BW, final BW, and initial BCS were entered into the animal parameters of the

model for each treatment. After all relevant model parameters were entered, TDN was manipulated in the 2016 BCNRM software until the NE allowable gain reflected observed animal performance. Crude protein, NDF, ether extract, and ash obtained by laboratory analysis were updated to reflect hay, corn, and CGF feed value, respectfully. The adjusted TDN value was entered into the University of Florida Feed Energy Calculator (University of Florida Extension) to obtain NE_m and NE_g values. The University of Florida Feed Energy Calculator utilizes the 1984 NRBCM (National Academies of Sciences, Engineering, and Medicine) energy equations for converting between energy estimates. This process was repeated for each of the 6 treatments to obtain the energy value of CGF relative to corn.

Return on supplement costs

Estimated value of gain and return on supplement costs were calculated utilizing actual costs and sale prices for the commodities in the current experiment. Grain was purchased from Augusta Cooperative Farm Bureau (Staunton, Virginia) and prices from each respective load of feed were utilized in calculating feed costs. Hay was sourced from a local producer, and cost per kg was calculated based on number of bales and bale weight. Average hay DMD for each treatment was utilized to obtain feed costs. Cattle prices used for analysis were obtained from USDA AMS Livestock Detailed Annual Quotations for 2017 for Auction Sales in Virginia (VDACS, 2017). Treatment initial and final BW were utilized to obtain cattle prices. Prices are reported as USD.

Statistical Analysis

Data were analyzed in SAS Software 9.4 (SAS Institute, Cary, NC) using a PROC MIXED procedure with supplement type (Corn or CGF) and supplement level (L, M, or H) as

fixed effects. Separation of means were conducted utilizing LSMEANS procedure in SAS. Treatment effects were considered significant at $P \leq 0.05$ and trends at $0.05 \leq P \leq 0.10$.

RESULTS AND DISCUSSION

Steer performance data is presented in Table 3.3. No significant supplement type by level of supplementation interactions were significant for any performance variables ($P \geq 0.103$). Only main effects of supplement type and supplement inclusion level are discussed. Steer initial BW was not different across treatment ($P \geq 0.852$). Initial FS ($P \geq 0.801$) and initial HSS ($P \geq 0.115$) were not different among treatments. Body weight was not different for steers of any treatment at any point during the experiment ($P \geq 0.226$).

Supplement type significantly affected ADG ($P = 0.034$), with steers supplemented with CGF exhibiting greater ADG than those fed corn. Level of supplementation had a significant effect on ADG, as expected ($P < 0.001$). There was no significant effect for the supplement type by level of supplementation interaction on ADG ($P = 0.544$). Existing literature supports improved ADG for cattle supplemented with co-products relative to cattle supplemented grain. In a meta-analysis by Klopfenstein et al. (2008) as level of DDGS in the diet increased from 0 to 40% diet DM, a quadratic response in ADG was observed, and optimal inclusion rate for maximum ADG was between 20 to 30% DDGS. Heifers supplemented at 0.21% BW with DDGS had greater ADG than those supplemented with dry rolled corn or a dry rolled corn-corn gluten meal composite supplement at the same level of supplementation (Loy et al., 2008). Cattle grazing pasture supplemented with a wheat middling-soybean hull energy supplement had similar ADG to cattle supplemented with sorghum grain (Bodine et al., 2001); indicating in forage-based production systems, high fiber energy sources do not negatively impact animal

performance. Stocker cattle grazing winter wheat supplemented with a soybean hull and wheat middling supplement resulted in improved ADG compared with steers supplemented with high starch corn grain-based energy supplements (Horn et al., 1995). Garcés-Yépez et al. (1997) observed improved ADG and BCS when cattle were supplemented soybean hulls at 1.04% compared to cattle supplemented a corn-soybean meal composite at 0.83% BW.

Forage quality may affect co-product supplement utilization and resulting animal performance. Heifers consuming low quality hay supplemented with varying levels DDGS demonstrated greater ADG relative to heifers fed the same levels of DDGS supplementation and high-quality forage rations (Morris et al., 2005). MacDonald et al. (2007) evaluated the contribution of UIP and EE in DDGS to diet protein and energy supply by supplementing heifers grazing smooth bromegrass pasture with DDGS, corn gluten meal to supply UIP, or corn oil to supply EE. Corn gluten meal and corn oil were supplemented at rates to provide equal UIP and EE, respectively, to that of DDGS (MacDonald et al., 2007). Heifers supplemented DDGS had greater ADG than heifers supplemented corn gluten meal and corn oil; suggesting that improvements in animal performance are not independently explained by UIP or EE content from DDGS (MacDonald et al., 2007). Supplementing corn co-products to cattle fed forage-based rations improves animal performance relative to cattle fed high-starch or grain energy supplements; however, management strategies and forage quality may also impact animal performance.

As supplement inclusion increased, total DMI increased ($P < 0.001$). Steers fed H had greater total DMI relative to steers fed M and L. Hay DMD was analyzed separately to allow detection of differences in forage consumption. Corn gluten feed supplementation tended to increase hay dry matter disappearance ($P = 0.090$). Level of supplementation did not affect hay

dry matter disappearance ($P = 0.278$). Heifers provided with high levels (0.81% BW) of energy supplement exhibited reduced hay DMI compared with those supplemented at 0.21% BW when basal diet was forage based (Loy et al., 2008). Collecting hay intake data in the current experiment was challenging because hay was not ground, making it possible for steers to steal hay when bunks were full. Literature regarding the effects of corn coproduct supplementation on hay intake is inconclusive. Loy et al. (2008) report no difference in hay DMI among cattle supplemented with dry rolled corn, DDGS, or a dry rolled corn and corn gluten meal composite. In an 84 d experiment with a silage-based ration, CGF supplementation did not affect DMI, whereas DDGS supplementation negatively impacted DMI (Segers et al., 2012). In another experiment, hay intake was not negatively impacted for cattle consuming either high-fiber or high-grain energy supplements (Bodine et al., 2001). Bodine et al. (2001) hypothesize that forage intake did not decrease for supplemented cattle relative to un-supplemented cattle because an adequate source of RDP was included in grain supplements. Other literature reports that forage intake was reduced when cattle were supplemented with corn coproducts (Fieser and Vanzant, 2004; Morris et al., 2005). Effects of co-product supplementation on hay intake are unclear and may be impacted by a multitude of factors including forage quality, ambient environment, diet composition, and experimental design.

Supplement DMI was not different among supplement types ($P = 0.534$). Supplement DMI was different between supplement inclusion levels, as expected ($P < 0.001$). This was a product of our experimental design. The authors of the current experiment did not anticipate any differences in supplement feed refusal because relatively low-levels of supplement inclusion were utilized, increasing the likelihood that steers would consume all supplement.

Overall G:F ratio was not affected by supplement type ($P = 0.342$) or the supplement type by level of supplementation interaction ($P = 0.740$). Steers supplemented at M and H levels were more efficient than steers supplemented at 0.15% BW ($P \leq 0.050$). Segers et al. (2012) compared CGF to DDGS and a corn and soybean meal supplement on growing cattle performance, steers fed CGF had reduced BW gain and improved feed efficiency relative to cattle fed DDGS and the corn and soybean meal-based diet. Beef cows fed silage-based diets supplemented with increasing levels of DDGS had lower DMI and were more efficient as level of DDGS supplementation increased (Taylor et al., 2017). Feed efficiency of steers fed a soybean hull and wheat middling energy supplement was not different compared with steers fed high starch corn-based energy supplements (Horn et al., 1995). Discrepancies regarding feed efficiency for cattle supplemented with co-products in forage-based rations make it difficult to interpret results. Additionally, hay disappearance measurement techniques utilized in the current experiment could have impacted observed overall G:F.

There were no significant effects for FS, final FS, or FS change for any treatment group ($P \geq 0.394$). Fleshy feeder calves are discounted when sold at auctions (Troxel and Barham, 2007), reducing producer incentive to supplement stocker or backgrounded steers if an undesirable degree of flesh results in a reduced selling price when cattle are marketed. Segers et al. (2012) report similar FS for stockers supplemented with CGF, DDGS, or a corn and soybean meal-based diet, suggesting that replacing traditional energy and protein supplements with limited corn co-products does not result in excessive FS. Other literature suggests BCS are improved for cattle fed high-fiber energy supplements relative to cattle fed a corn and soybean meal supplement (Garcés-Yépez et al., 1997). Cows fed low-quality forage had improved body condition scores as DDGS supplementation level increased (Winterholler et al., 2012). Body

condition score change was similar for gestating cows fed low-quality forage supplemented with DDGS or a wheat middlings and cottonseed meal-based supplement, despite DDGS having a higher RUP and TDN content than the composite (Winterholler et al., 2012). Data from the current experiment and previous research suggest that low levels of supplementation of corn coproducts to growing cattle in forage-based beef production systems can provide energy and protein to rations without resulting in excessive fat deposition.

Steer final HSS were not different treatment ($P \geq 0.167$). Hair shedding scores are utilized as an external indicator of ergot alkaloid toxicity because cattle experiencing fescue toxicosis do not shed their winter hair coats. There was a tendency for the supplement type by supplement level interaction to influence HSS change from initial to final observation ($P = 0.070$). Steers in the CGF L treatment group had 0.86 more desirable HSS change compared with steers fed CGF M, indicating steers in the CGF L treatment retained their winter coats to a greater degree than those in the CGF M treatment group ($P = 0.038$). Shoup et al. (2016) report greater hair shedding scores for early gestating beef cattle grazed on EI fescue pasture compared with cattle grazed on novel endophyte pastures from May to October. It is unclear why HSS change tended to be different between CGF M and CGF H, but no differences were observed among other treatments. Ultimately, all cattle lost their winter hair coats and the authors of the current experiment question the biological significance of the tendency for a difference in HSS change between CGF M and CGF H.

Derived Energy Value of CGF

The energy value of CGF relative to corn is presented in Table 4. The derived TDN value of corn-L, corn-M, corn-H, CGF-L, CGF-M, and CGF-H were 225%, 112%, 82%, 239%, 120%,

and 92%, respectfully. Animal performance often exceeds model predictions when cattle are supplemented low levels of corn co-products in forage-based rations. The energy value of hay may be under-predicted because data utilized to develop ration formulation software were from cattle fed feedlot rations. Additionally, the predictions in the model assume a universal DE and NE conversion among different types of feed. The energy values of CGF relative to corn were 106%, 107%, 112% and L, M, and H, respectfully. The increased energy content of co-products relative to corn has been well documented in grain-based rations, as well as forage-based rations with DDGS. High-fiber energy supplements may improve cattle performance in forage-based systems through positive associative effects that improve animal ADG relative to high-starch energy supplements. In a fiber-based ration, cattle consuming 0.4% and 0.2% BW corn supplementation gained faster, more efficiently, and maintained an acetate:propionate ratio greater than those observed in diets with corn inclusion levels of 60 and 30% diet DM (Russell et al., 2016). Russell et al. (2016) determined the optimal level of corn inclusion for ADG, G:F and NDFd in a highly digestible fiber diet was 0.4% BW corn inclusion. Determining the threshold for optimal corn inclusion level in forage-based rations is elusive, however, alternative energy sources serve as promising strategies to mitigate the negative associative effects encountered when feeding high-grain supplements at high levels of DMI.

Supplements with highly digestible fiber content have been suggested as a method to provide supplemental energy without negatively impacting the rumen environment (Bowman and Swanson, 1996). Feeding co-products above 15 to 20% of diet DM provides supplemental energy to cattle and protein is overfed when co-products are supplemented at this level (Klopfenstein et al., 2008). Utilizing corn co-products as energy and protein sources was a major paradigm shift in the mid- 2000's because of increased corn grain prices (Klopfenstein et al.,

2008). Because of transportation costs and storage concerns, feeding wet CGF is not economical for many beef producers, especially those who operate forage-based production systems in the Southeastern US. Additionally, feeding wet CGF requires purchasing an entire load and generally results in high storage losses.

Research reporting the effects of corn co-product supplementation on the rumen environment are contrasting. Loy et al. (2007) report supplementation of either dry rolled corn or DDGS reduced ruminal pH relative to unsupplemented cattle consuming hay. There were no differences in ruminal pH between corn supplemented or DDGS supplemented cattle (Loy et al., 2007). Supplementing DDGS resulted in faster hay NDF disappearance relative to dry rolled corn supplementation in cattle fed chopped hay (Loy et al., 2007). No differences in DMI or volatile fatty acid production between corn or DDGS supplementation were detected (Loy et al., 2007). Russell et al. (1979) observed a reduction in the number of cellulolytic bacteria as pH declined; indicating that modifications to the rumen environment can impact the bacterial colonization within the rumen. Results of the current experiment suggest that CGF supplementation did not negatively impact the rumen environment because cattle supplemented CGF gained faster than cattle supplemented cracked corn. Data characterizing the rumen environment and digestion kinetics are needed to make definitive claims regarding CGF utilization when supplemented at low levels to cattle consuming forage-based diets.

Increased feeding value of co-products relative to corn has been well reported in previous research (Larson et al., 1993; Klopfenstein et al., 2008; Loy et al., 2008); however, the reasons for improved feeding values have not been fully determined. The synergistic interaction between highly digestible fiber, moderate protein content, and fat profile of corn co-products may contribute to improved feeding value relative to corn (Jolly, 2013). Approximately 40% of the

zein protein, the primary protein in corn co-products, is utilized for microbial protein synthesis (McDonald, 1954). Concentrated sources of zein protein, such as CGF, may allow for more RUP supply to the animal. Increasing levels of dietary fat depresses fiber digestibility in cattle (Zinn, 1989), however, the type of fat found in co-products may not result in reduced fiber digestibility. Dietary fat that is predominantly degraded in the rumen reduces NDF digestibility (Zinn et al., 2000). Lipids in corn co-products do not seem to negatively affect fiber digestion like typical fat sources, potentially explaining the increased energy value of corn co-products compared with corn grain (Jolly, 2013). The nutrient profile of co-products may provide positive associative effects to the animal; resulting in improved performance relative to traditional feeds.

Return on supplement costs were calculated for each treatment group. Associated costs and returns of supplementation are listed in Table 5. Steers supplemented with corn at 0.15% BW had a higher return on supplement cost than steers supplemented with CGF at 0.15% BW. Supplementing cattle with CGF at 0.54% BW/d provided the greatest return at \$100.93/head increase in income compared with cattle supplemented corn at the same inclusion rate. Supplementing cattle with CGF at 0.96% BW/d increased return by \$36.59/head compared to cattle supplemented corn at the same inclusion rate.

Data from the current experiment indicate that the energy value of CGF in forage-based rations is under-predicted by the 2016 NRBCM (National Academies of Sciences, Engineering, and Medicine). Ration compositions listed in Table 3.1 also under-predict steer performance because these values are contingent on chemical composition. Cattle in the current experiment had improved ADG when supplemented with CGF relative to corn. Corn gluten feed supplementation did not negatively impact G:F or FS. In the current experiment, CGF provided 106%, 107%, and 112% energy relative to corn for 0.15%, 0.54%, and 0.96% inclusion rates,

respectively. Overall G:F was improved for cattle supplemented at H relative to cattle supplemented at M inclusion. Supplement inclusion level data from the current experiment can assist producers and researchers to formulate hay-based rations with optimal CGF inclusion. Further research in pasture-based production systems are needed to obtain energy estimates for grazing cattle supplemented with CGF because forage quality may impact nutrient utilization of corn co-products.

Acknowledgements

The authors of the current experiment express their gratitude to the Virginia Agricultural Council for funding this research.

LITERATURE CITED

- Aiken, G. E. and J. R. Strickland. 2013. Forages and Pastures Symposium: Managing the tall fescue-fungal endophyte symbiosis for optimum forage-animal production. *J. Anim. Sci.* 91:2369-2378. doi:10.2527/jas2012-5948
- Anderson., S. J., J. K. Merrill, and T. J. Klopfenstein. 1988. Soybean hulls as an energy supplement for the grazing ruminant. *J. Anim. Sci.* 66:2959-2964.
doi:10.2527/jas1988.66112959x
- AOAC. 1990. Official methods of analysis. 15th ed. Assoc. Of. Anal. Chem., Arlington, VA.
- Bodine, T. N., H. T. Purvis II, and D. L. Lalman. 2001. Effects of supplement type on animal performance, forage intake, digestion, and ruminal measurements of growing beef cattle. *J. Anim. Sci.* 79:1041-1051. doi:10.2527/2001.7041041x
- Bowman, J. G. P., and D. W. Swanson. 1996. Starch- or fiber-based energy supplements for grazing ruminants. In Proc. 3rd Grazing Livestock Nutrition Conf. M. B. Judkins and F. T. McCollum III ed Proc. West. Sect. Am. Soc. Anim. Sci. (Suppl. 1):118-135.
- Fieser, B. G., and E. S. Vanzant. 2004. Interactions between supplement energy source and tall fescue hay maturity on forage utilization by beef steers. *J. Anim. Sci.* 82:307-318.
doi:10.2527/2004.821307x
- Gadberry, M. S., J. Hawley, P. A. Beck, J. A. Jennings, E. B. Kegley, and K. P. Coffey. 2015. BILL E. KUNKLE INTERDISCIPLINARY BEEF SYMPOSIUM: A meta-analysis of research efforts aimed at reducing the impact of fescue toxicosis on cattle weight gain and feed intake. *J. Anim. Sci.* 93:5496-5505. doi: 10.2527/jas.2015-9245

- Garcés-Yéptez, P., W. E. Knuckle, D. B. Bates, J. E. Moore, W. W. Thatcher, and L. E. Sollenberger. 1997. Effects of supplemental energy source and amount on forage intake and performance by steers and intake and diet digestibility by sheep. *J. Anim. Sci.* 75:1918-1925. doi:10.2527/1997.7571918x
- Ham, G. A., R. A. Stock, T. J. Klopfenstein, and R. P. Huffman. 1995. Determining the net energy value of wet and dry corn gluten feed in beef growing and finishing diets. *Journal of animal science* 73:353-359. doi:10.2527/1995.732353x
- Horn, G. W., M. D. Cravey, F. T. McCollum, C. A. Strasia, E. G. Krenzer, Jr., and P. L. Claypool. 1995. Influence of high-starch vs high-fiber energy supplements on performance of stocker cattle grazing wheat pasture and subsequent feedlot performance. *J. Anim. Sci.* 73:45-54. doi:10.2527/1995.73145x
- Jolly, M. L. 2013. Evaluation of oil extraction on corn dry-milling byproducts in growing and finishing cattle diets. Thesis. Univ Nebraska, Lincoln.
- Klopfenstein, T. J., G. E. Erickson, and V. R. Bremer. 2008. BOARD-INVITED REVIEW: Use of distillers by-products in the beef cattle feeding industry. *J. Anim. Sci.* 86:1223-1231. doi:10.2527/jas.2007-0550
- Larson, E.M., R.A. Stock, T. J. Klopfenstein, M. H. Sindt, and R. P. Huffman. 1993. Feeding value of wet distillers byproducts for finishing ruminants. *J. Anim. Sci.* 71:2228-2236. doi:10.2527/1993.7182228x
- Leuchtman, A., C. W. Bacon, C. L. Schardl, J. F. White, and M. Tadych. 2014. Nomenclatural realignment of *Neotyphodium* species with genus *Epichloë*. *Mycologia* 106:202-215. doi:10.3852/13-251

- Liebe, D.M. and R. R. White. 2018. Meta-analysis of endophyte-infected Tall Fescue effects on cattle growth rates. *J. Anim. Sci.* 96(Suppl. 1):34-35. (Abstr.)
doi:10.1093/jas/sky0.27.064
- Loy, T. W., J. C. MacDonald, T. J. Klopfenstein, and G. E. Erickson. 2007. Effect of distillers grains or corn supplementation frequency on forage intake and digestibility. *J. Anim. Sci.* 85:2625-2630. doi:10.2527/jas.2005-750
- Loy, T. W., T. J. Klopfenstein, G. E. Erickson, C. N. Macken, and J. C. MacDonald. 2008. Effect of supplemental energy source and frequency on growing calf performance. *J. Anim. Sci.* 86:3504-3510. doi:10.2527/jas.2008-0924
- McDonald, I. W. 1954. The extent of conversion of food protein to microbial protein in the rumen of the sheep. *Biochem J.* 56:120-125.
- MacDonald, J. C., T. J. Klopfenstein, G. E. Erickson, and W. A. Griffin. 2007. Effects of dried distillers grains and equivalent undegradable intake protein or either extract on performance and forage intake of heifers grazing smooth brome grass pastures. *J. Anim. Sci.* 85:2614-2624. doi:10.2527/jas.2006-560.
- Malinowski, D. P., and D. P. Belesky. 2000. Adaptations of endophyte-infected cool-season grasses to environmental stresses: mechanisms of drought and mineral stress tolerance. *Crop Sci.* 40:923. doi: 10.2135/cropsci2000.404923x
- Morris, S., T. J. Klopfenstein, D. C. Adams, G. E. Erickson, and K. J. Vander Pol. 2005. The effects of dried distillers grains on heifers consuming low or high quality forage. *Nebraska Beef Cattle Reports.* 172.
- National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient requirements of beef cattle. 8th rev. ed. Natl. Acad. Press, Washington, DC

- Russell, J. R., W. J. Sexten, and M. S. Kerley. 2016. Effect of corn inclusion on soybean hull-based diet digestibility and growth performance in continuous culture fermenters and beef cattle. *J. Anim. Sci.* 94:2919-2926. doi:10.2527/jas2015-0180.
- Segers, J. R., A. M. Stelzleni, T. D. Pringle, M. A. Froetschel, C. L. Ross, and R. L. Stewart, Jr. 2012. Use of corn gluten feed and dried distillers grains plus solubles as a replacement for soybean meal and corn for supplementation in a corn silage-based stocker system. *J. Anim. Sci.* 91:950-956. doi:10.2527/jas2011-4392.
- Shoup, L. M., L. M. Miller, M. Srinivansan, F. A. Ireland, and D. W. Shike. 2016. Effects of cows grazing toxic endophyte-infected tall fescue or novel endophyte-infected tall fescue in late gestation on cow performance, reproduction, and progeny growth performance and carcass characteristics. *J. Anim. Sci.* 94:5105. doi:10.2527/jas2016-0819
- Strickland, J. R., M. L. Looper, J. C. Matthews, C. F. Rosenkrans, M. D. Flythe, and K. R. Brown. 2011. BOARD-INVITED REVIEW: St. Anthony's Fire in livestock: Causes, mechanisms, and potential solutions. *J. Anim. Sci.* 89:1603-1626. doi:10.2527/jas.2010-3478
- Taylor, E. G., R. P. Lemenager, V. Fellner, and K. R. Stewart. 2017. Effect of distiller's grains plus solubles in postpartum diets of beef cows on reproductive performance of dam and heifer progeny. *J. Anim. Sci.* 95:4543-4553. doi:10.2527/jas2017.1637
- Troxel, T. R., and B. L. Barham. 2007. Comparing the 2000 and 2005 factors affecting the selling price of feeder cattle sold at Arkansas livestock auctions. *J. Anim. Sci.* 85:3425-3433. doi:10.2527/jas.2007-0339

University of Florida Extension. Feed Energy Calculator. Accessed at: <http://rcrec-ona.ifas.ufl.edu/calculators.shtml>. (Accessed on 15 April 2018).

Virginia Department of Agriculture and Consumer Sciences. 2017. U. S. Department of Agriculture, Agriculture Marketing Service Livestock Detailed Annual Quotations for 2017, Staunton Union Market. Accessed at: <http://www.vdacs.virginia.gov/pdf/staunton2017.pdf> (Accessed on 30 April 2018).

Winterholler, S. J., C. P. McMurphy, G. L. Mourer, C. R. Krehbiel, G. W. Horn, and D. L. Lalman. 2012. Supplementation of dried distillers grains with solubles to beef cows consuming low-quality forage during late gestation and early lactation. *J. Anim. Sci.* 90:2014-2025. doi:10.2527/jas2011-4152

Zinn, R. A. 1989. Influence of level and source of dietary fat on its comparative feeding value in finishing diets for feedlot steers: metabolism. *J. Anim. Sci.* 67:1038-1049. doi:10.2527/jas1989.6741038x

Zinn, R. A., S. K. Gulati, A. Plascencia, and J. Salinas. 2000. Influence of ruminal biohydrogenation on the feeding value of fat in finishing diets for feedlot cattle. *J. Anim. Sci.* 78:1738-1746. doi:10.2527/2000.787138x

Table 3.1. Description of treatment rations fed to growing steers to determine the energy value of corn gluten feed in forage-based rations.

Item	Treatments ¹					
	Corn L	Corn M	Corn H	CGF L	CGF M	CGF H
Formulated Treatment Rations²						
Formulated DMI, kg/d						
Hay	9.2	9.2	9.2	9.2	9.2	9.2
Dry Rolled Corn	0.6	2.3	4.0			
CGF				0.6	2.3	4.0
Total	9.8	11.5	13.2	9.8	11.5	13.2
<i>Formulated Nutrient Composition</i>						
ME allowable gain, kg/d	0.36	0.80	1.27	0.35	0.73	1.15
MP allowable gain, kg/d	0.69	1.22	1.81	0.71	1.34	2.03
Actual Treatment Rations						
Actual DMI, kg/d						
Hay Disappearance ³	6.6	6.1	6.1	6.6	6.7	6.5
Dry Rolled Corn	0.6	2.8	3.9			
CGF				0.6	2.3	4.0
Total intake	7.2	8.9	10.0	7.2	8.9	10.5
<i>Actual Nutrient Composition</i>						
CP, % DM	10.4	9.7	9.3	11.4	12.7	13.7
Fat, % DM	2.4	2.5	2.5	2.5	2.6	2.6
NDF, % DM	57.2	48.6	42.1	59.2	54.3	50.8
NE _m Mcal/kg	1.72	1.58	1.52	1.74	1.72	1.64
NE _g Mcal/kg	1.06	0.96	0.92	1.08	1.08	1.02
ME allowable gain, kg/d	0.75	0.97	1.19	0.79	1.12	1.38
MP allowable gain, kg/d	0.34	0.72	1.14	0.40	0.98	1.56

¹ Corn L = Steers supplemented corn at 0.15% BW; Corn M = Steers supplemented corn at 0.54% BW; Corn H = Steers supplemented corn at 0.96% BW; CGF L = Steers supplemented corn gluten feed at 0.15% BW; CGF M = Steers supplemented corn gluten feed at 0.54% BW; CGF H = Steers supplemented corn gluten feed at 0.96% BW.

² Rations were formulated to target ADG 0.36, 0.81, and 1.28 kg for L, M, and H, respectively

³ Hay dry matter disappearance (**DMD**) for each treatment group is reported as opposed to hay DMI because steers were observed stealing hay from bunks.

Table 3.2. Nutrient composition of feedstuffs included in treatment rations.

Item	Analyzed nutrient content, % DM					
	DM, %	CP	NDF	ADF	Fat	Ash
Hay	94.3	10.7	61.6	40.3	2.2	5.7
Dry Rolled Corn	95.2	7.0	9.6	3.0	2.6	1.7
Corn Gluten Feed ¹	93.8	18.7	33.1	13.1	2.9	6.9
Load 1	94.8	18.5	35.1	9.1	2.9	6.9
Load 2	93.2	18.5	32.2	8.7	2.9	6.7
Feed Refusals	94.6	8.1	64.9	45.7	1.8	5.2

¹One representative sample from each load of corn gluten feed fed throughout the current experiment was analyzed for nutrient composition to evaluate variation in CGF.

Table 3.3. Effects of supplementing steers with corn or corn gluten feed (CGF) in forage-based rations.

Item	Treatments ¹						SEM	P-Values ²		
	Corn-L	Corn-M	Corn-H	CGF-L	CGF-M	CGF-H		Type	Level	Type × Level
BW, kg										
Initial	382	379	380	384	383	382	14	0.852	0.966	0.955
Final	432	441	456	435	454	470	17	0.463	0.266	0.934
ADG, kg/d	0.75 ^a	0.97 ^b	1.19 ^c	0.79 ^a	1.12 ^b	1.38 ^c	0.07	0.034	0.001	0.544
Hay DMD ⁴ , kg/d	6.6 ^x	6.1 ^x	6.4 ^x	6.6 ^y	6.7 ^y	6.5 ^y	0.3	0.090	0.278	0.103
Supplement DMI, kg/d	0.6 ^a	2.2 ^b	3.9 ^c	0.6 ^a	2.2 ^b	4.0 ^c	0.1	0.534	0.001	0.911
Total DMI, kg/d	7.2 ^a	8.3 ^b	10.4 ^c	7.2 ^a	8.9 ^b	10.5 ^c	0.4	0.118	0.001	0.235
G:F, kg										
Overall	0.047 ^d	0.054 ^{de}	0.052 ^e	0.050 ^d	0.057 ^{de}	0.060 ^e	0.003	0.141	0.065	0.771
Supplement	0.543 ^a	0.204 ^b	0.138 ^c	0.590 ^a	0.227 ^b	0.157 ^c	0.027	0.305	0.001	0.987
HSS ⁵										
Initial	5.0	4.9	4.6	4.7	5.0	4.7	0.1	0.677	0.303	0.115
Final	2.4	2.7	2.3	2.9	2.3	2.3	0.2	1.000	0.278	0.167
Change	-2.6 ^{xy}	-2.1 ^{xy}	-2.3 ^{xy}	-1.9 ^x	-2.7 ^y	-2.6 ^{xy}	0.3	0.837	0.683	0.070
Flesh Score										
Initial	5.6	5.6	5.4	5.6	5.6	5.6	0.2	0.859	0.664	0.801
Final	5.4	5.4	5.6	5.4	4.4	5.5	0.1	0.802	0.938	0.938
Change	0	-0.2	0.1	-0.2	-0.2	-0.1	0.2	0.797	0.394	0.805

¹ Corn-L = Steers supplemented corn at 0.15% BW; Corn-M = Steers supplemented corn at 0.54% BW; Corn-H = Steers supplemented corn at 0.96% BW; CGF-L = Steers supplemented corn gluten feed at 0.15% BW; CGF-M = Steers supplemented corn gluten feed at 0.54% BW; CGF-H = Steers supplemented corn gluten feed at 0.96% BW.

² Type = main effect of supplement type; Level = Level of supplement inclusion; Type × Level = interaction between supplement type and level of supplement inclusion.

³ FS = Flesh Score assigned on a 1 to 9 scale. A score of 1 indicates a steer that is severely emaciated and a score of 9 excessive fat.

⁴ Hay DMD = Hay Dry Matter Disappearance for each treatment group.

⁵ HSS = Hair Shedding Score assigned on a 1 to 5 scale. A score of 1 indicates a full winter coat and a score of 5 indicates a slick, short summer coat.

^{a,b,c} Means within row differ with a significant effect of supplement level $P \leq 0.05$.

^{d,e,f} Means within row tend to differ for main effect of supplement level $0.05 < P \leq 0.10$.

^{x,y} Means within row tend to differ for supplement type by level interaction $0.05 < P \leq 0.10$.

Table 3.4. Energy value of treatment supplements fed to growing steers

Item	Treatments ¹							
	Corn-L	Corn-M	Corn-H	CGF-L	CGF-M	CGF-H	Corn Avg	CGF Avg
Derived TDN ² , %	225	113	82	239	120	92	140	150
Supplement NE _m , Mcal/kg	1.350	0.595	0.414	1.482	0.636	0.473	0.786	0.864
Supplement NE _g , Mcal/kg	1.027	0.427	0.277	1.136	0.459	0.332	0.577	0.462
TDN Adjustment ³	2.57	1.29	0.94	2.99	1.5	1.16	1.60	1.54
Energy Relative to Corn ⁴ ,%	--	--	--	106	107	112	--	108

¹Corn-L = Steers supplemented 0.15% BW/d corn, Corn-M = Steers supplemented 0.54%/d BW corn, Corn H = Steers supplemented 0.96%/d BW corn, CGF L = Steers supplemented 0.15% BW/d corn gluten feed, CGF M = Steers supplemented 0.54% BW/d corn gluten feed, CGF H = Steers supplemented 0.96% BW/d corn gluten feed.

²Derived TDN values were calculated by adjusting the Nutrient Requirements of Beef Cattle Model (NRBCM) TDN values for corn and corn gluten feed until the model predicted ME or MP allowable gain matched observed animal performance for each treatment combination.

³TDN adjustment factor is the Nutrient Requirements of Beef Cattle Model standard TDN value multiplied by an adjustment factor until the NRBCM model report ME allowable gain, kg/d matched treatment average ADG.

⁴Energy value of CGF relative to corn obtained by dividing derived TDN values of CGF by derived TDN values of corn expressed as a percentage.

Table 3.5 Return on supplementation cost for steers supplemented corn or corn gluten feed in forage-based treatment rations

Treatment ¹	Purchase Price, \$/CWT ²	Gain, kg ³	Sale Price, \$/CWT ²	Value of Gain, \$ ⁴	Total Supp. Intake ⁵	Supplement Cost/head, \$ ⁶	Hay Cost, \$ ⁷	Feed Cost, \$ ⁸	Return, \$ ⁹
Corn L	116.79	47.376	123.03	211.61	38.11	9.26	45.88	55.14	153.12
Corn M	116.79	61.362	123.03	190.55	137.40	33.39	42.07	75.46	112.11
Corn H	116.79	74.907	127.44	356.07	245.70	59.71	44.63	104.34	197.76
CGF L	116.79	49.770	123.03	189.69	38.22	8.64	45.81	54.45	135.24
CGF M	116.79	70.749	127.44	291.07	140.74	31.81	46.22	78.03	213.04
CGF H	116.79	84.263	127.44	336.28	251.685	56.89	45.05	101.93	234.35

¹Corn L = Steers supplemented 0.15% BW/d corn, Corn M = Steers supplemented 0.54%/d BW corn, Corn H = Steers supplemented 0.96%/d BW corn, CGF L = Steers supplemented 0.15% BW/d corn gluten feed, CGF M = Steers supplemented 0.54% BW/d corn gluten feed, CGF H = Steers supplemented 0.96% BW/d corn gluten feed over a 63 d experiment.

² Prices are \$/CWT = \$/45 kg

³Treatment ADG over the 63 d treatment period.

⁴Represents total USD value of gain for each respective treatment group. Value of gain was calculating utilizing cattle prices (\$/kg) corresponding to initial treatment BW for each group from

⁵Treatment supplement intake over the 63 d treatment period.

⁶Total cost of grain for each treatment group was calculated by multiplying grain intake by 63.

⁷Average hay cost across all treatments throughout the 63 d experiment.

⁸Feed cost = grain cost + hay cost for each treatment.

⁹Return on supplement cost = value of gain – total feed cost. Prices are in USD.