Tall fescue (Festuca arundinacea) is a cool-season grass widely used as pasture and hay for livestock in the southeastern USA. Fescue toxicosis, a condition that alters beef cattle grazing behavior and reduces growth and reproductive performance in ruminant livestock, has been associated with consumption of ergot alkaloids produced in wild-type endophyte-infected (EI) tall fescue. Most tall fescue in improved USA grasslands is EI, and the economic losses from fescue toxicosis are estimated to exceed $600 million annually in the USA beef industry alone. Endophyte-free (EF) tall fescue is an alternative to EI tall fescue that provides good animal performance, however, endophyte-based plant persistence advantages are sacrificed. Nil ergot alkaloid producing endophyte-infected (AR542, AR502) tall fescue has potential for capitalizing on both good animal performance and enhanced plant persistence. A 3-yr grazing trial conducted with lambs in central Georgia indicated that fescue toxicosis is alleviated by incorporating AR542 and AR502 endophytes into tall fescue pastures. A similar study was conducted for 2-yr with stocker cattle in central Georgia and northwest Georgia. In both the lamb and stocker cattle trials, animal average daily gain was higher in livestock grazing AR542, AR502, and EF pastures over animals grazing EI pastures. Depressed serum prolactin levels and elevated rectal temperatures, indicative of fescue toxicosis, were observed in animals grazing EI tall fescue but not in animals grazing AR542, AR502, and EF tall fescue. A third experiment examined steer grazing behavior on AR542, EF,
and EI tall fescue pastures. Steers grazing AR542 and EF tall fescue spent more time grazing, took more bites, and had higher forage intake than steers grazing EI tall fescue. This helps explain differences in average daily gain. Additionally, steers grazing EI pastures spent more time standing and used more water than cattle on AR542 and EF pastures, possibly in an attempt to cope with heat stress associated with fescue toxicosis. Steer grazing behavior on AR542 and EF pastures favored superior growth performance over cattle grazing EI tall fescue. Nil ergot alkaloid producing endophyte technology provides cattle growth advantages on tall fescue pastures.

INDEX WORDS: Tall fescue, Fescue toxicosis, Nil ergot alkaloid producing endophytes, Grazing behavior, Beef cattle
USE OF NON-TOXIC ENDOPHYTE TECHNOLOGY IN TALL FESCUE FORAGE SYSTEMS: IMPACTS ON BEEF CATTLE PRODUCTION AND GRAZING BEHAVIOR

by

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B.S., Texas A&M University, 1997
M.S., Texas Tech University, 1998

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2001
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December 2001
ACKNOWLEDGMENTS

First and foremost, I would like to thank Dr. Mark McCann for his guidance and support during my graduate program. His advice, both professionally and personally, has been and continues to be very valuable. The contributions of my committee members, Drs. Joe Bouton, Carl Hoveland, Julia McCann, Mark Froetschel, and John McKissick are greatly appreciated. They each provided a unique perspective, and the combination of their efforts resulted in a well-rounded graduate program. I am thankful for the assistance and cooperation of the managers and staff at Eatonton and Calhoun. The early morning data collections at the branch stations were memorable. Richard Watson and Newton Paiva were great companions in the field and in the lab. Their senses of humor were very refreshing. I owe much appreciation to my family and friends in Texas. My parents were my greatest advocates. In particular, I would like to acknowledge the support that I received from Joel, Susan, and Heather. Their friendship has been very encouraging. Finally, I want to recognize my husband, Jimmy Ray Parish. I want him to know that his love, support, and understanding meant more to me than anything else during my time in Georgia. With faith in God and each other, we will have a promising future together.
# TABLE OF CONTENTS

ACKNOWLEDGMENTS.............................................................................................................. iv

CHAPTER

1 LITERATURE REVIEW................................................................. 1
   Introduction.......................................................................................... 1
   Effects of Fescue Toxicosis.............................................................. 6
   Alkaloids as Forage Anti-Quality Components............................... 16
   Management Strategies for Combating Fescue Toxicosis.............. 22
   Research Challenge....................................................................... 30
   Literature Cited................................................................................. 31

2 USE OF NIL ERGOT ALKALOID PRODUCING ENDOPHYTES FOR
   ALLEVIATING TALL FESCUE TOXICOSIS IN SHEEP ............. 46
   Introduction ................................................................................... 49
   Materials and Methods.................................................................. 51
   Results and Discussion................................................................. 54
   Implications ................................................................................... 57
   Literature Cited.............................................................................. 59
3 USE OF NIL ERGOT ALKALOID PRODUCING ENDOPHYTES FOR ALLEVIATING TALL FESCUE TOXICOSIS IN STOCKER CATTLE

Introduction ........................................................................... 73
Materials and Methods.............................................................. 75
Results and Discussion............................................................ 78
Implications ............................................................................. 84
Literature Cited.................................................................... 85

4 STEER GRAZING BEHAVIOR ON NIL ERGOT ALKALOID PRODUCING ENDOPHYTE-INFECTED, ENDOPHYTE-FREE, AND TOXIC ENDOPHYTE-INFECTED JESUP TALL FESCUE

Introduction ........................................................................... 98
Materials and Methods.............................................................. 99
Results and Discussion............................................................ 103
Implications ............................................................................. 108
Literature Cited.................................................................... 109

5 CONCLUSIONS ................................................................... 124
CHAPTER 1
LITERATURE REVIEW

Introduction

Forage-based ruminant livestock production is a significant and integral part of animal agriculture in the southeastern USA. In Georgia alone, there are approximately 800,000 acres of pastureland (U.S. Department of Agriculture, 1997) and 614,000 head of beef cattle valued at $386.8 million (Georgia Agricultural Statistics Service, 2001). Ruminant livestock, such as cattle and sheep, are useful in converting vast renewable resources from pasture into food and other products for human consumption. Land that is too poor or erodible for cultivation can become productive when utilized for ruminant grazing. One of the best ways to improve agricultural sustainability is by enhancing the yields and characteristics of forages used in livestock grazing (Oltjen and Beckett, 1996). The value of forages combined with the economic value of grazing livestock rival values for the most important field crops since ruminants obtain 60 to 100 percent of their feed nutrients from forages (Allen and Segarra, 2001).

Southeastern USA grasslands are primarily used for beef cow-calf production, while stockering weaned beef calves to feeder weight on high-quality pastures is another important enterprise (Hoveland, 2000). There are approximately 24 million hectares of pasture in the southeastern USA, accounting for 75 percent of the total USA humid pastureland (Hoveland, 1992). Tall fescue (*Festuca arundinacea* Schreb.) is a cool-season grass grown on over
14 million hectares in this region and is widely used as pasture or hay for livestock (Browning et al., 1998).

According to Thompson et al. (2001), tall fescue is an attractive forage species because of its ability to withstand drought, poor soil conditions, and intensive defoliation from grazing. Stuedemann and Hoveland (1988) report that ease of establishment, wide range of adaptation, long grazing season, tolerance to poor management, and good seed production are desirable agronomic characteristics associated with tall fescue. Despite attributes that make it a desirable forage crop, tall fescue is associated with fescue toxicosis, a condition that alters ruminant livestock grazing behavior (Seman et al., 1999) and adversely affects livestock growth and reproduction (Stuedemann and Hoveland, 1988). Animal toxicity problems are the result of grazing EI (wild-type endophyte-infected) tall fescue (Hill et al., 1994).

The tall fescue endophyte, *Neotyphodium coenophialum* [Glenn et al., 1996 (formerly *Acremonium coenophialum*)], is a fungus that resides within the tall fescue plant and imparts positive agronomic qualities to the plant. Surveys in states within the tall fescue region have shown that in excess of 90 percent of the tall fescue fields sampled contained high levels of the wild-type endophyte (Lacefield and Henning, 1995). Bacon et al. (1977) were the first to suggest an association between the fungal endophyte and animal toxicity. A four-year replicated grazing study by Hoveland et al. (1983) provided the convincing proof that poor beef cattle weight gains on tall fescue were related to toxins produced by the fungal endophyte.
Ergot alkaloids produced by *N. coenophialum* have been implicated as causative agents in fescue toxicosis (Hill et al., 1994; Stuedemann et al., 1998). Three classes of ergot alkaloids found in tall fescue are lysergic acid, lysergic acid amides, and ergopeptine alkaloids. Other compounds associated with EI tall fescue are the loline alkaloids and peramine (Siegal et al., 1989; Bush et al., 1990).

Ergovaline, an ergopeptine alkaloid, is generally accepted as the toxic component of EI tall fescue, however, no direct evidence supports this hypothesis (Hill et al., 2001). Toxicosis in animals consuming EI tall fescue has been reported to occur at levels of 50 ng of ergovaline/g of grass (Porter, 1995). Hill et al. (2001) observed that the ergot alkaloids with the greatest transport potential across isolated ruminant gastric tissues in vitro were lysergic acid and lysergol. Ergopeptine alkaloids were also transported across gastric tissues but at a level that was minimal compared to lysergic acid and lysergol, indicating that the latter alkaloids may play an important role in the pathogenesis of fescue toxicosis.

**Nil ergot alkaloid producing endophytes**

Hoveland (2000) lists the discovery of the tall fescue fungal endophyte and its effect on livestock and the grass plant as one of the major achievements in the management and utilization of southern USA grasslands. The development and use of stress-tolerant tall fescue with “friendly” nil ergot alkaloid producing endophytes is noted as a future area of emphasis in the improvement of these grasslands. Bush and Burrus (1988) indicated that the potential for
selectively eliminating livestock toxins in EI tall fescue existed since reports from New Zealand claimed that the livestock and insect toxins in EI tall fescue were different. Hill et al. (1991) concluded that reducing ergopeptine alkaloids in EI tall fescue plants resulted in little or no loss of competitive fitness of the plant and recommended selection of tall fescue plants containing little or no ergopeptine alkaloids. Reducing ergovaline concentration in EI tall fescue was postulated to improve animal performance (Agee and Hill, 1994).

Selective elimination of livestock toxins came to fruition in the form of nil ergot alkaloid producing endophytes (AR542 and AR502) discovered by Ag Research in New Zealand. To address the fescue toxicosis problem, these endophytes have been used to infect tall fescue varieties grown in the southeastern USA. These tall fescue varieties include Jesup (Bouton et al., 1997), Georgia-5 (GA-5) (Bouton et al., 1993), and Kentucky-31 (KY-31). Initial research findings indicate that the nil ergot alkaloid producing endophytes provide the benefits of enhanced tall fescue plant persistence without producing clinical signs of fescue toxicosis in livestock (Bouton et al., 2000). Knowledge concerning forage stand persistence is still limited, but the utilization of nil ergot alkaloid producing tall fescue endophytes holds great promise for reducing production losses from fescue toxicosis and enhancing forage-based livestock production. Hoveland (1993) expressed that “modification of the fungal endophyte to remove the harmful properties and maintain those beneficial to the host plant is the ultimate solution” to the fescue toxicosis problem.
MaxQ™ fescue, Jesup and GA-5 tall fescue infected with the AR542 nil ergot alkaloid producing endophyte evaluated in this study, is currently being commercially marketed by Pennington Seed, Inc. (Madison, GA). Therefore, the research findings from this investigation have immediate application in decisions regarding the incorporation of nil ergot alkaloid producing endophytes into tall fescue forage systems in the southeastern USA. The general objective of the present research effort is to evaluate lamb performance and toxicosis as well as beef steer performance, toxicosis, grazing behavior, and production economics on nil ergot alkaloid producing endophyte-infected, EF, and EI tall fescue treatments. Specific objectives of this study are to 1) determine animal performance and assess toxicosis signs in lambs grazing nil ergot alkaloid producing endophyte-infected Jesup and GA-5 tall fescue, Jesup EF tall fescue, and Jesup EI tall fescue pastures in central Georgia; 2) determine stocker steer performance and evaluate toxicosis in beef steers grazing nil ergot alkaloid producing endophyte-infected, EF, and EI Jesup and KY-31 tall fescue in central and northwest Georgia; 3) examine beef steer ingestive behavior, lying/standing activity, and walking activity on nil ergot alkaloid producing endophyte-infected, EF, and EI Jesup tall fescue in central Georgia; 4) assess the effect of nil ergot alkaloid producing, EF, and EI endophyte treatments on tall fescue productivity, quality, and persistence; and 5) determine the level and variability of net returns from nil ergot alkaloid producing, EF, and EI endophyte treatments for steers stockered on tall fescue in central and northwest Georgia if treatments were adopted on a commercial scale. The review of literature presented here
addresses the effects of fescue toxicosis on ruminant livestock production, anti-
quality components in forages, and management strategies for combating fescue
toxicosis and, in doing so, lays the foundation for achieving the objectives
described above.

**Effects of Fescue Toxicosis**

**Ruminant livestock performance impacts**

*Growth.* Fescue toxicosis adversely affects animal performance in the
form of decreased average daily gains (ADG) (Read and Camp, 1986;
McMurphy et al., 1990; Rice et al., 1997), lower gains per hectare (Stuedemann
et al., 1987), and reduced calf weaning weights (Gay et al., 1988; Peters et al.,
1992). Steer weight gains may be improved by 30 to over 100 percent on EF tall
fescue versus EI tall fescue (Hoveland, 1993). Shelby and Dalrymple (1987)
indicate that the average USA cattle producer utilizing EI tall fescue for grazing
loses 0.63 kg in ADG to fescue toxicity. Much of the ADG depression on EI tall
fescue may be due to lower forage intake. Depressed dry matter intake (DMI) in
beef steers is a consequence of grazing toxic tall fescue and may be
exacerbated during periods of elevated environmental temperatures (Hemken et
al., 1981; Osborn et al., 1992). Stuedemann et al. (1989) found that DMI
decreased from 6.6 kg/d to 4.2 kg/d in steers on EI pasture compared to EF
pasture. Similarly, Osborn et al. (1992) observed that DMI in steers consuming
EI or EF tall fescue seed was 6.0 kg/d and 3.2 kg/d, respectively. Lower DMI on
EI tall fescue versus EF tall fescue has also been seen in cows (Peters et al.,
1992) and lambs (Aldrich et al., 1993b).
Reduced calf weaning weights on EI tall fescue may be a result of lower milk consumption or lower forage intake or both. Milk production in beef cows has been found to be lowered by grazing EI tall fescue as compared to EF tall fescue (Schmidt et al., 1983; Peters et al., 1992). A 0.15 kg reduction in milk production for every 10 percent increase in tall fescue endophyte-infection level was calculated by Danilson et al. (1986). Lactation in cows grazing EI tall fescue may be decreased by either reduced DMI or inhibitory effects on prolactin (PRL) secretion prior to parturition (Porter and Thompson, 1992). In calves on EI tall fescue pastures milk consumption was reported to be 6.0 kg/d compared to 7.7 kg/d on EF tall fescue (Peters et al., 1992). Significant differences in ADG and adjusted 205-d weaning weights were seen in these calves with the calves in the EF pastures performing better than their peers in the EI pastures.

Part of the reduction in calf weaning weights on EI tall fescue may carry through to slaughter (Brown et al., 1999). Effects of grazing EI versus EF tall fescue during stockering on feedlot performance are not clear though. Several studies indicate that beef steers that grazed EI tall fescue exhibited compensatory gains in the feedlot (Cole et al., 1987; McDonald et al., 1988; Lusby et al., 1990). However, others have found that compensatory growth did not exist for steers entering the finishing phase from EI tall fescue pastures (Hancock et al., 1987; Duckett et al., 2001). Ambient temperature, relative humidity, and time of year when cattle were placed in the feedlot may have influenced feedlot cattle performance and may account for the inconsistency of these findings. Coffey et al. (1992b) and Beconi et al. (1995) suggest that the
length of time required to recover from the effects of grazing EI tall fescue is difficult to predict.

Reproduction. Lower pregnancy rates and decreased calving rates have been observed in cows and heifers grazing EI versus EF tall fescue (Gay et al., 1988; Tucker et al., 1989; Peters et al., 1992; Porter and Thompson, 1992). Peters et al. (1992) observed a 91 percent pregnancy rate in cows grazing EF tall fescue pasture and a 72 percent pregnancy rate in cows grazing EI tall fescue pasture. Porter and Thompson (1992) indicated that pregnancy rate reductions due to EI tall fescue consumption may be as great as 60 percent. Cows grazing EI tall fescue also underwent greater body weight loss after calving than cows grazing EF tall fescue. Bolt and Bond (1985) did not find a delay in initiation of cycling activity in heifers grazing EI tall fescue as compared with those grazing EF tall fescue. According to Burke et al. (2001), consumption of EI tall fescue seed resulted in fewer large follicles during the estrous cycle in beef heifers and reduced serum estradiol. Impaired follicular function may play a role in reduction of pregnancy rates in heifers grazing EI tall fescue.

Ergot alkaloids associated with EI tall fescue can affect plasma concentrations of hormones that regulate ruminant reproductive functions (Browning et al., 1997). Plasma concentrations of reproductive hormones are altered during the late luteal phase of the estrous cycle in cows consuming EI tall fescue (Browning et al., 1998). Reduced circulating progesterone levels were seen in heifers on EI tall fescue (Estienne et al., 1990). Ergot alkaloids have been shown to decrease levels of PRL and luteinizing hormone (Browning et al.,
1997) and increased prostaglandin F$_{2\alpha}$ in cattle (Browning et al., 1998).

Depressed PRL levels (Hoveland et al., 1983; Fribourg et al., 1991; Rice et al., 1997) are often used as an indicator of fescue toxicosis. Inhibition of PRL release is regulated by the D$_2$ dopamine receptor to which ergot alkaloids bind (Larson et al., 1999). PRL is involved in corpus luteum function and gonadotropin secretion (Porter and Thompson, 1992). Studies indicate that effects of EI tall fescue consumption on the corpus luteum may limit the ability of an animal to maintain pregnancy (Ahmed et al., 1990; Estienne et al., 1990).

**Body temperature regulation.** Physiological responses of fescue toxicosis include elevated rectal temperature (Hoveland et al., 1983; Fribourg et al., 1991; Rice et al., 1997), decreased blood flow to the skin (Solomon et al., 1989), impaired evaporative cooling (Aldrich et al., 1993b), and increased respiration rate (Jackson et al., 1988). A marked increase in core body temperature in cattle, especially at nighttime, resulted from EI tall fescue consumption during continuous heat challenge (Al-Haidary et al., 2001). This is thought to be due mainly to a reduction in cutaneous heat transfer rather than an effect on heat production. Watson et al. (2001) observed increased body temperatures in cattle suffering from fescue toxicosis during periods of high ambient temperatures (>23°C) as well as depressed body temperatures during periods of low ambient temperatures (<12°C). McMurphy et al. (1988) found elevated rectal temperatures only during May in steers grazing high EI tall fescue (83 percent endophyte-infected) versus low EI tall fescue (0 to 6 percent endophyte-infected) from November 1986 to May 1987. Some studies in beef cattle have not shown
increased rectal temperatures on EI tall fescue over EF tall fescue (Aldrich et al., 1993a; Emile et al., 2000). In sheep consuming EF or EI tall fescue seed and hay, elevated core body temperature was observed on the EI diet, but there were mixed results for the effects of endophyte presence on rectal and skin temperatures between two experiments (Aldrich et al., 1993b). Contrasting results for tall fescue endophyte effects on rectal temperatures may be explained by variations in factors such as animal handling and stress, exposure to sunlight, and ambient temperature that influence rectal temperature measurements.

Evidence supporting the idea that smooth muscle cell hyperplasia within the blood vessel wall is a vascular complication of fescue toxicosis was presented by Strickland et al. (1996). Pathogenesis of fescue toxicosis may originate from damage to vascular epithelium (Thompson et al., 2001). Hyperplasia of vascular smooth muscle can result in decreased luminal diameter and subsequent blood flow reductions (Strickland et al., 1996). Alkaloids produced in EI tall fescue, i.e., lysergic acid amide, ergonovine, and ergotamine, have been shown to have vasoconstrictive effects on bovine vasculature (Oliver et al., 1993). Reduced blood flow could result in tissue death and loss of ability to dissipate heat. This would explain the thermoregulatory challenge evident in animals grazing EI tall fescue.

Affected livestock exhibit clinical signs including excessive salivation, rough hair coats (Stuedemann and Hoveland, 1988), and increased respiration rates (Osborn et al., 1992). Excessive salivation could enhance water intake needs of grazing animals, however, inconsistent findings have been reported for
the effects of tall fescue endophyte status on water intake. Water intake was reported to be higher in sheep on EI tall fescue diets than EF contemporaries and similar in a separate experiment (Aldrich et al., 1993b), but a study conducted in beef cattle concluded that EI tall fescue ingestion did not influence water intake (Aldrich et al., 1993a). Peters et al. (1992) noted that hair coat scores were lower (rougther, shaggier hair coats) and respiration rate was greater during August but not during June in beef cows grazing EI tall fescue as compared to cows grazing EF tall fescue. Respiration rate was found to be similar in lambs consuming EF or EI tall fescue (Aldrich et al., 1993b). Increased respiration rates may be an attempt to dissipate more heat during conditions of heat stress.

**Immunosuppression.** Saker et al. (1998) indicated that EI tall fescue consumption compromises the immune function of grazing steers. Steers grazing EI tall fescue exhibited lower phagocytic activity, major histocompatibility complex class II expression, and ceruloplasmin than steers grazing EF tall fescue. Loss in immune function is long-lasting and exists beyond removal of livestock from EI pastures and into the finishing phase of production (Allen et al., 2001; Saker et al., 2001). Rice et al. (1997) indicated that increased incidence of bovine respiratory disease in cattle grazing EI tall fescue was not associated with a lack of humoral immune response to vaccinations as a result of fescue toxicosis.

**Blood constituents.** Fescue toxicosis also impacts blood constituents. Levels of amylase (Thompson et al., 2001) and erythrocytes (Oliver et al., 2000)
in the blood of grazing livestock may be increased by the toxic condition. Sera or plasma constituents reduced by EI tall fescue consumption include alkaline phosphatase, aspartate aminotransferase, cholesterol, creatine kinase, insulin-like growth factor, lactate dehydrogenase, and melatonin (Thompson et al., 2001).

**Economic impacts**

Fescue toxicosis impacts beef cattle performance and production profitability throughout the production cycle. Conditions like fescue toxicosis that impair reproductive performance in cattle will significantly impact cow-calf operation profitability. Herd reproductive efficiency is of the utmost economic importance to cow-calf producers (Browning et al., 1998). Additionally, negative effects of fescue toxicosis on calf weaning weights will lower net returns in cow-calf enterprises. The combination of fewer calves and lower calf weaning weights results in less pounds of product sold from cow-calf operations and has associated repercussions on profitability. During stockering the effects of fescue toxicosis on growth rates can be a major obstacle for efficient and profitable production. Then when steers are shipped west to feedlots from the southeastern USA, they are exposed to added stress from shipping and adjustment from a forage-based diet to a concentrate-based diet. Under these conditions, the lower stress tolerance threshold of EI tall fescue grown stockers can compromise animal health and performance and place these animals at a disadvantage at the start of the finishing phase. Added costs of medications and labor in treating animals less tolerant to stress and disease as a result of lower
immune function associated with fescue toxicosis may be incurred (Purdy et al., 1989). In addition, steers entering feedlots at lower weights can take more days on feed to reach market weights. Producers who retain ownership of their cattle in the feedlot incur increased input (feed) costs. Stockering profitability can also be affected via price discounts for “fescue cattle” sold to feedlots due to unthrifty appearances and concern about carryover effects (Burton et al., 1994; Paterson et al., 1995).

The economic impacts of forage anti-quality factors on individual herds may be devastating yet definable (Allen and Segarra, 2001). Cost of pasture establishment will vary from region to region (VanTassell et al., 1991). Negative effects on profits when renovating pastures include pasture reestablishment costs as well as costs related to lost grazing (Harwell, 1991). Pasture production may be reduced by 40 percent in the first year of establishment. Profitability of pasture conversion varies with planning horizon, interest rates, cattle prices, input prices, EI tall fescue endophyte infection rates, cattle productivity differences, stocking rate, and stocking duration.

Pasture cost per pound of gain in stocker steers has been estimated to be 2 to 27 cents lower when white clover was present with EI tall fescue as compared to that of EI tall fescue alone (Ball and Crews, 1998). Interseeding clover with EI tall fescue resulted in pasture cost per pound of gain of 10 to 25 cents lower than EF tall fescue (Crews and Ball, 1991). Mean returns over total costs were -$54.05/acre for EI tall fescue, $58.22/acre for EF tall fescue, $155.28/acre for EI tall fescue with ladino clover, and $57.24/acre for EI tall
fescue with birdsfoot trefoil. Assuming that EI tall fescue interseeding with clover gives cow-calf gains and condition equal to EF tall fescue (0.1 lbs/day improvement in 205 day calf weights and 0.3 lbs/day increase in cow weights during nursing) net returns were estimated by Harwell (1991) at $164.73/acre. Burton et al. (1994) estimated returns above costs for steers grazing EI tall fescue, EI tall fescue interseeded with ladino clover, and EF tall fescue pastures at -$41.42/acre, $21.69/acre, and -$8.76/acre, respectively. Although steers stockered on EI tall fescue were most profitable in the feedlot phase, due to compensatory gains and lower purchase costs per head for smaller steers, EI tall fescue interseeded with ladino clover was most profitable in a production program that included both grazing and feedlot phases. Retaining ownership through the feedlot phase was more profitable than selling after grazing for steers stockered on EI tall fescue, EI tall fescue interseeded with ladino clover, and EF tall fescue.

Renovation of EI tall fescue pastures with EF tall fescue may be profitable under certain conditions, but establishment and maintenance of EF tall fescue requires a higher level of management than EI tall fescue (Ball et al., 1996). A net benefit of $213.86/acre was estimated for renovating EI tall fescue pastures to EF tall fescue for cow-calf production. This assumes a seven year planning horizon, a 10 percent interest rate, a 60 percent level of endophyte infection, 0.1 lbs/day improvement in 205 day calf weights, 0.3 lbs/day increase in cow weights during nursing, and calf crop improvement of 15 percentage points. An estimated net effect on stocker production profits from renovation to EF tall
fescue was $71.66/acre assuming increased ADG of 0.1 lbs/day and reduction in supplementation expense by half.

Ball and Crews (1998) indicated that the pasture cost per pound of gain for stocker steers in Alabama was inversely proportional to the level of endophyte infection. The cost per pound of gain ranged from 22 to 26 cents for low EF tall fescue, while it ranged from 26 to 37 cents on EI tall fescue. In an earlier study Crews and Ball (1991) reported that pasture cost per pound of gain ranged from 22 to 27 cents for EF tall fescue and 27 to 43 cents for EI tall fescue. Standaert (1987) determined that a positive internal rate of return could be realized from renovating EI tall fescue pastures to EF tall fescue when endophyte infection levels in EI pastures were 20 to 30 percent and above. Endophyte infection levels of at least 11 percent and 28 percent assuming 10-year and four-year planning horizons, respectively, were required for profitable conversion of existing EI tall fescue pastures to EF tall fescue for stocker operations according to VanTassell et al. (1991). Higher cattle prices and discount rate reduction each made EF tall fescue establishment more profitable. Positive net present value could be obtained by reestablishing EI tall fescue pastures as EF pastures assuming that a 30 percent or better improvement in animal gains would result from switching to EF tall fescue (Jacobs, 1983).

It is far more difficult to estimate broadscale economic consequences of forage anti-quality attributes (Allen and Segarra, 2001). In terms of economic loss to livestock producers, tall fescue toxicosis remains the most important grass-related disease in the USA (Oliver et al., 2000). The estimated annual
monetary losses of $609 million in the USA beef industry in 1993 associated with fescue toxicosis illustrate the significant economic impact that fescue toxicosis has on animal agriculture (Hoveland, 1993). Reduced calf numbers accounted for $354 million of this estimate, while reduced weaning weights accounted for the remaining $255 million. Allen and Segarra (2001) indicate that economic losses from fescue toxicosis in the USA beef industry are underestimated at $600 million annually. In addition to impacting beef production, fescue toxicosis has negative economic consequences for other grazing livestock industries including sheep and horse production (Thompson et al., 2001). The potential payoff is extremely high if even a small proportion of the expected losses from fescue toxicosis are eliminated via research (Allen and Segarra, 2001).

**Alkaloids as Forage Anti-Quality Components**

**Forage quality and anti-quality**

In realizing optimum livestock performance on pasture, forage quality is paramount (Allen and Segarra, 2001). Forage quality is defined as “the degree to which a forage meets the nutritional requirements of a specific kind and class of animal.” Palatability, rate of passage, digestibility, nutrient density and balance, and intake determine the degree to which a forage meets the nutritional demands of an animal. Thus, forage quality is driven by the chemical and physical attributes that influence forage nutritive value and intake (Mott and Moore, 1969). In most southeastern USA livestock operations, the primary factor limiting production is nutrition (Crews and Ball, 1991).
Forage nutritional quality is affected most by plant maturity (Buxton and Fales, 1994). Differences in plant maturity in tall fescue pastures may be related to endophyte-based effects on forage intake by grazing livestock. If cattle on EI tall fescue consume less forage than contemporaries on EF tall fescue, then available forage in the EI pastures may be more mature than that in the EF pastures at a given stocking rate. Stocking rate may be increased on EI pastures over EF pastures if this is the case. In tall fescue, endophyte presence does not appear to change forage quality parameters such as in vitro dry matter disappearance, crude protein, neutral detergent fiber, or acid detergent fiber (Bush and Burrus, 1988). Forage quality in terms of nutritional parameters, therefore, does not explain differences in ADG among cattle grazing different fescue endophyte treatments.

Alkaloids produced in EI tall fescue can be considered forage anti-quality components or factors. Problems associated with endophyte-infected grasses are probably the oldest known forage anti-quality factors in human history (Bacon, 1995). Anti-quality components are factors that diminish the degree to which a forage meets the nutritional requirements of a specific kind and class of animal (Allen and Segarra, 2001). Anti-quality components may have evolved as plant structural components or as secondary metabolites involved in plant defense mechanisms. Forage anti-quality components may function as an indirect toxin, reduce DMI, lower dry matter digestibility, result in nutritional imbalances, or act directly as a toxin to the animal.
The characteristics of other plants available to the grazing animal and animal selectivity determine the influence of a given forage anti-quality trait (Laca et al., 2001). If an animal selects an alternative forage over a forage with a given anti-quality characteristic, then the influence of that anti-quality characteristic on the diet quality of the grazing animal will be lessened. This selective dilution of a forage anti-quality factor is possible in a mixed species pasture as opposed to a forage monoculture. Season affects each forage differently in a mixed sward, e.g., bermudagrass (*Cynodon dactylon*) grown with tall fescue. Bermudagrass forage availability peaks during summer months, while tall fescue forage availability is higher during spring and autumn months. Bermudagrass may be more competitive than tall fescue during summer, while tall fescue may shade out bermudagrass during spring and autumn. Thus, there may be a greater opportunity for animal selectivity away from toxic alkaloids in EI tall fescue in a tall fescue/bermudagrass sward during the summer months when relative forage availability and competitiveness of bermudagrass versus fescue is highest. Seasonal differences in alkaloid concentration in EI tall fescue may also contribute to differences in the effects of the alkaloids on the grazing animal (Rottinghaus et al., 1991). In addition to seasonal variations, forage anti-quality characteristic effects may vary with other factors that impact forage productivity and composition, such as temperature and soil moisture.

**Anti-quality effects on grazing behavior**

Animal behavior and adaptation are important aspects of anti-quality factors. Plant toxins can alter both ingestive and reproductive behavior in
grazing animals (Pfister et al., 1992). Grazing livestock possess adaptive mechanisms to reduce the impacts of anti-quality factors in forages (Launchbaugh et al., 2001). Herbivores may limit consumption of potentially harmful plant compounds by grazing selectively. Livestock select parts of the plant of relatively low toxin concentration when possible, but they must be able to distinguish between the different toxin concentrations (Pfister, 1999).

It is unclear whether endophyte infection affects the palatability of tall fescue and whether animals can distinguish between EF and EI tall fescue (Latch, 1993). Wahab (1986) observed no differences in the ingestive behavior of tethered steers grazing EI KY-31 tall fescue or EF Johnstone tall fescue. The use of two different cultivars for comparison makes this finding inconclusive since tall fescue cultivars may differ in palatability (Bush and Burrus, 1988; Shewmaker et al., 1997). Eleven of twelve heifers offered diets containing 60 percent EI or EF tall fescue seed avoided diets with EI seed (Garner and Cornell, 1987). In another study, steers appeared to prefer clover over EI tall fescue in EI tall fescue/clover pastures and EF tall fescue over clover in EF tall fescue/clover pastures (Fribourg et al., 1991).

Palatability trials in cattle, sheep, and goats grazing in tall fescue have focused on different EF cultivars. In cattle, differences in palatability of EF tall fescue cultivars are related to total non-structural carbohydrate (Mayland et al., 2000b) and volatile compound concentrations (Mayland et al., 1997) and are unrelated to malate, citrate, or amino acid concentrations (Mayland et al., 2000a). Burns et al. (2001) reported that preference among EF tall fescue cultivars by
sheep and goats was similar to that expressed by cattle and was based, in part, on subtle differences in soluble carbohydrate and fiber fractions. The impacts of alkaloid presence on animal preference for tall fescue are uncertain. In order to clarify the effects of endophyte status of tall fescue on palatability and animal selectivity, palatability trials need to be conducted comparing EI and EF pastures within cultivars.

Reduced DMI on EI tall fescue compared EF tall fescue may be due to the effect of the toxins on animal health that decreases desire to graze rather than animal preference for EF tall fescue (Latch, 1993). Grazing livestock may avoid or lessen toxicoses by limiting their consumption of a specific toxic forage each day to allow sufficient detoxification time (Foley et al., 1995). They might also alter daily toxic plant consumption to limit potential cumulative toxin effects (Pfister et al., 1988).

Research shows that ruminants grazing EI tall fescue pastures alter grazing behavior in response to consumption of forage anti-quality factors, i.e., alkaloids. Howard et al. (1992) report that steers on low EI (< 1 percent infection) tall fescue spent more time lying down during daytime than steers on high EI (> 60 percent infection) tall fescue. The longer time spent standing by steers grazing high EI tall fescue in conjunction with more time idling and less time grazing may signify a behavioral response to the stress of fescue toxicosis. The longer standing duration may represent an effort to assume a posture that maximizes evaporative cooling during heat stress (Low et al., 1981).
Cattle grazing EI tall fescue spent more time under shade than those grazing EF tall fescue (Hoveland et al., 1983) and spent less time grazing during daylight hours (Coffey et al. 1992a). Semen et al. (1990) indicated that the increased time standing in shaded areas by cattle grazing EI tall fescue over cattle grazing EF tall fescue occurred during the heat of the day. This reduction in daylight grazing time was not, however, compensated by increased nighttime grazing. Coffey et al. (1992a) observed that grazing time for cattle grazing EI tall fescue was negatively correlated with temperature and solar radiation. Paterson et al. (1995) indicated that in the absence of temperature stress, < 32°C, cows consumed similar amounts of EI and EF tall fescue. However, when environmental temperature exceeded 32°C, cows grazing EI tall fescue consumed less forage than cows grazing EF tall fescue. This may be a behavioral adaptation to cope with heat intolerance associated with fescue toxicosis during periods of elevated ambient temperature.

Semen et al. (1990) report that cattle grazing EF tall fescue not only grazed longer but were more mobile in their grazing activities than their EI counterparts. This may indicate a higher level of comfort for cattle consuming EF tall fescue (Coffey et al., 1992a). Cattle took more prehensile bites to harvest forage on low EI tall fescue than on high EI tall fescue (Howard et al., 1992). This higher number of prehensions may be related to longer grazing time. Bite size and biting rate did not differ between steers grazing high EI tall fescue and those grazing low EI tall fescue. Stuedemann et al. (1985) observed a residual effect on grazing behavior in steers moved from grazing EI KY-31 tall fescue (>
95 percent infected) to grazing EI KY-31 tall fescue (< 1 percent infected) when compared with control steers that remained on either the high or low EI tall fescue treatments for the duration of the study. Developing grazing plans to minimize the impacts of tall fescue anti-quality factors necessitates an understanding of livestock grazing behavior in response to various endophyte situations.

Management Strategies for Combating Fescue Toxicosis

Management approaches to assist animals in dealing with forage anti-quality components include modifications to the plant community, grazing strategy, or the grazing animal (Launchbaugh et al., 2001). Modifications to the plant community to address the fescue toxicosis problem may involve dilution of EI tall fescue pastures with other forages, renovation of EI pastures with EF or nil ergot alkaloid producing endophyte-infected tall fescue, or changes to fertilization or mowing practices. Grazing strategy modifications include rotational grazing, moving animals to alternative forages, and changes in stocking rates. Modifications in managing the grazing animal include offering proper early life experiences, selecting appropriate livestock species and individuals for forage conditions, breeding animals with desirable attributes, and using nutritional or pharmacological intervention to assist dilution, detoxification, or blocking of toxic effects. Nutritional approaches for addressing tall fescue toxicosis include energy supplementation, protein supplementation, and ammoniation of hay. Pharmacological approaches for alleviating tall fescue toxicosis include dopamine receptor antagonists and immunization. Altering the plant community
or grazing strategy are the most commonly applied techniques for coping with forage anti-quality factors.

**Plant community modifications**

*Dilution of pastures with other forages.* Clovers (Ellis et al., 1983; McMurphy et al., 1990; Thompson et al., 1993), bermudagrass (Chestnut et al., 1991), crabgrass, cool-season annual grasses, and other forages can be used to dilute EI tall fescue pastures and reduce the toxicosis condition. In a survey of county extension agents in Kentucky and Alabama, growing legumes with EI tall fescue was reported to be the most frequent approach livestock producers use to combat fescue toxicosis (Lacefield et al., 1993). Lomas et al. (1999) suggested that interseeding ladino clover (*Trifolium repens*) into existing EI tall fescue pastures to reduce the adverse effects of fescue toxicosis on animal performance is preferable to interseeding with lespedeza (*Lespedeza stipulacea*) or red clover (*Trifolium pratense*). Overall steer grazing and finishing gains were higher on EI tall fescue pastures interseeded with ladino clover than EI pastures interseeded with lespedeza or red clover. Introducing ladino (white) clover into EI tall fescue pastures has been shown to improve calf weight gains, raise beef cow conception rates (Gay et al., 1988), increase forage yield and quality, and reduce N fertilization requirements of the grass (Danso et al., 1991). Henning et al. (1993) reported that a tall fescue-ladino clover mixture will furnish higher quality feed than tall fescue alone and will produce as much forage as tall fescue alone fertilized with 80 lbs. N per acre. Thompson et al. (2001) pointed out that when diluting with clovers, the potential for utilizing clover varies greatly among
geographical regions. In addition, clovers are susceptible to viruses and drought stress. Including bermudagrass in EI tall fescue pastures was shown to result in greater forage dry matter production which supported more steer grazing days and beef production per hectare (Chestnut et al., 1991). Crabgrass, ryegrass, and other endogenous grasses and weeds may volunteer in EI tall fescue pastures and dilute the toxic effects on grazing livestock.

_Endophyte-free tall fescue._ Plant breeders have successfully selected tall fescue plants that are EF and non-toxic to livestock, however, plant persistence is lower in these EF plants than in EI tall fescue (Hill et al., 1991). Thus, animal toxicity problems are avoided with the use of EF tall fescue at the expense of plant persistence. When compared with endophyte-free (EF) tall fescue, EI tall fescue has agronomic advantages in drought tolerance, disease resistance, enhanced plant growth, and resistance to herbivory by insects and livestock (Clay, 1988). For example, drought-induced leaf rolling, leaf senescence, osmotic adjustment, and stomatal closure are more common in EI than in EF tall fescue plants (Joost, 1995). During drought stress, EF tall fescue is more susceptible to stand loss than EI tall fescue (West et al., 1993; Joost, 1995).

Because EI tall fescue is more competitive than EF tall fescue, pastures established as EF may increase in endophyte-infection level over time (Shelby and Dalrymple, 1993). A rapid shift toward higher endophyte-infection percentages could occur in only a few plant generations (Rice et al., 1990). To reduce the risk of EF tall fescue stand loss, grazing must be delayed on newly established pastures to ensure adequate herbage and root development, and
thereafter grazing pressure needs to be closely monitored to avoid overgrazing (Joost, 1995). Moderate and high grazing pressures may increase the endophyte-infection levels of tall fescue pastures (Gwinn et al., 1998). Stand losses of EF tall fescue are greatest in the southern part of the USA tall fescue belt where environmental stresses are greatest (Hoveland, 1993).

The dissemination of the tall fescue endophyte is by seed as opposed to rain, wind, mowing, or pollen dissemination for other fungi. Additionally, viable seed containing live endophytes have been recovered from the feces of both cattle and horses grazing EI tall fescue, indicating that livestock may be a source of endophyte infection when moved to endophyte-free (EF) tall fescue pastures without a quarantine period (Shelby and Schmidt, 1991). Therefore, for establishment of EF tall fescue, removing or destroying EI seed is critical to prevent contamination of stands. Furthermore, managing EF tall fescue pastures after establishment to prevent contamination with EI seed involves animal cleanout periods before moving livestock from EI tall fescue pastures onto EF pastures.

Nil ergot alkaloid producing endophytes. Several studies have demonstrated the potential of nil ergot alkaloid producing endophytes for alleviating endophyte-induced toxicosis in grazing livestock. An ergovaline-free endophyte (AR501) was inserted into EF KY-31 tall fescue and evaluated against EI and EF KY-31 tall fescue in a grazing trial in New Zealand with lambs (Fletcher et al., 2000). ADG and serum PRL levels in lambs on AR501-infected and EF tall fescue were similar and significantly higher in summer and autumn
than ADG in lambs on EI tall fescue. Rectal temperatures and respiration rates were lower in lambs grazing AR501-infected and EF tall fescue compared to EI tall fescue. In Arkansas and Missouri, several strains of tall fescue endophytes which did not produce ergot alkaloids were isolated and inserted into an EF variety, HiMag tall fescue (Nihsen et al., 2000). In steers, ADG and serum PRL levels were significantly lower when grazing EI HiMag tall fescue versus nil ergot alkaloid producing endophyte-infected and EF HiMag tall fescue. Mean rectal temperature, mean respiration rate, and mean hair score were all significantly higher in EI HiMag tall fescue as compared with nil ergot alkaloid producing endophyte-infected and EF HiMag tall fescue in this trial.

*Other plant community modifications.* Additional plant community modification management techniques to control fescue toxicosis in cattle include maintaining tall fescue in the vegetative state to prevent seedhead ingestion and reducing late spring nitrogen fertilization rates (Joost, 1995). *N. coenophialum* is found in individual tall fescue plants in leaf sheaths, seeds, crowns, stems, leaf blades, and roots in decreasing order of concentration (Siegal et al., 1984). High concentrations of endophyte have been observed in leaf sheaths and seeds, while very low concentrations have been seen in leaf blades and roots. Ergot alkaloid consumption may be reduced by clipping seed heads and lowering ergot alkaloid levels available to grazing livestock. Late spring nitrogen fertilization was shown to increase ergot alkaloid levels in tall fescue, so reducing nitrogen fertilization rates may reduce ergot alkaloid consumption by livestock (Lyons et al., 1986). A study by Stuedemann et al. (1986) indicated that the role of
nitrogen fertilization in fescue toxicosis was uncertain, however. These techniques will not eliminate ergot alkaloid consumption and thus have limited value for improving animal performance on EI tall fescue.

**Grazing strategy modifications**

Moving cattle to warm-season grasses during mid-summer may be a viable alternative for combating fescue toxicosis (Joost, 1995). Forcherio et al. (1992) found that moving steers from EI tall fescue to warm-season grasses, i.e., Caucasian bluestem (*Bothriocloa caucasica*) or sorghum-sudan (*Sorghum sp.*), improved ADG over steers remaining on EI tall fescue and provided weight gains similar to steers grazing EF tall fescue. Aiken and Piper (1999) found that weight gains of feeder steers grazing EI tall fescue improved if the steers were moved to eastern gamagrass (*Tripsacum dactyloides*) in late spring and summer.

Utilization of warm season grasses to reduce the adverse effects fescue toxicosis allows producers to extend the time that cattle can remain on pasture for additional backgrounding for the feedlot or to wait for favorable market conditions.

Mixed results have been reported for the effects of stocking rate changes on animal performance on EI tall fescue. Increasing stocking rates on EI pastures may improve animal performance and production (Bransby et al., 1988). This may be related to the reduction in overall alkaloid production with repeated defoliation (Belesky and Hill, 1997). Higher steer growth performance has been obtained with moderate to heavy stocking rates on EI tall fescue plus a broiler litter:corn supplement, while lighter stocking rates improved growth performance
when steers on EI tall fescue were moved to eastern gamagrass in late spring (Aiken and Piper, 1999). On the other hand, moderate and high grazing pressures have been reported to increase tall fescue pasture endophyte-infection levels (Gwinn et al., 1998). Rotational stocking did not improve animal performance over continuous stocking in EI tall fescue/clover pastures (Chestnut et al., 1992).

**Grazing animal modifications**

*Diet-based approaches.* Nutritional supplementation may diminish the negative effects of fescue toxicosis on grazing livestock by diluting alkaloids in the diet. However, some cattle may be too sensitive to alkaloids for dilution of alkaloids to eliminate fescue toxicosis completely (Aiken and Piper, 1999). Energy supplementation with concentrated feedstuffs has potential to lessen the toxic effects in cattle (Tucker et al., 1989). Goetsch (1989) reported a twofold increase in ADG for calves on EI tall fescue when ground corn was fed at 0.75 percent body weight. Mixed results on the usefulness of protein supplementation for alleviation of toxicosis have been reported (Forcherio et al., 1995; Aiken et al., 2001). Combined energy and protein supplementation has produced positive effects on growth performance of cattle grazing EI pastures (Elizalde et al., 1998). Aiken and Piper (1999) reported that weight gains of feeder steers grazing EI tall fescue were improved by daily feeding of a 1:1 broiler litter:corn supplement in an as fed quantity of at least 0.8 percent of body weight, but signs of fescue toxicosis were still evident. Steer ADG improved in animals grazing EI tall fescue when supplemented with 0.9 kg/d of an 85:15 corn:soybean mixture.
Cost effectiveness of supplementation depends, at least in part, upon the cost of supplements.

Ammoniation of hay may improve steer performance on EI tall fescue (Kerr et al., 1990). Ammonia acts as an antifungal agent reducing alkaloid content of EI tall fescue. Simeone et al. (1998b) reported that ammoniation of EI tall fescue seed reduced total pyrrolizidine alkaloid and ergovaline content by 24 and 54 percent, respectively. Feed intake, weight gain, and feed efficiency of rats fed ammoniated EI tall fescue seed were 24, 41, and 13 percent higher, respectively, over the same performance parameters in rats feed EI tall fescue seed. However, ammoniation did not alleviate endophyte-induced immune function depression in rats feed EI tall fescue seed (Simeone et al., 1998a). Higher prolactin levels and lower rectal temperatures were observed in beef cattle fed ammoniated EI tall fescue hay over cattle fed EI tall fescue hay without ammoniation (Kerr et al., 1990). Increased intake of steers on ammoniated tall fescue hay may be the result of increased rate and extent of fiber digestion (Chestnut et al., 1987) because ammoniation will decrease the inhibitory effect of lignin on fiber digestion. Thiabendazole, another antifungal agent, did not improve prolactin concentrations and rectal temperatures in steers fed EI tall fescue hay (Kerr et al., 1990).

**Dopamine antagonist approaches.** Metoclopramide, a dopamine receptor antagonist, increased ADG, grazing time, and serum PRL levels when supplemented to steers consuming EI tall fescue (Lipham et al., 1989) and increased DMI when supplemented to sheep consuming EI tall fescue (Aldrich et
al., 1993b). Injections of Ro 24-0409, another dopamine antagonist, were shown to decrease rectal temperatures and increase serum PRL levels in steers fed EI tall fescue (Samford-Grigsby et al., 1997). Oliver et al. (1998) suggested that for drug therapy to be successful in reversing the negative effects of fescue toxicosis in cattle, the effects of EI tall fescue exposure on the $\alpha_2$-adrenergic tissue receptors must be neutralized. Immunization against fescue toxicity in cattle may be an option in the future, but there are currently no such vaccines commercially available (Hill et al., 1994; Filipov et al., 1998; Thompson et al., 2001). For immunization to be practical in beef cattle operations, vaccines would need to have long-lasting effects. Daily injections, e.g., would be precluded by labor and animal handling requirements in most cattle grazing systems. Horse owners have a viable pharmaceutical treatment option, domperidone, a dopamine antagonist effective in treatment of fescue toxicosis in horses when fed daily (Redmond et al., 1994; Cross et al., 1995).

**Research Challenge**

In order to develop more sustainable tall fescue forage systems for grazing livestock, relationships among the animal, plant, and endophyte must be optimized. Forage managers must consider the effects of endophytes on both tall fescue stands and the livestock grazing these forage stands. Toxic EI tall fescue is a highly persistent pasture but is associated with poor animal performance. Although EF tall fescue provides improved animal performance, it has been rejected by most livestock producers because of poor seedling vigor and stand survival. Tall fescue containing nil ergot alkaloid producing endophyte
provides both excellent animal performance and long pasture stand life, offering a new opportunity to livestock producers.

Profitable conversion of EI pastures to nil ergot alkaloid producing endophyte-infected pastures requires greater returns and reduced costs from increased animal reproductive and growth performance to exceed the costs of pasture renovation and lost returns from pasture idle time. The implications of alleviating tall fescue toxicosis with nil ergot alkaloid producing endophytes include improved animal health and performance, reduced feed costs, improved profitability, and more viable livestock production enterprises, all of which serve to improve the sustainability of forage-based livestock production.

Interdisciplinary research comparing livestock and plant performance, grazing behavior, and production economics of grazing nil ergot alkaloid producing endophyte-infected, EI, and EF tall fescue pastures is needed to clarify the potential for incorporating nil ergot alkaloid producing endophytes into tall fescue forage systems used for ruminant livestock production in the southeastern USA. Livestock performance and toxicity data as well as forage performance, quality, and persistence data are required for biological and economic evaluations of different tall fescue endophyte treatments. In addition, animal grazing behavior data is necessary to further explain the relationships among the animal, plant, and endophyte.

Literature Cited


Watson, R. H., M. A. McCann, J. A. Bondurant, J. G. Andrae, and L. L. Hawkins. 2001. Use of temperature data loggers to measure body temperature in

CHAPTER 2

USE OF NIL ERGOT ALKALOID PRODUCING ENDOPHYTES FOR
ALLEVIATING TALL FESCUE TOXICOSIS IN SHEEP

ABSTRACT

Nil ergot alkaloid producing endophytes from New Zealand were inserted into tall fescue (*Festuca arundinacea*) cultivars in an attempt to address the problem of fescue toxicosis in grazing sheep. A 3-yr grazing study was conducted to determine animal performance and evaluate toxicosis in lambs grazing nil ergot alkaloid producing endophyte-infected (AR542 or AR502), endophyte-free (EF), or wild-type toxic endophyte-infected (EI) Jesup tall fescue or nil ergot alkaloid producing endophyte-infected (AR542) Georgia-5 tall fescue. Replicated 0.11-ha tall fescue paddocks were established at the central Georgia Branch Station during September 1997 and were stocked with lambs from spring 1998 through autumn 2000. Mean ergot alkaloid levels were higher (*P* < 0.05) in EI forage than in AR542, AR502, and EF tall fescue, and plants infected with AR542 and AR502 endophytes produced nil or near nil ergot alkaloids. Forage availability was similar (*P* > 0.20) across all treatments. Initial serum prolactin (PRL) levels were similar (*P* > 0.20) across all treatments, while d-14+ serum PRL levels were depressed (*P* < 0.05) on EI compared to AR542, AR502, and EF in both spring and autumn. Signs of heat stress were observed in EI animals during periods of high ambient temperatures. Mean d-14+ rectal temperature and mean stocking rate exhibited treatment x year interactions (*P* < 0.05). Lamb ADG was higher (*P* < 0.05) on AR542, AR502, and EF as compared to EI tall fescue. Similarly, gain/ha was higher (*P* < 0.05) on AR542, AR502, and EF than on EI. Tall fescue pastures containing nil ergot alkaloid producing endophytes furnished lamb performance similar to EF and superior to EI tall fescue.
Depressed PRL levels and elevated rectal temperatures as indicators of toxicosis were evident only in lambs on EI tall fescue suggesting that nil ergot alkaloid producing endophyte-infected tall fescue is a viable alternative for alleviating tall fescue toxicosis.

Key words: nil ergot alkaloid producing endophytes, tall fescue, lambs, toxicosis, grazing
Introduction

Tall fescue (*Festuca arundinacea*) is a cool-season grass widely used as pasture or hay for livestock in the southeastern USA. Despite attributes that make it a desirable forage crop, tall fescue is associated with fescue toxicosis, a condition that adversely affects livestock performance (Stuedemann and Hoveland, 1988). Fescue toxicosis has negative economic consequences for grazing of cattle, sheep, and horses (Thompson et al., 2001). Animal toxicity problems are the result of grazing wild-type toxic endophyte-infected (EI) tall fescue. The tall fescue endophyte (*Neotyphodium coenophialum*) is a fungus that resides within the tall fescue plant and imparts positive agronomic qualities to the plant such as enhanced drought tolerance and improved vigor. However, the wild-type endophyte produces ergot alkaloids that have been associated with fescue toxicosis (Hill et al., 1994). Surveys in states within the tall fescue growing region have shown that in excess of 90 percent of the tall fescue fields sampled contained high levels of the wild-type endophyte (Lacefield and Henning, 1995). Plant breeders have developed endophyte-free (EF) cultivars, which are non-toxic to livestock, but plant persistence is lower than in EI tall fescue (Hill et al., 1991).

To address this problem, nil ergot alkaloid producing endophytes (AR542 and AR502) discovered by Ag Research in New Zealand have been incorporated into EF Jesup and Georgia-5 tall fescue cultivars. The Jesup cultivar was developed for use in the main tall fescue growing regions (Bouton et al., 1997), while the Georgia-5 cultivar was developed for use in the southern Gulf coast
region (Bouton et al., 1993). The Jesup and Georgia-5 cultivars with AR542 and AR502 endophyte strains have been shown to produce none of the ergot alkaloids that are responsible for the toxicosis conditions in grazing ruminants (Bouton et al., 1999). These cultivars containing nil ergot alkaloid producing endophytes have better stand survival than EF checks and survival similar to EI checks when subjected to close grazing in bermudagrass (Cynodon dactylon) sod (Bouton et al., 2000).

Toxicosis evaluation of these tall fescue cultivars infected with nil ergot alkaloid producing endophyte strains with grazing animals was the next step following plot evaluation and selection for grazing persistence. Initial grazing research was conducted in lambs because nil ergot alkaloid producing endophyte-infected tall fescue seed supplies were limited and the grazing area per paddock for lambs was much less than for cattle. Other researchers have found lambs to be good animal models for assessing fescue toxicosis in ruminants (Aldrich et al., 1993; Fletcher et al., 2000). The objectives of the present study were to determine animal performance and evaluate toxicosis in lambs grazing nil ergot alkaloid producing endophyte-infected Jesup and Georgia-5 tall fescue, Jesup EF tall fescue, and Jesup EI tall fescue pastures in central Georgia.
Materials and Methods

Pasture Establishment and Management

Five pasture treatments: (i) Georgia-5 AR542-infected tall fescue, (ii) Jesup AR542-infected tall fescue, (iii) Jesup AR502-infected tall fescue, (iv) Jesup EF tall fescue, and (v) Jesup EI tall fescue were compared for lamb toxicity and performance for three yr. The experiment had a completely randomized design with two replications of each paddock treatment. The 0.11-ha paddocks were tall fescue monocultures established at the Central Georgia Branch Station near Eatonton, GA (latitude 33.3972°N; longitude 83.4883°W; elevation 167 m) in September 1997. Seed supplied by J. H. Bouton was drilled into well-prepared Mecklenburg sandy loam soil at a seeding rate of 33.6 kg/ha. The paddocks were fertilized uniformly with 67 kg N/ha and P and K according to soil tests at establishment and in February and September of each subsequent year.

Animal and Grazing Management

Rambouillet-Suffolk crossbred lambs (mean BW = 23 kg) were randomly assigned to the treatment paddocks. Paddock fencing consisted of 0.91-m Flexinet electric netting (Horizont UK, Ltd., Gloucester, UK). The animals were supplied at all times with fresh water, free choice copper-free mineral blocks (Table 2.1), and shade in each paddock. The lambs were shorn, paint branded, and treated for internal parasites at the initiation of each grazing season. In an attempt to maintain similar forage availability among the paddocks, a put-and-take method of stocking was used. Two animals in each paddock were
designated as testers, and the remaining animals were designated as grazers. Based on forage availability, stocking rate was adjusted by removing or adding grazer animals while tester animals remained on the paddocks for the duration of the grazing season. Paddocks were restocked with new animals at the onset of each grazing season. The spring grazing seasons averaged 75 d, while the autumn grazing seasons averaged 66 d (Table 2.2). Grazing began later in the spring of the first year than in succeeding years to ensure that new forage plantings were vigorous and well established. Grazing was initiated when there was approximately 2600 kg DM/ha of available forage and continued until forage availability dropped below approximately 1800 kg DM/ha.

Data Collection

At the beginning of grazing and at 2-wk intervals thereafter, paddocks were sampled for available forage by clipping herbage within a 0.09-m² quadrat from 10 randomly selected sites within each paddock. The material was dried in a forced-air oven at 60°C, weighed, and kg DM/ha calculated. Rate of endophyte infection was assayed on tall fescue tillers near the onset and conclusion of each grazing season using an immunoblot procedure of Hiatt et al. (1998). Total ergot alkaloid concentration was determined using an ELISA procedure described by Adcock et al. (1992).

Lamb wt, blood samples, and rectal temperatures were collected at the onset of each grazing season and at 14-d intervals. Initial and final lamb wt were collected on two consecutive days and averaged. Approximately 7 ml of blood was collected from each lamb via jugular venipuncture. Blood samples were
centrifuged at 3000 g to separate and harvest serum that was then frozen (0°C). Analysis was then performed to determine serum prolactin (PRL) levels according to the RIA procedure of Mizinga et al. (1992).

Animal days were calculated as the sum of the days tester and grazer animals remained on each paddock treatment. Lamb ADG was computed by dividing mean tester lamb gain in a given paddock by the number of days in the grazing period. Gain/ha was calculated as the number of animal days multiplied by the ADG of testers. Mean stocking rate was computed by dividing animal days by the duration of the grazing season in days.

**Statistical Analysis**

PROC GLM/LSMEANS of SAS (SAS Inst. Inc., Cary, NC) was used to analyze the available forage and animal data. Ergot alkaloid concentration data was subjected to square root transformation and subsequent least squares difference comparisons. A completely randomized experimental design was used with paddock as the experimental unit. There were two replications of each experimental unit. Main effects were endophyte treatment, season, and year. The model included main effects and their interactions. Orthogonal contrasts among treatments included: EI vs all other treatments, EF vs non-toxic endophyte treatments, AR502 vs AR542, and Jesup AR542 vs Georgia-5 AR542.
Results and Discussion

Ergot Alkaloid Production and Forage Availability. Rate of endophyte infection exceeded 68 percent in nil ergot alkaloid producing and EI pastures throughout the duration of the study. Mean ergot alkaloid levels were higher \( (P < 0.05) \) in EI forage than in AR542, AR502, and EF tall fescue (Table 2.3). Along with EF tall fescue, plants infected with AR542 and AR502 endophytes produced nil or near nil ergot alkaloids. Using put-and-take grazing management, average forage availability was maintained at similar levels \( (P > 0.20) \) among all treatments. Average forage availability was higher \( (P < 0.01) \) in the autumn as compared to the spring (2648 vs 2246 ± 146 kg DM/ha). This resulted from stockpiling forage to target at least 60 d of autumn grazing each year. There was a year effect \( (P < 0.01) \) for available forage. Least squares means were 2158, 2247, and 2936 ± 113 kg DM/ha for 1998, 1999, and 2000, respectively. This trend of increasing annual forage availability over time was related to improved plant vigor as tall fescue stands matured. Root development likely played a role in this enhanced plant productivity over time.

Serum Prolactin. Depressed PRL levels are widely accepted as an indicator of fescue toxicosis (Hoveland et al., 1983; Fribourg et al., 1991; Rice et al., 1997). Initial pretreatment PRL levels \( (d-0) \) were similar \( (P > 0.20) \) among all treatments. There was a treatment x season interaction \( (P < 0.01) \) for d-14+ PRL levels that may be associated with photoperiod influencing PRL levels to different degrees based on whether or not they subject to the effects of ergot alkaloid consumption (Table 2.4). Mean PRL levels from d-14 through the end of each
grazing period were depressed ($P < 0.05$) on EI as compared to AR542, AR502, and EF tall fescue during both spring and autumn grazing. This treatment response of serum PRL levels is consistent with findings of Fletcher et al. (2000) for lambs grazing nil ergot alkaloid producing (AR501), EF, and EI tall fescue. In addition, the upper PRL values reported in the current study are within the range of values reported by Fletcher et al. (2000). Spring d-0 and d-14+ PRL levels were higher ($P < 0.01$) than corresponding autumn values. This seasonal difference in d-0 and d-14+ PRL levels is likely related to the photoperiod. Sheep are seasonal breeders and have been shown to have increased PRL levels during periods of increasing day length (spring) over periods of decreasing day length (autumn) (Foldes et al., 1991; Cerna et al., 2000; Lincoln and Clarke, 2000).

Rectal Temperatures. No treatment effects ($P > 0.20$) were observed for initial (d-0) rectal temperatures, but there were year ($P < 0.01$) and season ($P < 0.10$) effects as well as a year x season interaction ($P < 0.01$). These differences were likely due to environmental conditions, the use of different lambs each grazing season, and time of day when measurements were taken. In addition, rectal temperature measurements were subject to confounding variables such as animal handling and stress, ambient temperature, humidity, and exposure to sunlight. After autumn 1999, rectal temperature collections were moved from the morning hours to the afternoon hours in order to record animal temperatures during periods of higher ambient temperatures in an attempt to increase the likelihood of capturing treatment differences. There was a year x treatment
interaction \( (P < 0.05) \) for d-14+ rectal temperatures (Figure 2.2). Lamb rectal temperatures were elevated to a greater extent during 1999 and 2000 on EI pastures over AR542, AR502, and EF pastures than during 1998. Moving rectal temperature collections from morning to afternoon hours may have influenced annual d-14+ rectal temperatures to a greater degree on the EI than on the other treatments, contributing to the significance of this interaction. Lambs on EI tall fescue were observed exhibiting signs of heat stress (e.g., panting and lying under shade while lambs on EF and non-toxic endophyte treatments were grazing) during periods of elevated environmental temperatures. Higher temperatures have been documented on EI tall fescue over EF tall fescue in cattle (Hoveland et al., 1983; Schmidt et al., 1983) and over EF and AR501 tall fescue in sheep (Fletcher et al., 2000).

**Stocking Rate.** Put-and-take grazing management based on available forage was used to adjust stocking rate. There was a year x treatment interaction \( (P < 0.05) \) for stocking rate that may be explained by the more pronounced impacts that the animal has on EF grass over time in conjunction with ergot alkaloid-based negative feedback on forage intake by lambs in the EI paddocks (Figure 2.3). Lower forage intake has been documented on EI vs EF tall fescue in lambs (Aldrich et al., 1993), steers (Stuedemann et al., 1989), and cows (Peters et al., 1992). The difference between mean stocking rates on EI and EF was particularly pronounced in 1999, when rainfall totals during the grazing seasons were moderate relative to spring 1998 and autumn 2000 (Figure 2.1a). This
suggests that EF pastures could not support as many grazing animals because of a plant persistence disadvantage.

Average Daily Gain. Lamb ADG was higher ($P < 0.05$) on AR542, AR502, and EF than on EI pastures (Table 2.5). This agrees with the findings of Fletcher et al. (2000) in lambs grazing AR501, EF, and EI tall fescue. A year effect ($P < 0.01$) was observed for ADG with least squares means of 116, 137, and $77 \pm 6$ g/d for 1998, 1999, and 2000, respectively. There was an inverse relationship between annual ADG and annual grazing days that may have contributed to the year effect.

Gain/ha. Gain/ha was higher ($P < 0.05$) on AR542, AR502 and EF than on EI tall fescue (Table 2.5). There was a seasonal effect for gain/ha with values being higher ($P < 0.01$) in spring than in autumn. This finding is not unexpected as there were 222 d of spring grazing compared with only 197 d of autumn grazing. A gain/ha year effect ($P < 0.01$) was found with least squares means of 253, 282, and $202 \pm 13$ kg/ha for 1998, 1999, and 2000, respectively. As with ADG, the number of annual grazing days may have influenced the gain/ha year effect.

Implications

Lambs grazing nil ergot alkaloid producing endophyte-infected (AR542, AR502) and EF tall fescue pastures did not exhibit depressed serum PRL levels or elevated rectal temperatures indicative of fescue toxicosis as did animals on EI tall fescue. In addition, grazing performance of lambs on nil ergot alkaloid producing endophyte-infected and EF tall fescue was superior to that of animals
on EI pasture. Removal of ergot alkaloids alleviated negative animal responses associated with fescue toxicosis regardless of the nil ergot alkaloid producing endophyte strain or tall fescue cultivar host. Nil ergot alkaloid producing endophytes appear to be a viable alternative to EF tall fescue for good lamb performance without toxicity problems. The implications of alleviating tall fescue toxicosis include improved animal health and performance, reduced feed costs, and improved profitability, all of which serve to improve the sustainability of forage-based livestock production.


Figure 2.1. Total rainfall (2.1a) and average maximum and minimum daily temperatures (2.1b) at the Central Georgia Branch Station from spring 1998 through autumn 2000.
Figure 2.2. Least squares means of treatment x year interaction for lamb rectal temperature in Georgia-5 AR542 (GA5542), Jesup AR542 (J542), Jesup AR502 (J502), Jesup endophyte-free (JEF), and Jesup toxic endophyte-infected (JEI) tall fescue pastures, 1998 – 2000. SE = 0.10.
Figure 2.3. Least squares means of treatment x year interaction for mean stocking rate in Georgia-5 AR542 (GA5542), Jesup AR542 (J542), Jesup AR502 (J502), Jesup endophyte-free (JEF), and Jesup toxic endophyte-infected (JEI) tall fescue pastures, 1998 – 2000. SE = 0.86.
Table 2.1. Composition of mineral block supplement

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<th>Item</th>
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<tr>
<td>Calcium, maximum %</td>
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<td>Phosphorus, minimum %</td>
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<td>Flourine, maximum %</td>
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<td>Vitamin D-3, minimum IU/kg</td>
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<td>Vitamin E, minimum IU/kg</td>
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Table 2.2. Central Georgia lamb grazing dates

<table>
<thead>
<tr>
<th>Season</th>
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<th>Duration, d</th>
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<tr>
<td>Spring</td>
<td>April 7 to June 30, 1998</td>
<td>84</td>
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<tr>
<td></td>
<td>March 16 to May 24, 1999</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>March 22 to May 30, 2000</td>
<td>69</td>
</tr>
<tr>
<td>Autumn</td>
<td>October 14 to December 8, 1998</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>October 12 to December 8, 1999</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>October 4 to December 19, 2000</td>
<td>75</td>
</tr>
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</table>
Table 2.3. Least squares means of mean ergot alkaloid levels as affected by endophyte status in Jesup and Georgia-5 tall fescue during spring and autumn in central Georgia, 1998 - 2000

<table>
<thead>
<tr>
<th></th>
<th>Mean ergot alkaloids, ppb</th>
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<tr>
<td></td>
<td>Spring (3-yr mean)</td>
</tr>
<tr>
<td>Georgia-5 AR542</td>
<td>24&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Jesup AR542</td>
<td>29&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Jesup AR502</td>
<td>39&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Jesup EF</td>
<td>31&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Jesup EI</td>
<td>1184&lt;sup&gt;a&lt;/sup&gt;</td>
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</tbody>
</table>

<sup>ab</sup> Within a column, means without a common superscript letter differ ($P < 0.05$).
Table 2.4. Least squares means of d-14+ lamb serum prolactin (PRL) levels as affected by endophyte status in Jesup and Georgia-5 tall fescue during spring and autumn in central Georgia, 1998 – 2000

<table>
<thead>
<tr>
<th></th>
<th>D-14+ PRL levels, ng/ml</th>
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<tr>
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<tr>
<td>Georgia-5 AR542</td>
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</tr>
<tr>
<td>Jesup AR542</td>
<td>301.70 a</td>
</tr>
<tr>
<td>Jesup AR502</td>
<td>299.98 a</td>
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<tr>
<td>Jesup EF</td>
<td>300.42 a</td>
</tr>
<tr>
<td>Jesup EI</td>
<td>9.84 b</td>
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<tr>
<td>SE</td>
<td>30.70</td>
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Within a column, means without a common superscript letter differ ($P < 0.05$).
Table 2.5. Least squares means of lamb ADG and gain/ha as affected by endophyte status in Jesup and Georgia-5 tall fescue in central Georgia, 1998 - 2000

<table>
<thead>
<tr>
<th>Item</th>
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<th>P-value</th>
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<tr>
<td>(3-yr mean)</td>
<td>G542</td>
<td>J542</td>
<td>J502</td>
<td>JEF</td>
<td>JEI</td>
<td>SE</td>
<td></td>
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<tr>
<td>ADG, g/d</td>
<td>122</td>
<td>118</td>
<td>109</td>
<td>126</td>
<td>75</td>
<td>8</td>
<td>0.0001</td>
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<tr>
<td>kg/ha</td>
<td>278</td>
<td>258</td>
<td>254</td>
<td>268</td>
<td>170</td>
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<td>0.0001</td>
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<tr>
<td>Gain/ha,</td>
<td>G542</td>
<td>J542</td>
<td>J502</td>
<td>JEF</td>
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<td>J542+G542</td>
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CHAPTER 3

USE OF NIL ERGOT ALKALOID PRODUCING ENDOPHYTES FOR
ALLEVIATING TALL FESCUE TOXICOSIS IN STOCKER CATTLE

1Parish, J. A., M. A. McCann, R. H. Watson, C. S. Hoveland, A. H. Parks, and J.
ABSTRACT

In order to address the issue of fescue toxicosis in grazing cattle, nil ergot alkaloid producing endophytes were inserted into tall fescue (*Festuca arundinacea*) cultivars. A 2-yr grazing study was conducted to determine animal growth performance and evaluate toxicosis in stocker cattle grazing nil ergot alkaloid producing endophyte-infected (AR542 or AR502), endophyte-free (EF), or wild-type toxic endophyte-infected (EI) Jesup, Georgia-5, and Kentucky-31 tall fescue. Replicated 0.81-ha tall fescue paddocks were established at the Central Georgia Branch Station at Eatonton and the Northwest Georgia Branch Station at Calhoun during October 1998 and were stocked with beef cattle from autumn 1999 through spring 2001. Forage availability was similar (*P* > 0.20) across all treatments with the exception that available forage in EI pastures was higher (*P* < 0.05) than AR542 available forage at Calhoun and than AR542, AR502, and EF available forage at Eatonton during spring. At both locations, d-14+ serum PRL levels were depressed (*P* < 0.05) on EI compared to AR542, AR502, and EF. Cattle on AR542, AR502, and EF pastures had lower (*P* < 0.05) d-14+ rectal temperatures than cattle grazing EI tall fescue averaged over autumn and spring at Eatonton and during spring at Calhoun. A treatment x grazing year interaction (*P* < 0.01) for mean stocking rate was detected at Calhoun in which mean stocking rate increased in year 2 on EI pastures while remaining fairly constant or declining in year 2 on AR542, AR502, and EF pastures. Calf ADG was higher (*P* < 0.05) on AR542, AR502, and EF as compared to EI tall fescue during autumn and spring grazing at Eatonton, and treatment response of ADG at Calhoun
followed the same trends as at Eatonton with cattle on EI pastures showing inferior wt gains. Gain/ha was higher \( (P < 0.05) \) on AR542, AR502, and EF than on EI during autumn at Eatonton and during spring at both locations. In autumn at Calhoun, gain/ha was greater \( (P < 0.05) \) on AR502 and EF compared to EI tall fescue. Thus, stocker growth on AR542 and AR502 tall fescue pastures was similar to cattle growth on EF and exceeded cattle growth on EI tall fescue. Indicators of toxicosis, depressed serum PRL levels and elevated rectal temperatures, were observed only in cattle grazing EI pastures. These results indicate that nil ergot alkaloid producing endophyte technology is a promising option for alleviating tall fescue toxicosis in stocker cattle.

Key words: nil ergot alkaloid producing endophytes, tall fescue, toxicosis, stocker cattle, grazing
Introduction

Stockering weaned beef calves to feeder wt on high-quality pastures is an important enterprise in the southeastern USA (Hoveland, 2000). Tall fescue (Festuca arundinacea) is a cool-season grass that accounts for the majority of improved pastureland in the southeastern USA (Hoveland, 1992; Browning et al., 1998). Despite agronomic attributes that make it an attractive forage crop, tall fescue is associated with fescue toxicosis, a condition that alters ruminant grazing behavior (Seman et al., 1999) and adversely affects grazing cattle performance (Stuedemann and Hoveland, 1988). Allen and Segarra (2001) estimate that economic losses from fescue toxicosis in the USA beef industry exceed $600 million annually.

Animal toxicity problems result from grazing wild-type toxic endophyte-infected (EI) tall fescue. The tall fescue endophyte (Neotyphodium coenophialum) resides within the tall fescue plant and imparts positive agronomic qualities to the plant, e.g., enhanced drought tolerance and improved vigor. Plant breeders have developed endophyte-free (EF) cultivars, which are non-toxic to livestock. However, plant persistence is lower in EF than in EI tall fescue (Hill et al., 1991), and a higher level of management is required to maintain productive EF forage stands. Selective elimination of livestock toxins in EI tall fescue was proposed as a solution to the fescue toxicosis problem that would avoid sacrificing plant persistence advantages provided endophyte presence (Bush and Burrus, 1988; Hill et al., 1991; Agee and Hill, 1994).
Nil ergot alkaloid producing endophyte-infected tall fescue was developed by re-infecting EF tall fescue cultivars with nil ergot alkaloid producing endophyte strains. Nil ergot alkaloid producing *N. coenophialum* strains have been shown to produce none of the ergot alkaloids that are responsible for the toxicosis conditions in grazing ruminants (Bouton et al., 1999). Grazing research trials conducted in lambs (Fletcher et al., 2000; Bouton et al., 2000) and steers (Nihsen et al., 2000) have shown that nil ergot alkaloid producing endophyte-infected tall fescue pastures provide animal performance similar to EF tall fescue and superior to EI tall fescue without indications of toxicosis. Better stand survival than EF checks and survival similar to EI checks has been observed in Jesup and Kentucky-31 (*KY-31*) cultivars containing nil ergot alkaloid producing endophytes when subjected to close grazing in bermudagrass (*Cynodon dactylon*) sod (Bouton et al., 2000).

Nil ergot alkaloid producing endophytes (AR542 and AR502) discovered by Ag Research in New Zealand were incorporated into EF Jesup, Georgia-5, and KY-31 tall fescue cultivars. Jesup tall fescue was developed for use in the main tall fescue growing regions (Bouton et al., 1997), while Georgia-5 was developed for use in the southern Gulf coast region (Bouton et al., 1993). Kentucky-31 is the predominant tall fescue cultivar in the southeastern USA (Paterson et al., 1995). The objectives of the present study were to determine animal performance and evaluate toxicosis in stocker cattle grazing nil ergot alkaloid producing endophyte-infected, EF, and EI Jesup, Georgia-5, and KY-31 tall fescue pastures.
Materials and Methods

Pasture Establishment and Management

Five pasture treatments: (i) AR542-infected Georgia-5 tall fescue, (ii) AR542-infected Jesup tall fescue, (iii) AR502-infected tall Jesup fescue, (iv) EF Jesup tall fescue, and (v) EI Jesup tall fescue were compared for beef cattle toxicity and growth performance for two yr at the Central Georgia Branch Station near Eatonton, GA (latitude 33.3972°N; longitude 83.4883°W; elevation 167 m) (Trial 1). At the Northwest Georgia Branch Station near Calhoun, GA (latitude 34.5577°N; longitude 84.8158°W; elevation 209 m), four KY-31 pasture treatments: (i) AR542-infected tall fescue, (ii) AR502-infected tall fescue, (iii) EF tall fescue, and (iv) EI tall fescue were compared for animal toxicity and growth performance for two yr (Trial 2). The grazing trial at each location had a completely randomized design with two replications of each paddock treatment. The 0.81-ha paddocks were tall fescue monocultures established in October 1998. Seed supplied by J. H. Bouton was precision drilled into well-prepared seedbeds at a seeding rate of 33.6 kg/ha. Soil at Eatonton was Pacolet sandy loam soil, while soil at Calhoun was Sequatchie loam and Pope fine sandy loam soil. Pastures were fertilized uniformly with 67 kg N/ha and P and K according to soil tests at establishment and in February and September of each subsequent year. During spring 1999 paddocks were stocked with cattle for 49 d at Eatonton and 84 d at Calhoun.
Animal and Grazing Management

Hereford crossbred steers (mean BW = 254 kg) and Angus crossbred cattle (mean BW = 227 kg) were randomly assigned to the treatment paddocks at Eatonton and Calhoun, respectively. Steers were used during all grazing periods at Eatonton and during autumn 1999 and spring 2000 at Calhoun, while heifers were used during autumn 1999 and spring 2000 at Calhoun. The animals were supplied at all times with fresh water, free choice mineral blocks (Table 3.1), and shade in each paddock. Cattle were treated for internal and external parasites at the initiation of each trial. In an attempt to maintain similar forage availability among paddocks, put-and-take grazing management was used. Based on forage availability, stocking rate was adjusted by removing or adding grazer animals with tester animals remaining on the paddocks for the duration of the experiment. Cattle were taken off of the experimental pastures at the conclusion of each autumn grazing period, grazed on EF tall fescue, and fed bermudagrass hay until they were reallocated to treatment pastures at the beginning of the following spring grazing period. Paddocks were restocked with new animals at the beginning of the autumn 2000 grazing season.

Autumn grazing seasons tended to be shorter than spring grazing seasons, and both autumn and spring grazing durations were shorter at Eatonton than at Calhoun (Table 3.2). Grazing was initiated when there was adequate forage available, approximately 2700 kg DM/ha at Eatonton and 1800 kg DM/ha at Calhoun. Grazing continued until forage availability dropped below approximately 2300 kg DM/ha at Eatonton and 1300 kg DM/ha at Calhoun.
Generally higher precipitation and better soil water holding capacity at Calhoun played a role in decisions regarding the management of available forage levels (Figure 3.1a).

Data Collection

Paddocks were sampled for available forage on dates corresponding to animal data collection dates by clipping herbage within a 0.09 m² quadrat from 10 randomly selected sites within each paddock. The material was dried in a forced-air oven at 60°C, weighed, and kg DM/ha calculated. Rate of endophyte infection was assayed on tall fescue tillers near the onset and conclusion of each grazing season using an immunoblot procedure of Hiatt et al. (1998). Animal wt, blood samples, and rectal temperatures were collected at the onset of each grazing season, d 14, d 28, and then at 28-d intervals, thereafter. Initial and final animal wt were collected on two consecutive days and averaged. Approximately 7 ml of blood was collected from each animal in the caudal vein at the base of the tail. Blood samples were centrifuged at 3000 g to separate and harvest serum that was then frozen (0°C). Analysis was then performed to determine serum prolactin (PRL) levels according to the RIA procedure of Mizinga et al. (1992).

Animal days for each paddock were calculated as the sum of the days each animal, tester or grazer, spent grazing the paddock during a given grazing season. Animal ADG was computed by dividing mean tester animal gain in a particular paddock by the number of days in the grazing season. Gain/ha was calculated as the number of animal days multiplied by tester animal ADG. Mean
stocking rate was computed by dividing animal days by the duration of the grazing season in days.

**Statistical Analysis**

PROC GLM/LSMEANS of SAS (SAS Inst. Inc., Cary, NC) was used to separately analyze the data from the Eatonton trial and the Calhoun trial. For each grazing trial a completely randomized experimental design was used with paddock as the experimental unit. There were two replications of each experimental unit. Main effects were endophyte treatment, season, and grazing year. Grazing year one included autumn 1999 and spring 2000, while grazing year two included autumn 2000 and spring 2001. The model included main effects and their interactions.

**Results and Discussion**

*Forage Availability.* Rate of endophyte infection exceeded 62 percent in nil ergot alkaloid producing and EI pastures throughout the duration of the study. A treatment x season interaction \( P < 0.01 \) was present for mean available forage at Eatonton (Table 3.3). Autumn forage availability at Eatonton was similar \( P > 0.20 \) across treatments, while mean available forage was higher \( P < 0.05 \) on EI pastures than Jesup AR542, AR502, and EF tall fescue pastures in spring. There was a year x season interaction \( P < 0.01 \) for available forage that were likely related to differences in environmental conditions over time (Figure 3.1).

Mean available forage was higher \( P < 0.05 \) on EI pastures than AR542 pastures at Calhoun. This may have been related to flooding in an AR542
paddock during one spring grazing period that stunted forage growth in low-lying areas. Mean available forage was higher \((P < 0.05)\) in spring than autumn. This was likely due to more productive forage growth during spring as daylength increased and tall fescue entering a reproductive state. In addition, mean available forage was higher \((P < 0.01)\) in grazing year one than in grazing year two likely resulting from annual precipitation differences (Figure 3.1a).

*Serum Prolactin.* Depressed serum PRL levels are a well-documented sign of fescue toxicosis (Hoveland et al., 1983; Fribourg et al., 1991; Rice et al., 1997). At Eatonton, pretreatment PRL levels \((d-0)\) were similar \((P > 0.10)\) among all treatments during autumn, while d-0 PRL levels in cattle on Georgia-5 AR542 pastures were higher \((P < 0.01)\) than on the remaining treatments in spring. A treatment x season interaction \((P < 0.01)\) existed for d-14+ PRL levels (Table 3.4). Mean PRL levels from d-14 through the end of the grazing period were depressed \((P < 0.05)\) at Eatonton on EI as compared to Jesup AR542, AR502, and EF tall fescue in autumn and on EI as compared to Georgia-5 AR542, Jesup AR542, AR503, and EF during spring. The spread between mean d-14+ serum PRL levels in cattle on nil ergot alkaloid producing endophyte-infected and EF tall fescue pastures over levels on EI tall fescue pastures was greater during spring than autumn. This is likely due to photoperiod-based seasonal variations in cattle PRL levels previously documented (Stanisiewski et al., 1988; Petitclerc et al., 1989; Cho et al., 1998). Cattle serum PRL levels vary with the photoperiod and tend to increase with increasing daylength. In the Eatonton trial, d-14+ PRL levels were higher \((P > 0.01)\) during spring than autumn.
At Calhoun, pretreatment PRL levels were similar ($P > 0.10$) among all treatments. A treatment x season interaction ($P < 0.01$) was present for d-14+ serum PRL levels (Table 3.4) that may be explained by endocrine response in cattle to changes in the photoperiod in conjunction with ergot alkaloid consumption-based depression of serum PRL levels. Mean d-14+ serum PRL levels were depressed ($P < 0.01$) in cattle grazing EI tall fescue during both autumn and spring. The treatment results for both the Eatonton and Calhoun grazing trials agree with the findings of Nihsen et al. (2000) for cattle grazing KY-31 EI, HiMag EF, nil ergot alkaloid producing endophyte-infected HiMag tall fescue.

Rectal Temperatures. The only pretreatment (d-0) rectal temperature difference at Eatonton involved elevated temperatures in cattle assigned to EF pastures over Jesup AR542, EF, and EI pastures. At Eatonton, cattle on EI tall fescue had higher ($P < 0.05$) d-14+ rectal temperatures than animals grazing AR542, AR502, and EF tall fescue (Table 3.5). This treatment difference is consistent with findings of other researchers in cattle grazing nil ergot alkaloid producing endophyte-infected tall fescue (Nihsen et al., 2000), EF and EI tall fescue (Hoveland et al., 1983; Schmidt et al., 1983). Alkaloids produced in EI tall fescue have been shown to have vasoconstrictive effects on bovine vasculature (Oliver et al., 1993). Reduced blood flow could result in tissue death and impaired ability to dissipate heat. This may explain the thermoregulatory challenge evident in cattle grazing EI tall fescue.
At Calhoun, there were no d-0 rectal temperature differences ($P > 0.20$) among treatments. There was a treatment x season interaction ($P < 0.01$) for d-14+ rectal temperatures (Table 3.5). No treatment effects ($P > 0.20$) were observed for autumn d-14+ rectal temperatures at Calhoun. This may have been due to confounding variables, i.e., animal handling induced stress, ambient temperature, humidity, and exposure to sunlight. Despite the lack of significant rectal temperature differences during autumn at Calhoun, cattle on EI tall fescue were observed exhibiting signs of heat stress during periods of elevated environmental temperatures, i.e., panting and seeking shade while cattle on EF and nil ergot alkaloid producing endophyte treatments grazed. During spring at Calhoun, d-14+ rectal temperatures were elevated ($P < 0.01$) in cattle grazing EI tall fescue as compared to AR542, AR502, and EF tall fescue. It is logical that a treatment difference was observed at Calhoun in spring instead of autumn, because average daily temperature maximums and minimums were greater during spring periods than autumn periods (Figure 3.1).

**Stocking Rate.** Stocking rate treatment differences were not present at Eatonton ($P > 0.20$). At Calhoun, a treatment x year interaction ($P < 0.01$) existed because stocking rate was increased in grazing year two on EI tall fescue and was lowered or remained fairly constant in the second grazing year on all other treatments (Figure 3.2). Increased alkaloid production in EI forage after the first year may have led to decreased forage consumption on EI pastures. Ergot alkaloid consumption produces a negative feedback on forage intake by grazing animals. Lower forage intake on EI tall fescue compared with EF tall fescue has
been reported in both steers (Stuedemann et al., 1989) and cows (Peters et al.,

Mean spring stocking rate was higher \( (P < 0.01) \) than mean autumn
stocking rate. This was possible because spring available forage was higher \( (P
< 0.05) \) than autumn available forage. Mean available forage had least squares
means of 2643 and 2423 ± 58 kg DM/ha in spring and autumn, respectively. A
grazing year effect \( (P < 0.01) \) was present for stocking rate as well with least
squares means of 4.47 and 4.26 ± 0.02 animals/ha in grazing year one and
grazing year two, respectively. The number of animal grazing days (329 in
grazing year one vs 339 in grazing year two) may have played a role in the year
effect for stocking rate.

**Average Daily Gain.** For the Eatonton grazing trial, a treatment x season
interaction \( (P < 0.01) \) was detected for ADG (Table 3.6). Cattle ADG was
decreased during spring grazing relative to during autumn grazing on EI tall
fescue. This was likely related to higher plant ergot alkaloid levels in forage
leaves during the spring (Rottinghaus et al. 1991) and the presence of seed in
which endophyte and alkaloid levels tend to be concentrated during spring as tall
fescue enters a reproductive state (Siegal et al., 1984; Ball, 1997). This may
have enhanced the toxicosis condition in EI pastures during spring and
depressed ADG further. Another possible explanation may involve more mature
forage in the EI pastures because of lower spring grazing pressure compared to
the other treatment pastures.
Calf ADG was higher \( (P < 0.05) \) on AR542, AR502, and EF than on EI pastures in both seasons at Eatonton (Table 3.6). This is consistent with the results of Nihsen et al. (2000) in which higher steer ADG on nil ergot alkaloid producing endophyte-infected and EF tall fescue over EI tall fescue were reported. Additionally, during spring at Eatonton, ADG was higher \( (P < 0.05) \) on AR502 and EF than AR542 pastures. Although the endophyte strains evaluated in this study did not produce ergot alkaloids, they may have differed in production of other metabolites that impair grazing animal health and performance.

A treatment x grazing year interaction \( (P < 0.05) \) was found for the Calhoun trial in which ADG increased on all treatments in the second year. The most dramatic annual increases in ADG were exhibited on AR502 pastures. Flooding in the second year on an AR542 pasture at Calhoun and increased alkaloid consumption-based depression of forage intake in the second year in EI pastures may have tempered annual ADG improvements in the pastures. The use of different animals each year may also have played a role in this interaction.

\textit{Gain/ha}. Gain/ha treatment x season \( (P < 0.10) \) (Table 3.6) interactions for both grazing trials resulted for the same reasons as the corresponding ADG interaction at Eatonton discussed previously. As was the case with ADG, gain/ha was higher \( (P < 0.05) \) on AR542, AR502 and EF than on EI tall fescue in both seasons at each location with the exception that during autumn at Calhoun gain/ha was similar \( (P > 0.10) \) between AR542 and EI pastures (Table 3.6). There was flooding in a portion of one of the Calhoun AR542 pastures during
autumn 2000 that may have depressed the autumn AR542 gain/ha value for this location. At both locations, there were seasonal effects for gain/ha with values being higher \( (P < 0.05) \) in spring than in autumn. This finding is reasonable as the grazing seasons were longer and the mean available forage was greater \( (P < 0.05) \) in the spring periods. A treatment x grazing year interaction \( (P < 0.05) \) was detected at Calhoun for gain/ha and may be explained by the factors that influenced the ADG treatment x grazing year interaction at Calhoun described previously. Differences in annual stocking rate and restocking with new animals at the beginning of year two may account for the difference \( (P < 0.01) \) in annual gain/ha values for each grazing trial.

**Implications**

Use of nil ergot alkaloid producing endophytes (AR542, AR502) in tall fescue-based stockering systems appears to be a viable option to EF tall fescue for good animal growth performance without toxicity problems. Grazing performance of cattle on nil ergot alkaloid producing endophyte-infected and EF pastures was superior to that of animals on EI tall fescue. Furthermore, beef cattle grazing nil ergot alkaloid producing endophyte-infected and EF tall fescue pastures did not exhibit depressed PRL levels or elevated rectal temperatures indicative of fescue toxicosis as did in cattle on EI pastures. Alleviating tall fescue toxicosis via incorporation of nil ergot alkaloid producing endophytes into tall fescue grazing programs has implications for animal health and grazing performance and ultimately enterprise profitability and sustainability.
Literature Cited


ergovaline consumption by beef cows grazing endophyte fungus-infected
tall fescue, endophyte fungus-free tall fescue, and orchardgrass pastures.

concentrations of prolactin in serum of prepubertal bulls exposed to short-

Rice, R. L., D. J. Blodgett, G. G. Schurig, W. S. Swecker, J. P. Fontenot, V. G.
in cattle grazing endophyte-infected or endophyte-free fescue. Vet.

method for quantitating ergovaline in endophyte-infested tall fescue:
Seasonal variation of ergovaline levels in stems with leaf sheaths, leaf

57:295. (Abstr.)

77:1402-1411.

endophyte in tall fescue: incidence and dissemination. Phytopathology.
74:932-937.

1988. Melatonin and prolactin concentrations in blood of cattle exposed to


(Acremonium coenophialum) infection of tall fescue and paddock
Grasslands Congress, Nice, France. p 1243-1244.
Figure 3.1. Total rainfall (3.1a) and average maximum and minimum daily temperatures (3.1b) at the Central Georgia Branch Station and Northwest Georgia Branch Station from autumn 1999 through spring 2001.
Figure 3.2. Least squares means of treatment x year interaction for mean stocking rate in nil ergot alkaloid producing endophyte-infected (AR542, AR502), endophyte-free (EF), and toxic endophyte-infected (EI) Kentucky-31 tall fescue pastures at Calhoun, autumn 1999 through spring 2001. SE = 0.07.
Table 3.1. Composition of mineral block supplement

<table>
<thead>
<tr>
<th>Item</th>
<th>As-fed basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium, minimum %</td>
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</tr>
<tr>
<td>Calcium, maximum %</td>
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<tr>
<td>NaCl, minimum %</td>
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</tr>
<tr>
<td>NaCl, maximum %</td>
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</tr>
<tr>
<td>Sulfur, minimum %</td>
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</tr>
<tr>
<td>Copper, minimum ppm</td>
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<td>Iron, minimum ppm</td>
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<tr>
<td>Manganese, minimum ppm</td>
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</tr>
<tr>
<td>Selenium, minimum ppm</td>
<td>10</td>
</tr>
<tr>
<td>Zinc, minimum ppm</td>
<td>2500</td>
</tr>
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Table 3.2. Stocker cattle grazing dates

<table>
<thead>
<tr>
<th>Season</th>
<th>Location</th>
<th>Grazing dates</th>
<th>Duration, d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn</td>
<td>Eatonton</td>
<td>October 20 to December 16, 1999</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>October 10 to December 18, 1999</td>
<td>69</td>
</tr>
<tr>
<td>Spring</td>
<td>Eatonton</td>
<td>March 2 to May 25, 2000</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>March 5 to June 11, 2001</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Calhoun</td>
<td>October 6 to December 21, 1999</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>September 14 to December 7, 2000</td>
<td>84</td>
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<tr>
<td></td>
<td></td>
<td>March 28 to July 18, 2000</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td></td>
<td>March 22 to June 18, 2001</td>
<td>88</td>
</tr>
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</table>
Table 3.3. Least squares means of paddock average available forage and stocking rate as affected by endophyte status in Georgia-5, Jesup, and Kentucky-31 tall fescue pastures at Eatonton and Calhoun, autumn 1999 – spring 2000

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Autumn (2-yr mean)</th>
<th>Spring (2-yr mean)</th>
<th>Grazing year (2-yr mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia-5 AR542</td>
<td>3003 $^b$</td>
<td>3629 $^{bc}$</td>
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</tr>
<tr>
<td>Jesup/Kentucky-31 AR542</td>
<td>3388 $^b$</td>
<td>3136 $^{cd}$</td>
<td>1633 $^c$</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 AR502</td>
<td>3013 $^b$</td>
<td>3201 $^{cd}$</td>
<td>1775 $^{bc}$</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 EF</td>
<td>2909 $^b$</td>
<td>2964 $^d$</td>
<td>1936 $^b$</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 EI</td>
<td>3081 $^b$</td>
<td>4115 $^b$</td>
<td>2015 $^b$</td>
</tr>
<tr>
<td>SE</td>
<td>166</td>
<td>211</td>
<td>86</td>
</tr>
</tbody>
</table>

$^a$ Season x treatment interaction ($P < 0.01$).

$^bcd$ Within a column, means without a common superscript letter differ ($P < 0.05$).
Table 3.4. Least squares means of d-14+ cattle serum prolactin (PRL) levels as affected by endophyte status in Georgia-5, Jesup, and Kentucky-31 tall fescue during autumn and spring at Eatonton and Calhoun, autumn 1999 – spring 2001

<table>
<thead>
<tr>
<th></th>
<th>Eatonton</th>
<th>Calhoun</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Autumn (2-yr mean)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia-5 AR542</td>
<td>9.87</td>
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</tr>
<tr>
<td>Jesup/Kentucky-31 AR542</td>
<td>12.76</td>
<td>15.81 b</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 AR502</td>
<td>17.40 b</td>
<td>17.82 b</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 EF</td>
<td>17.11 b</td>
<td>14.81 b</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 EI</td>
<td>0.85 c</td>
<td>1.12 c</td>
</tr>
<tr>
<td>SE</td>
<td>3.35</td>
<td>2.16</td>
</tr>
<tr>
<td><strong>Spring (2-yr mean)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia-5 AR542</td>
<td>125.23 b</td>
<td></td>
</tr>
<tr>
<td>Jesup/Kentucky-31 AR542</td>
<td>133.48 b</td>
<td>133.11 b</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 AR502</td>
<td>132.56 b</td>
<td>149.98 b</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 EF</td>
<td>94.32 b</td>
<td>141.71 b</td>
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<tr>
<td>Jesup/Kentucky-31 EI</td>
<td>3.50 c</td>
<td>22.86 c</td>
</tr>
<tr>
<td>SE</td>
<td>17.09</td>
<td>3.37</td>
</tr>
</tbody>
</table>

\(^a\) Season x treatment interaction (P < 0.01).
\(^bc\) Within a column within season, means without a common superscript letter differ (P < 0.05).
Table 3.5. Least squares means of d-14+ cattle rectal temperatures as affected by endophyte status in Georgia-5, Jesup, and Kentucky-31 tall fescue at Eatonton and Calhoun, autumn 1999 – spring 2001

<table>
<thead>
<tr>
<th></th>
<th>Grazing year (2-yr mean)</th>
<th>Autumn (2-yr mean)</th>
<th>Spring (2-yr mean)</th>
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<tbody>
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<td>Eatonton</td>
<td>Calhoun</td>
<td>Eatonton</td>
</tr>
<tr>
<td>Georgia-5 AR542</td>
<td>39.72&lt;sup&gt;cd&lt;/sup&gt;</td>
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</tr>
<tr>
<td>Jesup/Kentucky-31 AR542</td>
<td>39.77&lt;sup&gt;c&lt;/sup&gt;</td>
<td>39.31&lt;sup&gt;b&lt;/sup&gt;</td>
<td>39.33&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 AR502</td>
<td>39.52&lt;sup&gt;d&lt;/sup&gt;</td>
<td>39.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>39.17&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 EF</td>
<td>39.72&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>39.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>39.22&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Jesup/Kentucky-31 EI</td>
<td>40.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>39.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>39.87&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>SE</td>
<td>0.08</td>
<td>0.09</td>
<td>0.10</td>
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<sup>a</sup> Season x treatment interaction ($P < 0.01$).

<sup>bcd</sup> Within a column, means without a common superscript letter differ ($P < 0.05$).
Table 3.6. Least squares means of cattle ADG and gain/ha as affected by endophyte status in Georgia-5, Jesup, and Kentucky-31 tall fescue during autumn and spring at Eatonton and Calhoun, autumn 1999 – spring 2001

<table>
<thead>
<tr>
<th></th>
<th>Eatonton</th>
<th></th>
<th>Calhoun</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADG, kg/d&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Gain/ha, kg/ha&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Gain/ha, kg/ha&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Autumn (2-yr mean)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Georgia-5 AR542</td>
<td>1.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>234&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Jesup/Kentucky-31 AR542</td>
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<td>211&lt;sup&gt;b&lt;/sup&gt;</td>
<td>202&lt;sup&gt;bc&lt;/sup&gt;</td>
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<tr>
<td>Jesup/Kentucky-31 AR502</td>
<td>1.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>246&lt;sup&gt;b&lt;/sup&gt;</td>
<td>236&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
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<td>222&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Jesup/Kentucky-31 EI</td>
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<td>SE</td>
<td>0.05</td>
<td>12</td>
<td>24</td>
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<tr>
<td>Spring (2-yr mean)</td>
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<td>Georgia-5 AR542</td>
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<td>526&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Jesup/Kentucky-31 EF</td>
<td>1.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>351&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Jesup/Kentucky-31 EI</td>
<td>0.37&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>SE</td>
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<sup>a</sup> Season x treatment interaction (<i>P</i> < 0.10).

<sup>bcd</sup> Within a column within main effect and season, means without a common superscript letter differ (<i>P</i> < 0.05).
CHAPTER 4

STEER GRAZING BEHAVIOR ON NIL ERGOT ALKALOID PRODUCING ENDOPHYTE-INFECTED, ENDOPHYTE-FREE, AND TOXIC ENDOPHYTE-INFECTED JESUP TALL FESCUE

ABSTRACT

Replicated 0.81-ha tall fescue pastures established at the Central Georgia Branch Station near Eatonton, GA in October 1998 were stocked with Hereford steers during spring 2001. Steers were grazed on nil ergot alkaloid producing endophyte-infected (AR542), endophyte-free (EF), and wild-type toxic endophyte-infected (EI) Jesup tall fescue. Grazing behavior data was collected during four 5-d periods during March, April, May, and June. Forage availability was higher \( P < 0.05 \) in EI pastures than EF pastures during May and June. Steers spent 8% more \( P < 0.05 \) time grazing and had 25% more \( P < 0.05 \) prehensions/d on AR542 and EF tall fescue than on EI tall fescue. Biting rate was higher \( P < 0.05 \) on AR542 tall fescue than EF and EI tall fescue. There were no differences \( P > 0.20 \) among pasture treatments for bite size. Steer DMI and ADG were higher \( P < 0.05 \) on AR542 and EF tall fescue than EI tall fescue. Ruminating time was higher \( P < 0.05 \) on AR542 pastures than EF and EI pastures. Cattle grazing EI pastures spent 26% more time idling \( P < 0.05 \), 21% more \( P < 0.05 \) time standing, and used 41% more \( P < 0.05 \) water than cattle on AR542 and EF tall fescue. This was likely in response to heat stress associated with fescue toxicosis. These findings indicate that steers grazing AR542 and EF tall fescue exhibited grazing behavior that supported superior growth performance over steers grazing EI tall fescue.

Key words: grazing behavior, steer, nil ergot alkaloid producing endophyte, tall fescue, toxicosis
Introduction

Tall fescue (*Festuca arundinacea*) is a cool-season grass grown on over 20 million ha of pastures and hayfields in the USA (Bouton, 2000). Despite attributes that make it a desirable forage crop, tall fescue is associated with fescue toxicosis, a condition that alters steer grazing behavior (Seman et al., 1999) and adversely affects beef cattle performance (Stuedemann and Hoveland, 1988). Economic losses to the USA beef industry from depressed growth and reproduction associated with fescue toxicosis exceed $600 million annually (Allen and Segarra, 2001). Ergot alkaloids produced by wild-type toxic endophyte-infected tall fescue (EI) have been implicated as causative agents in fescue toxicosis (Stuedemann et al., 1998). The tall fescue endophyte (*Neotyphodium coenophialum*) is a fungus that resides within the tall fescue plant and imparts positive agronomic qualities to the plant such as enhanced drought tolerance and improved vigor. Over 90 percent of tall fescue pastures in the USA contain high levels of the wild-type endophyte (Lacefield and Henning, 1995). Plant breeders have selected tall fescue plants that are endophyte-free (EF) and non-toxic to livestock, but plant persistence is lower in these EF plants than in EI tall fescue (Hill et al., 1991).

A nil ergot alkaloid producing endophyte, AR542, discovered by Ag Research in New Zealand, has been inserted into EF Jesup tall fescue, a cultivar developed for use in the main tall fescue growing regions of the southeastern USA (Bouton et al., 1997). Jesup tall fescue infected with AR542 produces none of the ergot alkaloids responsible for fescue toxicosis (Bouton et al., 1999) and
has better stand survival than EF checks and survival similar to EI checks when subjected to close grazing in bermudagrass (*Cynodon dactylon*) sod (Bouton et al., 2000). Studies in grazing lambs (McCann et al., 2000) and stocker cattle (Bondurant et al., 2000) have shown that ADG for animals grazing AR542 tall fescue were superior to animals grazing EI tall fescue and similar to animals grazing EF tall fescue. In addition, serum prolactin levels in lambs and cattle grazing EI tall fescue were depressed compared to serum prolactin levels in animals grazing AR542 and EF tall fescue. Depressed serum prolactin levels are a well-documented indicator of fescue toxicosis (Hoveland et al., 1983; Fribourg et al., 1991; Rice et al., 1997).

While grazing behavior differences have been observed in cattle on EF and EI tall fescue (Hoveland et al., 1983; Semen et al., 1990; Coffey et al., 1992), the impacts of AR542 tall fescue on cattle grazing behavior are unknown. Developing grazing systems to optimize utilization of tall fescue pastures necessitates an understanding of livestock grazing behavior in response to various endophyte situations. The objective of the present study was to compare steer grazing behavior on nil ergot alkaloid producing endophyte-infected (AR542), EF, and EI Jesup tall fescue pastures in central Georgia.

**Materials and Methods**

*Pasture Establishment and Management*

Steer grazing behavior during spring 2001 was compared on three pasture treatments: (i) AR542 Jesup tall fescue, (ii) EF Jesup tall fescue, and (iii) EI
Jesup tall fescue. Replicated (n = 2) 0.81-ha tall fescue pastures were established at the Central Georgia Branch Station near Eatonton, GA (latitude 33.3972°N; longitude 83.4883°W; elevation 167 m) on October 6, 1998. Seed supplied by J. H. Bouton was precision drilled into well-prepared Pacolet sandy loam soil at a rate of 33.6 kg/ha. The pastures were fertilized uniformly with 67 kg N/ha and P and K according to soil tests at establishment and in February and September of each subsequent year. Prior to the grazing behavior trial, from spring 1999 through autumn 2001, pastures were grazed with steers at a mean stocking rate of 3.67 steers/ha for an average of 67-d during spring and 63-d during autumn. At the beginning of spring 2001 grazing and at 4-wk intervals, thereafter, pastures were sampled for available forage by clipping herbage within a 0.09 m² quadrat from 10 randomly selected sites within each paddock. The material was dried in a forced-air oven at 60°C for 48 h, weighed, and kg DM/ha calculated. Rate of endophyte infection was assayed on tall fescue tillers near the onset and conclusion of the grazing season using an immunoblot procedure of Hiatt et al. (1998).

Animal Management and Data Collection

Eighteen Hereford steers (mean BW = 377 kg) were stocked on tall fescue pastures at an initial stocking rate of three steers/paddock in early March 2001. Two steers in each paddock were designated prior to the start of the trial as testers, while a third steer was used as a grazer in a put-and-take grazing management system. The 12 tester steers were halter broken for ease of handling prior to the start of the trial. Paddock fencing consisted of a single-
strand of polywire. Portable shades, automatic waterers, and free choice mineral blocks (Table 4.1) were available at all times in each paddock. Steers were treated for internal and external parasites at the initiation of the grazing trial.

Steer wt were collected at the initiation of grazing, d 14, d 28, and then at 5-wk intervals. Initial and final steer wt were collected on two consecutive days and averaged. Behavioral measurements were taken on tester steers over four 5-d collection periods during spring 2001 (Table 4.2). The onset of the March behavioral data collection period coincided with d 0 of the grazing trial. Prior to beginning grazing on the treatment pastures, steers were grazed on EF tall fescue and fed bermudagrass hay. Automatic jaw movement sensors (Rutter et al., 1997), leg movement sensors (Champion et al., 1997), and data recorders (Ultra Sound Advice, London, United Kingdom) (Figure 4.1) were used to measure grazing time, ruminating time, number of jaw movements (prehensions vs mastications), number of steps taken, and lying time. During each 5-d collection period behavioral data were collected for five 24 h periods that were staggered to allow time to handle animals to change recorder data cards and batteries. Data were downloaded from recorder data cards to a portable laptop computer after every 24 h of behavioral data collection. In addition, in-line water flow meters attached to automatic watering tanks measured paddock water usage. Meter readings were recorded daily during behavioral data collection periods and every 5 wk throughout the duration of the grazing trial. Paddock water usage was converted to a steer BW water usage basis by adjusting for stocking rate and steer BW.
In order to measure forage quality, two esophageally cannulated Jersey steers were fasted overnight, fitted with plastic collection bags, and grazed in each paddock until bags were filled to collect esophageal samples of forage harvested by these steers. Esophageal extrusa samples were frozen in liquid N, lyophilized, and ground through a 1 mm screen in a Wiley mill (Arthur A. Thomas, Philadelphia, PA). Samples were analyzed for DM by drying in a forced air oven at 135°C for 2 h. Crude protein was determined for extrusa samples by combustion in a Leco FP-528 Nitrogen/Protein Determinator (Leco Corp., St. Joseph, MI) and then multiplying N content by 6.25. Determination of IVDMD was performed in a Daisy™ incubator (ANKOM Technology Corp., Fairport, NY) with a modification (Holden, 1999) of the ANKOM procedure. NDF and ADF were sequentially determined using the ANKOM² Fiber Analyzer (ANKOM Technology Corp, Fairport, NY). Samples were placed in a muffle furnace (Fisher Scientific, Pittsburg, PA) at 600°C for 8 h for ash content analysis. Indigestible ADF (IADF) was determined according to the procedure of Bernard and McNeill (1991).

Controlled-release chromic oxide boli (Captec Ind., New Zealand) were orally administered as an external marker to tester steers one wk prior to each behavioral data collection period. After an 8-d equilibration period, fecal grab samples were collected for five consecutive days corresponding with behavioral data collection periods. Fecal grab samples were dried in a forced air oven at 50°C for 96 h, composited over 5-d periods by steer, ground to pass through a 1 mm screen, and analyzed for DM and IADF content according the procedures
detailed for esophageal samples. Chromium content was determined using the procedure of Fenton and Fenton (1979).

Daily fecal output was estimated by dividing the quantity of chromium released daily from the chromic oxide boli as supplied by the manufacturer by the concentration of fecal chromium. Forage indigestibility was calculated using IADF as an internal marker by dividing forage IADF content from esophageal samples by fecal IADF content. DMI was computed by dividing fecal output by forage indigestibility. Steer DMI was then adjusted for steer BW. Mean bite size in kg/prehension was determined by dividing mean daily DMI by mean daily prehensions. Biting rate was calculated by dividing prehensions by grazing time.

Statistical Analyses. GRAZE (Ultra Sound Advice, London, United Kingdom), a software program designed to analyze the behavior data files (Rutter, 2000), was used to identify periods of grazing, ruminating, and lying, and to count prehensions, mastications, and steps. Forage availability, forage quality, steer performance, grazing behavior, and water intake data were analyzed with PROC GLM/LSMEANS in SAS (SAS Inst. Inc., Cary, NC) as a completely randomized design. Paddock was the experimental unit. Main effects were endophyte treatment and period. The model included main effects and their interaction.

Results and Discussion

Weather. Maximum and minimum daily temperatures at the Central Georgia Branch Station were consistently lower during March grazing behavior data
April temperatures were warmer than typical for that time of year, and April temperature maximums were comparable to May and June temperature maximums. The difference between daily temperature maximum and minimum tended to be larger in May than in the other months. Daily minimum temperatures tended to be highest during June. Rainfall totals on grazing behavior collection dates were 0.15, 0.03, 1.57, and 1.32 cm on April 13, April 14, May 19, and June 22, respectively. No precipitation occurred on the other grazing behavior data collection dates.

**Forage Availability and Quality.** Rate of endophyte infection exceeded 62 percent in nil ergot alkaloid producing and EI pastures throughout the duration of the grazing trial. Using put-and-take grazing management, forage availability was maintained at similar levels \( (P > 0.10) \) among all treatments during during March and April (Figure 4.3). Available forage was higher \( (P < 0.05) \) in May and June than initial March available forage. May and June available forage was higher \( (P < 0.05) \) on EI pastures than EF pastures. Thus, forage on EI pastures was likely more mature than forage on EF pastures later in spring. This helps explain lower \( (P < 0.05) \) IVDMD on EI tall fescue pastures compared to EF pastures (Table 4.3). Other forage quality attributes (CP, NDF, and ADF) were similar \( (P > 0.20) \) across pasture treatments. IVDMD and CP were highest \( (P < 0.05) \) in March and lowest \( (P < 0.05) \) in May. NDF and ADF increased \( (P < 0.05) \) from March through May. Improved forage quality in June over May was likely the result of increased rainfall.
Average Daily Gain. Steer ADG from March 5 to June 11, 2001 was higher 
(P < 0.01) on AR542 and EF tall fescue than on EI tall fescue. Least squares 
means for steer ADG were 0.60, 0.71, and 0.07 ± 0.02 kg/d for AR542, EF, and 
EI tall fescue, respectively. Steer ADG was similar (P > 0.10) among pasture 
treatments during the first 28 d of grazing (Figure 4.4). Thus, adverse effects of 
EI tall fescue on steer growth performance were not pronounced during March. 
However, as ambient temperatures rose and duration of alkaloid consumption on 
EI pastures lengthened, impacts of fescue toxicosis on steer growth became 
evident. Steer ADG was lower (P < 0.05) on EI pastures and than on AR542 and 
EF pastures during 35 d beginning April 2. From May 7 to June 11, ADG was 
negative for all treatments. This may have been related to a drop in forage 
quality in May as well as elevated ambient temperatures.

Grazing Behavior. Steers spent more (P < 0.05) time grazing on AR542 and 
EF tall fescue than steers on EI tall fescue during April through June (Figure 4.5). 
This is consistent with observations by Howard et al. (1992) in which steers on 
high EI (> 60 percent wild-type endophyte infection) tall fescue grazed for a 
shorter duration than steers on low EI (< 1 percent wild-type endophyte infection) 
tall fescue. Ruminating time was highest (P < 0.05) on AR542 pastures 
compared to EF and EI pastures across periods. Idling time, time spent neither 
grazing nor ruminating, was highest (P < 0.05) on EI tall fescue than on AR542 
and EF tall fescue across months. Howard et al. (1992) reported longer idling 
time for steers grazing high EI over low EI tall fescue pastures.
Steers on AR542 and EF pastures took more prehensions/d than steers grazing EI pastures across months and during April and June (Table 4.4). Number of prehensions increased as grazing time increased. Howard et al. (1992) obtained similar results for prehensions in cattle grazing low EI tall fescue compared with high EI tall fescue. Biting rate, prehensions/h grazing, was higher \((P < 0.05)\) on AR542 tall fescue than on EF and EI tall fescue and higher \((P < 0.05)\) on EF tall fescue than on EI tall fescue (Table 4.4). Bite size was similar \((P > 0.20)\) among forage treatments and higher \((P < 0.05)\) in March than in April, May, and June (Table 4.5). The period effect for bite size was likely related to available forage levels. As available forage increased later in spring, bite size also increased. In the Howard et al. (1992) study, bite size and biting rate did not differ between steers grazing high EI tall fescue and those grazing low EI tall fescue.

Daily DMI, as estimated by the chromic oxide/IADF marker method, was adjusted for steer BW. Daily DMI was greater \((P < 0.05)\) in steers grazing AR542 and EF tall fescue than in steers grazing EI tall fescue (Table 4.5). March daily DMI was higher \((P < 0.05)\) than April, May, and June daily DMI. This period effect was likely associated with higher IVDMD and CP values in March that increased forage rate of passage through steer digestive tracts. As forage digestibility decreased later in spring, forage rumen residence time likely increased, influencing intake via gut fill. The superior forage quality in March may have resulted from the onset of the March grazing behavior collection period coinciding with d 0 of the grazing trial. Steers were on hay diets prior to March.
When grazing began, steers had access to forage that had been ungrazed for several months. This, in conjunction with lower maximum ambient temperature in March, may have contributed to higher March DMI. Paterson et al. (1995) indicated that in the absence of temperature stress, > 32°C, cows consumed similar amounts of EI and EF tall fescue. However, when environmental temperature exceeded 32°C, cows grazing EI tall fescue consumed less forage than cows grazing EF tall fescue.

Lying time was higher \((P < 0.05)\) on AR542 and EF pastures than on EI pastures during April through June (Figure 4.6). Thus, steers spent more time standing \((P < 0.05)\) on EI tall fescue. In addition, cattle spent more \((P < 0.05)\) time lying and less \((P < 0.05)\) time standing in March than in later months. Forage treatment and period effects may be the result of elevated ambient temperatures in late spring. Low et al. (1981) suggested that cattle assume a standing posture over a lying posture during heat stress in an attempt to maximize evaporative cooling. Increased time standing in shaded areas during the heat of the day has been reported for cattle grazing EI tall fescue over cattle grazing EF tall fescue (Semen et al., 1990).

Daily steer water usage adjusted for BW was higher \((P < 0.05)\) in EI and EF tall fescue pastures than AR542 pastures during May (Table 4.6). During June and across months, daily steer water usage was higher \((P < 0.05)\) on EI pastures than on AR542 and EF pastures. Additionally, steers used more water during April, May, and June than March. Elevated ambient temperatures during late spring may have been a factor in both treatment and period effects. Steers
likely used more water in response to heat stress. Excessive salivation (Stuedemann and Hoveland, 1988) and increased respiration rates (Osborn et al., 1992) have been documented for cattle grazing EI tall fescue and could enhance water intake needs. However, inconsistent findings have been reported for the effects of tall fescue endophyte status on water intake (Aldrich et al., 1993a, 1993b).

**Implications**

Steer grazing behavior on EI pastures was altered relative to AR542 and EF pastures as part of an animal response to fescue toxicosis. Cattle grazing EI pastures spent less time grazing, took fewer bites, and had lower forage intake than steers grazing AR542 and EF pastures. This helps explain lower ADG of steers on EI pastures compared with steers on AR542 and EF tall fescue. In addition, steers grazing EI tall fescue spent more time standing and used more water than steers on AR542 and EF pastures, particularly later in the spring, possibly in an attempt to cope with heat stress associated with fescue toxicosis. Thus, steers on AR542 and EF tall fescue exhibited grazing behavior that supported superior growth performance over steers on EI tall fescue. Nil ergot alkaloid producing endophyte-infected tall fescue pastures provide similar cattle growth performance as EF tall fescue pastures.
Literature Cited


Figure 4.1. Steer fitted with computerized grazing behavior measurement equipment
Figure 4.2. Maximum and minimum daily temperatures at the Central Georgia Branch Station during March (a), April (b), May (c), and June (d) 2001 on observation days for steer grazing behavior
Figure 4.3. Least squares means of available forage in nil ergot alkaloid producing endophyte-infected (AR542), endophyte-free (EF), and endophyte-infected (EI) Jesup tall fescue pastures in central Georgia during spring 2001. SE = 573. ** indicates difference between EI and EF means at each date ($P < 0.05$).
Figure 4.4. Mean steer wt on nil ergot alkaloid producing endophyte-infected (AR542), endophyte-free (EF), and endophyte-infected (EI) Jesup tall fescue during spring 2001.
Figure 4.5. Proportions of 24-h periods steers spent grazing, ruminating, or idling in March and April to June 2001 in Jesup nil ergot alkaloid producing endophyte-infected (AR542), endophyte-free (EF), and endophyte-infected (EI) tall fescue pastures.
Figure 4.6. Proportions of 24-h periods steers spent lying or standing in March and April to June 2001 in Jesup nil ergot alkaloid producing endophyte-infected (AR542), endophyte-free (EF), and endophyte-infected (EI) tall fescue pastures.
Table 4.1. Composition of mineral block supplement

<table>
<thead>
<tr>
<th>Item</th>
<th>As-fed basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium, minimum %</td>
<td>1.80</td>
</tr>
<tr>
<td>Calcium, maximum %</td>
<td>2.80</td>
</tr>
<tr>
<td>NaCl, minimum %</td>
<td>90.00</td>
</tr>
<tr>
<td>NaCl, maximum %</td>
<td>95.00</td>
</tr>
<tr>
<td>Sulfur, minimum %</td>
<td>1.00</td>
</tr>
<tr>
<td>Cobalt, minimum ppm</td>
<td>25</td>
</tr>
<tr>
<td>Copper, minimum ppm</td>
<td>150</td>
</tr>
<tr>
<td>Iodine, minimum ppm</td>
<td>90</td>
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<tr>
<td>Iron, minimum ppm</td>
<td>1500</td>
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<tr>
<td>Manganese, minimum ppm</td>
<td>3000</td>
</tr>
<tr>
<td>Selenium, minimum ppm</td>
<td>10</td>
</tr>
<tr>
<td>Zinc, minimum ppm</td>
<td>2500</td>
</tr>
</tbody>
</table>
Table 4.2. Central Georgia steer grazing behavior data collection periods

<table>
<thead>
<tr>
<th>Collection period</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>March 5 to March 10, 2001</td>
</tr>
<tr>
<td>April</td>
<td>April 9 to April 14, 2001</td>
</tr>
<tr>
<td>May</td>
<td>May 14 to May 19, 2001</td>
</tr>
<tr>
<td>June</td>
<td>June 18 to June 23, 2001</td>
</tr>
</tbody>
</table>
Table 4.3. Least squares means for nutrient composition of esophageal extrusa samples of nil ergot alkaloid producing endophyte-infected (AR542), endophyte-free (EF), and endophyte-infected (EI) Jesup tall fescue during spring 2001

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Tall fescue endophyte treatment (E)</th>
<th>Month (M)</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AR542</td>
<td>EF</td>
<td>EI</td>
</tr>
<tr>
<td>IVDMD</td>
<td>71.0 b,c</td>
<td>72.7 b</td>
<td>68.3 c</td>
</tr>
<tr>
<td>CP</td>
<td>20.0 b</td>
<td>19.9 b</td>
<td>20.1 b</td>
</tr>
<tr>
<td>NDF</td>
<td>47.6 b</td>
<td>47.7 b</td>
<td>50.3 b</td>
</tr>
<tr>
<td>ADF</td>
<td>27.3 b</td>
<td>26.6 b</td>
<td>29.1 b</td>
</tr>
</tbody>
</table>

a Level of significance for endophyte treatment x month interaction is denoted by NS for not significant \( (P > 0.20) \).
b,c,d Within a row within endophyte treatment or month, means without a common superscript differ \( (P < 0.05) \).
Table 4.4. Least squares forage and period means for prehensions and biting rate in Jesup nil ergot alkaloid producing endophyte-infected (AR542), endophyte-free (EF), and endophyte-infected (EI) tall fescue pastures during spring 2001

<table>
<thead>
<tr>
<th>Item</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>Forage mean</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prehensions, bites/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR542</td>
<td>30592 ae</td>
<td>28421 ae</td>
<td>36954 ad</td>
<td>33766 ade</td>
<td>32433 a</td>
<td>1889</td>
</tr>
<tr>
<td>EF</td>
<td>27211 ae</td>
<td>28844 ae</td>
<td>36984 ad</td>
<td>36090 ad</td>
<td>32282 a</td>
<td></td>
</tr>
<tr>
<td>EI</td>
<td>28064 ad</td>
<td>22620 ad</td>
<td>25758 bd</td>
<td>26694 bd</td>
<td>25784 b</td>
<td></td>
</tr>
<tr>
<td>Period mean</td>
<td>28622 e</td>
<td>26628 e</td>
<td>33232 d</td>
<td>32183 d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biting rate,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bites/h grazing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR542</td>
<td>3384 aef</td>
<td>3148 af</td>
<td>3890 ad</td>
<td>3655 ade</td>
<td>3519 a</td>
<td>135</td>
</tr>
<tr>
<td>EF</td>
<td>3080 ae</td>
<td>2851 abe</td>
<td>3749 ad</td>
<td>3529 ad</td>
<td>3302 b</td>
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<tr>
<td>EI</td>
<td>3073 ade</td>
<td>2661 be</td>
<td>2804 be</td>
<td>3239 ad</td>
<td>2944 c</td>
<td></td>
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<tr>
<td>Period mean</td>
<td>3179 e</td>
<td>2887 f</td>
<td>3481 d</td>
<td>3474 d</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

abc Within a column within prehensions or biting rate, means without a common superscript differ, \( P < 0.05 \).

def Within a row within prehensions or biting rate, means without a common superscript differ, \( P < 0.05 \).
Table 4.5. Least squares forage and period means for DMI, bite size, and water usage in Jesup nil ergot alkaloid producing endophyte-infected (AR542), endophyte-free (EF), and endophyte-infected (EI) tall fescue pastures, 2001

<table>
<thead>
<tr>
<th>Item</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>Forage mean</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI, g DM · kg BW⁻¹ · d⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR542</td>
<td>25.4 (^{ac})</td>
<td>12.4 (^{ad})</td>
<td>16.9 (^{ad})</td>
<td>13.0 (^{ad})</td>
<td>16.9 (^{a})</td>
<td>3.0</td>
</tr>
<tr>
<td>EF</td>
<td>23.6 (^{ac})</td>
<td>15.4 (^{acd})</td>
<td>16.0 (^{acd})</td>
<td>12.3 (^{ad})</td>
<td>16.8 (^{a})</td>
<td></td>
</tr>
<tr>
<td>EI</td>
<td>18.7 (^{ac})</td>
<td>9.5 (^{ad})</td>
<td>11.6 (^{acd})</td>
<td>9.6 (^{ad})</td>
<td>12.4 (^{b})</td>
<td></td>
</tr>
<tr>
<td>Period mean</td>
<td>22.6 (^{c})</td>
<td>12.4 (^{d})</td>
<td>14.8 (^{d})</td>
<td>11.6 (^{d})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bite size, g DM/bite</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR542</td>
<td>0.32 (^{ac})</td>
<td>0.18 (^{ac})</td>
<td>0.21 (^{ac})</td>
<td>0.17 (^{ac})</td>
<td>0.22 (^{a})</td>
<td>0.04</td>
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<tr>
<td>EF</td>
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<td>0.23 (^{acd})</td>
<td>0.20 (^{acd})</td>
<td>0.16 (^{ad})</td>
<td>0.24 (^{a})</td>
<td></td>
</tr>
<tr>
<td>EI</td>
<td>0.25 (^{ac})</td>
<td>0.17 (^{ac})</td>
<td>0.18 (^{ac})</td>
<td>0.14 (^{ac})</td>
<td>0.18 (^{a})</td>
<td></td>
</tr>
<tr>
<td>Period mean</td>
<td>0.31 (^{c})</td>
<td>0.19 (^{d})</td>
<td>0.20 (^{d})</td>
<td>0.16 (^{d})</td>
<td></td>
<td></td>
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<tr>
<td>Water usage, L · kg BW⁻¹ · d⁻¹</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>AR542</td>
<td>0.056 (^{ad})</td>
<td>0.107 (^{ac})</td>
<td>0.090 (^{bcd})</td>
<td>0.112 (^{bc})</td>
<td>0.091 (^{b})</td>
<td>0.015</td>
</tr>
<tr>
<td>EF</td>
<td>0.069 (^{ac})</td>
<td>0.111 (^{ac})</td>
<td>0.095 (^{ac})</td>
<td>0.091 (^{bc})</td>
<td>0.092 (^{b})</td>
<td></td>
</tr>
<tr>
<td>EI</td>
<td>0.072 (^{ae})</td>
<td>0.139 (^{acd})</td>
<td>0.128 (^{ad})</td>
<td>0.178 (^{ac})</td>
<td>0.129 (^{a})</td>
<td></td>
</tr>
<tr>
<td>Period mean</td>
<td>0.066 (^{d})</td>
<td>0.119 (^{c})</td>
<td>0.104 (^{c})</td>
<td>0.127 (^{c})</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{ab}\) Within a column within DMI, bite size, or water usage, means without a common superscript differ, \((P < 0.05)\).

\(^{cde}\) Within a row within DMI, bite size, or water usage, means without a common superscript differ, \((P < 0.05)\).
CONCLUSIONS

For optimum beef cattle production on tall fescue pastures, it is important to demonstrate the impacts of endophyte status on livestock toxicity and plant persistence. Livestock toxicity problems on wild-type endophyte-infected (EI) tall fescue resulting in depressed animal growth and reproductive performance have been a limiting factor in tall fescue-based cattle stockering systems. Growth performance is particularly important in stocker cattle operations since stockering is a major growth phase in beef production and product is sold on a weight basis. Use of endophyte-free (EF) tall fescue as an alternative to EI tall fescue has been limited by disadvantages in plant persistence. These studies evaluated the use of nil ergot alkaloid producing endophyte-infected (AR542, AR502) tall fescue for ruminant livestock production against EI and EF tall fescue.

Results of this research indicate that AR542 and AR502 tall fescue can be used to alleviate tall fescue toxicosis in grazing beef cattle and sheep. Absence of fescue toxicosis in ruminants grazing AR542, AR502, and EF tall fescue may have implications for animal health and comfort. Better animal health and a higher level of animal comfort are important aspects of good animal husbandry and can often translate into higher economic gains for livestock producers.

Endophyte status of tall fescue pastures affects cattle grazing behavior. Grazing time, bite count, and dry matter intake (DMI) are increased with use of non-toxic endophyte-infected and EF tall fescue over EI tall fescue. As DMI is increased, animal average daily gain is improved. Efficient animal growth
performance is key for profitability of stocker cattle enterprises on tall fescue pastures. Grazing pressure may need to be increased on EI pastures relative to non-toxic endophyte-infected and EF pastures to avoid accumulation of more mature forage as a result of lower DMI/animal. Forage nutritional quality will likely decline with increased maturity, and this can have a negative effect of animal weight gains.

Although endophyte enhancement of plant persistence has been shown to be similar between nil ergot alkaloid producing and wild-type endophytes, AR542 and AR502 tall fescue do not exert the negative feedback effect on forage intake by grazing livestock exhibited in EI tall fescue. Nil ergot alkaloid producing endophyte-infected pastures will, therefore, need to be managed more intensely than EI tall fescue. Stocking rate may need to be lower on AR542 and AR502 pastures than on EI tall fescue to maintain productive forage stands because livestock will harvest more of the nil ergot alkaloid producing endophyte-infected forage.

Management requirements and resources should be assessed when use of nil ergot alkaloid producing endophyte-infected tall fescue for ruminant livestock production is considered. Nil ergot alkaloid producing endophytes provide livestock producers with a viable option for alleviating fescue toxicosis in grazing cattle without sacrificing plant persistence. This desirable combination has been elusive in tall fescue pastures until recently. Research on production economics and forage stand persistence over time of nil ergot alkaloid producing endophyte-infected tall fescue pastures used in ruminant livestock grazing
systems is still needed to characterize this forage in terms that are relevant to beef cattle producers.