ABSTRACT

INGRAM, SAMMUEL HARPER. Renovation Strategies for Toxic Endophyte-Infected Tall Fescue for Profitability, Animal and Agronomic Performance, and Soil Health. (Under the direction of Dr. Matt Poore).

Tall fescue [Lolium arundinaceum (Schreb.) Darbysh.] is the base pasture forage for the transition zone of the eastern U.S. The majority of tall fescue pastures are infested with a fungal endophyte (Epichloë coenophiala) that produces ergot alkaloids. Specifically, ergovaline has been linked to fescue toxicosis, a $600 million annual problem for beef cattle producers. Mitigation of fescue toxicosis can be achieved through various approaches, but eradication of wild-type, endophyte-infected tall fescue and replacement with novel-endophyte tall fescue is a more certain strategy to eliminate fescue toxicosis.

Three renovation strategies for wild-type, endophyte-infected tall fescue pastures to novel endophyte-infected tall fescue were investigated for effects on soil health, animal and agronomic performance and cost during the renovation. Sixteen 0.8-ha plots previously established in wild-type, endophyte-infected tall fescue were used for this replicated field study beginning in May 2017. Novel endophyte-infected tall fescue was established in Sep 2018. Treatments included: wild-type, endophyte-infected tall fescue as control (Con), one season single species smother crop (1-SM), three-season single species smother crop (3-SM), and three-season complex mixture smother crop (3-CM). Mean initial soil bulk density was less than mean final bulk density across treatments and 3-CM and 3-SM bulk density values were higher than the control at planting. Mean initial total organic C, total N, and surface residue mass were greater than mean final concentrations, but not affected by treatments during renovation. Soil biological properties (i.e. soil microbial biomass, potential C and N mineralization, and the flush of CO₂) were generally lower for mean final concentration in comparison to initial mean concentrations.
and not affected by renovation treatments. Herbage accumulation for 3-SM was greater than the control and 1-SM, while 3-CM did not differ from the control and 1-SM HA in Summer 2017. In Summer 2018, herbage accumulation for 3-CM was greater than the control and 3-SM. Planted desirable species was >50% for the first three sampling dates in Summer 2017, but was consistently <50% for 1-SM, 3-SM, and 3-CM in Summer 2018. Animal performance on the control treatment without renovation was lower in each season compared with all other treatments. Animal performance did not differ between 3-SM and 3-CM for any grazing period and these animals had higher average daily gain (ADG) compared to all other treatments for each grazing period. Bodyweight (BW) gain per hectare was less for the control for all grazing periods in comparison to 3-SM and 3-CM in Summer 2017 and to all other treatments for Winter 2018 and Summer 2018. The observed BW gain per hectare and animal unit grazing days for 3-SM in Winter 2018 were greater than the control and 3-SM. Total return ($/ha) from BW gain per hectare was lower for the control compared to all other treatments for each grazing season. When examining total return from hay harvested in Spring 2019, no differences were observed among treatments. Net cost ($/ha) for each renovation strategy was: 1-SM, $510.68; 3-SM, $109.21; 3-CM; $247.47. All renovation treatments resulted in successful establishment of novel endophyte-infected tall fescue in Sep 2018 with an average pasture rating score (1-5) of 4.57, 4.55, 4.48 for 1-SM, 3-SM, and 3-CM, respectively. With adequate herbage accumulation and high nutritive value, animal performance was improved during the annual-forage renovation periods and offset some of the costs of renovation. However, net economic return was positive only in the control due to very low costs despite the lower returns. This study highlights the opportunity costs farmers face when renovating wild-type, endophyte-infected tall fescue pastures.
Renovation Strategies for Toxic Endophyte-Infected Tall Fescue for Profitability, Animal and Agronomic Performance, and Soil Health.

by
Sammuel Harper Ingram

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Animal Science & Poultry Science

Raleigh, North Carolina
2019

APPROVED BY:

Matt Poore
Chair of Advisory Committee

Daniel H. Poole

Miguel Castillo

Alan Franzluebbers
DEDICATION

To my family. Thank you. I love you.
BIOGRAPHY

Sam Ingram, raised in Rome, GA, developed his passion for beef cattle and agriculture during his many days spent with his grandfather, John Mack Ingram. He attended the University of Georgia where he received in B.S. and M.S. in Animal Science. He was a county extension agent from 2011-2016. In 2016, Sam came to North Carolina State University to pursue his Ph.D. in Animal Science under the direction of Dr. Matt Poore. Sam’s passion for working directly with the producer aligned perfectly with Dr. Poore’s research and extension focus. While at NC State, Sam has worked on several projects, been active in commodity organizations and helped with the extension efforts of the Poore lab. Upon completion of his Ph.D., Sam plans to work directly with the beef cattle producer to improve their productivity and sustainability.
ACKNOWLEDGMENTS

Thank you to my committee, I am appreciative of your time and guidance during this adventure. I hope to maintain relationships with you all as I have enjoyed working and learning from you. A special thanks to my advisor and mentor Dr. Matt Poore, I am so glad I made the decision to return to school and pursue a Ph.D. You have provided amazing guidance and I will always be grateful for the time and effort you put toward shaping me as a professional. To April Shaeffer, I am super thankful for you being involved in my development as a professional and I think I am stronger in the lab and field because of your guidance.

To the crew at Butner, I am very thankful for your hard work and dedication to my project. It could not have been completed without you. Thank you to Thomas Cobb and Greg Shaeffer for their tireless efforts in collecting data and responding promptly to my calls and text messages.
TABLE OF CONTENTS

List of Tables .................................................................................................................. vi
List of Figures ..................................................................................................................... vii

Chapter 1: Literature Review ............................................................................................. 1
  1.1 Tall Fescue ............................................................................................................... 2
      1.1.1 Toxicity ........................................................................................................... 4
      1.1.2 Endophyte ....................................................................................................... 5
      1.1.3 Ergot Alkaloids ............................................................................................... 6
      1.1.4 Measuring Infection and Alkaloid levels ....................................................... 7
  1.2 Fescue Toxicosis ................................................................................................ ....... 8
      1.2.1 Animal Performance .................................................................................... 8
      1.2.2 Animal Welfare ........................................................................................... 11
      1.2.3 Heat Stress ................................................................................................... 11
  1.3 Mitigation of Fescue Toxicosis ................................................................................. 12
      1.3.1 Genetics ......................................................................................................... 12
      1.3.2 Supplemental Feeding .................................................................................. 13
      1.3.3 Pasture Management .................................................................................... 14
      1.3.4 Stockpiling ................................................................................................... 14
      1.3.5 Seedhead Suppression .................................................................................. 15
  1.4 Non-Toxic Tall Fescue ............................................................................................. 16
      1.4.1 Endophyte-Free Tall Fescue .......................................................................... 16
      1.4.2 Novel Endophyte-Infected Tall Fescue ........................................................ 17
      1.4.3 Establishment ............................................................................................... 19
      1.4.4 Controlling the Tall Fescue Seedhead ........................................................... 20
      1.4.5 Killing Tall Fescue ........................................................................................ 20
      1.4.6 Interim Cropping .......................................................................................... 21
  1.5 Soil Health ................................................................................................................. 27
  1.6 Economic Analysis ................................................................................................... 29
  1.7 Conclusions and Research Objectives ..................................................................... 30

Literature Cited ............................................................................................................... 31

Chapter 2: Soil changes during the replacement of wild-type endophyte-infected tall fescue .................................................................................................................. 46
  2.1 Introduction .............................................................................................................. 46
  2.2 Materials and Methods ........................................................................................... 48
      2.2.1 Data Collection .............................................................................................. 48
      2.2.2 Statistical Analysis ....................................................................................... 50
  2.3 Results and Discussion ........................................................................................... 50
  2.4 Summary .................................................................................................................. 56

Tables and Figures ........................................................................................................... 58
Acknowledgements .......................................................................................................... 66
Literature Cited ............................................................................................................... 67
LIST OF TABLES

Chapter 2

Table 2.1 Average air temperature (°C) summary for 2017, 2018, 2019 and 30 yr-average at the North Carolina Department of Agriculture and Consumer Services Oxford Tobacco Research Station, Oxford, NC. .......................................................... 58

Table 2.2 Mean bulk density across treatments at initiation (March 2017) and final bulk density for each treatment at planting of novel-endophyte tall fescue (October 2018). ............................................................................................................ 59

Table 2.3 Mean initial concentration of routinely analyzed soil chemical properties across treatments at three soil depths (March 2017) and final concentration at two depths for each treatment at planting of novel-endophyte tall fescue (October 2018). .................................................................................................................. 60

Table 2.4 Mean initial concentration of soil chemical properties across treatments at three soil depths (March 2017) and final concentration at two depths for each treatment at planting of novel-endophyte tall fescue (October 2018). ............... 62

Table 2.5 Mean initial surface residue, C and N content, and C-to N ratio across treatments (March 2017) and final residue amount, C and N content, and C-to-N ratio for each treatment at planting of novel-endophyte tall fescue (October 2018). ........................................................................................................ 63

Table 2.6 Mean initial concentration of soil biological properties across treatments at three soil depths (March 2017) and final concentration at two depths for each treatment at planting of novel-endophyte tall fescue (October 2018). .................. 64

Chapter 3

Table 3.1 Forage species maintained or planted across treatments for the experimental period. ........................................................................................................................................................................ 88

Table 3.2 Herbage mass (HM) across treatments for each grazing period. .......................... 89

Table 3.3 Percentage of planted desirable species by weight across treatments for all sampling dates in the grazing period (2017-2019). ........................................................................................................... 90

Table 3.4 Percentage of total desirable species by weight across treatments for all sampling dates in the grazing period (2017-2019). ............................................................................................................. 91

Table 3.5 Crude Protein (CP) composition across treatments for all sampling dates in the grazing period (2017-2019). ...................................................................................................................... 92
Table 3.6 Neutral detergent fiber (NDF) composition across treatments for all sampling dates in the grazing period (2017-2019).......................... 93

Table 3.7 Acid detergent fiber (ADF) composition across treatments for all sampling dates in the grazing period (2017-2019).......................... 94

Table 3.8 Harvested hay yield for C and 1-SM (2018) and all treatments (2019). ............... 95

Chapter 4

Table 4.1 Effects of treatment on cattle BW and performance (2017-2019). ...................... 108

Chapter 5

Table 5.1 Agronomic costs for each season within the experiment. ......................... 117

Table 5.2 Agronomic cost, return and, net return for each treatment (2017-2019). ............. 120

Appendix

Table A.1 Pasture scale rating (1-5) used for rating newly established novel-endophyte tall fescue................................................................. 133
LIST OF FIGURES

Chapter 2

Figure 2.1 Monthly rainfall (mm) at the North Carolina Department of Agriculture and Consumer Services Oxford Tobacco Research Station, Oxford, NC, for 2017, 2018, 2019, and 30 yr-average. ................................................................. 58

Appendix

Table 5.1 Examples of animals from this study during the summer months in NC, including a steer on Kentucky 31 (top) and a steer on annual forage (bottom). Which steer do you want in your pasture? .............................................................. 131
CHAPTER 1: Literature Review

1.1 Tall Fescue

Tall fescue \([Lolium arundinaceum}\) (Schreb.) Darbysh. = \(Schedonorus arundinaceus\) (Schreb.) Dumort., a cool-season perennial grass, is reported to have evolved in both northern Europe and the western Mediterranean region (Borrill et al., 1971). The northern European allohexaploid (6x) tall fescue plant is believed to be a hybrid of meadow fescue (2x) \([Lolium pretense}\) (Huds.) Darbysh. = \(Festuca pratensis\) Huds.] and tetraploid fescue (4x) \(Lolium arundinaceum = [Festuca arundinacea subsp. fenas}\) (Lag.) Arcang. = \(F. arundinacea\) var. \(glaucens\) Boiss.] (Borrill, 1972). This hybrid contains the germplasm that is most commonly used to develop new tall fescue cultivars, and is likely the ancestor to Kentucky 31, the popular ecotype that was released in the U.S. in 1943 (Craven et al., 2009). Further confirming this theory, the northern European ecotypes contain the same endophytic fungus, \(Epichloë coenophiala\). found in tall fescue in the U.S., whereas several of the western Mediterranean tall fescue ecotypes contain different fungi, \(Epichloë\) sp. FaTG-2, or \(Epichloë\) sp. FaTG-3 (Young et al., 2014).

Tall fescue is best suited for well-drained soils containing moderate levels of organic matter, a temperate climate, and adequate rainfall, but it can persist in a range of soil types and withstand drought conditions and high ambient temperatures (Burns and Chamblee, 1979; Hannaway et al., 2009). This grass makes the majority of its growth in the spring and autumn but can make notable growth in mild winters and wet summers (Leasure, 1952; Cooper and Tainton, 1968; Hoveland et al., 1974). It has a growth habit similar to a bunchgrass but also produces short rhizomes (Sleper & West, 1996). Additionally, it has an extensive root system that goes
deep into the soil profile, making it a useful forage for environments with fluctuating soil conditions (Bennett, 1979).

Although tall fescue originated in Europe, where environmental conditions are more favorable for its growth, European farmers often do not plant it because of the availability of higher quality forages, such as perennial ryegrass (Whyte et al., 1959). In comparison, the harsher environmental conditions in the U.S. limit the success of many forage species that thrive in Europe. The majority of forage seed was imported to the U.S. from regions such as Europe up until the late 19th century (Vinall, 1909). Tall fescue was one imported cool-season plant that had great success in the U.S. because of its high adaptability, but its importation may have been an accident.

It is believed that tall fescue was first introduced into the U.S. by mistake as contaminant seed in meadow fescue (Vinall, 1909). There is no recorded date of introduction for tall fescue, but it is believed that meadow fescue was introduced into the U.S. prior to 1800 (Kennedy, 1900). Issues such as mischaracterization of tall fescue with meadow fescue and vice versa makes tracking the early history of tall fescue in the U.S. difficult. The rise in popularity of tall fescue was closely related to the decline in acceptance of meadow fescue in the U.S. (Buckner et al., 1979). At the Kentucky Agricultural Experiment Station in Lexington, Kentucky, tall fescue was described as being taller, more drought tolerant, more winter hardy, and better able to form a dense sod than meadow fescue (Garman, 1900). On the Potomac flats in Washington, D.C., the USDA conducted forage testing of several types of grasses, including tall fescue, and it was described as a valuable grass for hay or pasture (Lamson-Scribner, 1896). At the turn of the 20th century, research efforts for meadow fescue were deemed complete and attention was then given to tall fescue. At the same time, tall fescue was sown in Pullman, Washington to study its seed
production traits, providing information about a crucial aspect for successful large-scale adoption (Oakley, 1908). For several years following this research, tall fescue was studied and examined in an effort to release a forage well suited for many of the growing conditions across the U.S.

In the 1940s, Alta and Kentucky 31 tall fescue cultivars were released in the U.S. At the time of release of these two cultivars, tall fescue planted was present on 16,000 ha. In 1979, Buckner et al. (1979) estimated occurrence on 14 million ha. These two cultivars are recognized as the major reason for a dramatic shift to perennial grass plantings in the U.S. and the increase in forage research (Buckner et al., 1979; Hoveland, 2009).

The cultivar ‘Alta’, originated from the Oregon Experiment Station in Corvallis, Oregon under the direction of H.A. Schoth (Hollowell, 1945). This ecotype was selected from a four-year-old tall fescue stand in 1923. It is believed that a portion of the germplasm for Alta came from the sowing of tall fescue previously mentioned in this section. It was selected for its winter hardiness and ability to stay green during prolonged drought conditions in southern Oregon (Cowan, 1956). It was recognized as a high forage producer and was very prolific compared to meadow fescue, so it quickly replaced it. It was planted extensively in the Pacific Northwest and could also be found in the southwest U.S. in irrigated pastures (Asay et al., 1979).

Kentucky 31 tall fescue is an ecotype developed at the Kentucky Agricultural Experiment Station in Lexington, Kentucky under the direction of E. N. Fergus (Fergus and Buckner, 1972). It originated from a farm in Menifee County, Kentucky. Dr. Fergus took notice of the grass in 1931 after hearing from local farmers about a productive forage that stayed green throughout most of the year (Fergus, 1952). Seed was collected from this farm and after 12 years of trials and selection, Kentucky 31 was released in 1942 (Fergus and Buckner, 1972). This cultivar is widely adapted to a range of climates and soils and is more resistant to leaf diseases than Alta.
(Asay et al., 1979). It was the most drought-resistant cool-season grass for the southeastern U.S. at the time of its release, and it soon dominated the southern pasture landscape, where no previous cool-season grass had been able to survive the harsh summers (Ball et al., 2015).

1.1.1 Toxicity

Shortly after the release of Kentucky 31, lameness in cattle grazing tall fescue was reported in the U.S. (Pratt and Haynes, 1950). In New Zealand, Cunningham (1949) described similar symptoms in cattle grazing tall fescue during the winter. This syndrome, known as fescue foot, is most prevalent in the northern areas of the U.S. tall fescue region but is also observed in the southern areas during the winter months (Bush et al., 1979; Bacon, 1994). Cattle with the syndrome that are left on tall fescue do not recover, and in severe cases, must be euthanized (Cunningham, 1949). Fat necrosis syndrome is characterized by the presence of hard fat masses in the adipose tissue, most frequently the adipose tissue of the abdominal cavity (Bush et al., 1979). This syndrome can cause disruption in digestion and calving (Edgson, 1952; Bush et al., 1979). It was first associated with poultry production areas of the southeastern U.S., and Stuedemann et al. (1975) reported an increase in fat necrosis occurrence in cattle grazing tall fescue pastures heavily fertilized with poultry litter. Summer syndrome describes the overall poor performance of cattle grazing tall fescue, including intolerance to heat and inability to shed the winter hair coat, and is most prevalent during the summer months (Stuedemann and Hoveland, 1988; Ball et al., 2015). Fescue toxicosis is an all-encompassing term that describes the range of issues observed in animals grazing wild-type, endophyte-infected tall fescue. It is estimated that this disease costs livestock farmers $1 billion annually (Bouton 2007; Strickland et al., 2011).
1.1.2 Endophyte

Shortly after the release of tall fescue, it was suspected that the issues reported in cattle grazing tall fescue were related to ergotism, which is commonly seen in animals and humans consuming ergot-contaminated grain, but this theory could not be proven at the time (Ball et al., 2015; Strickland et al., 2011). Several scientists actually ruled out fungi as a cause of the symptoms because it was not visibly present on the seed or the plant, possibly delaying the identification of the cause (Fribourg and Waller, 2009). It was not until 1973 when Drs. J.D. Robbins, C.W. Bacon, and J.K. Porter from the USDA Russell Research Center in Athens, GA isolated endophytic fungi from a tall fescue pasture within the state that researchers began to focus on this group of symptomless (nonsporulating) fungi as the causative agent of the disease (Bacon et al., 1977). The fungus was identified as *Epichloë typhina* by the group based on previous work from Sampson (1933). Shortly thereafter, the fungus was renamed *Acremonium coenophialum* by Morgan-Jones and Gams (1982). After reclassification of *Acremonium* fungi to *Neotyphodium*, the fungus was renamed *Neotyphodium coenophialum* (Glenn et al., 1996). After a shift in fungi nomenclature rules in 2011, Leuchtmann et al. (2014) reclassified all members of the *Neotyphodium* clade in the genus *Epichloë*. Therefore, the fungus observed in tall fescue is now recognized as *Epichloë coenophiala*.

It is now known that tall fescue, along with many other grass species within the subfamily Pooideae, can form a mutualistic relationship with *Epichloë* fungi (Christensen and Voisey, 2009). *E.coenophiala* can be found in all above-ground plant tissues, including plant seed. The plant provides space and nutrients to the endophyte. The fungal endophyte provides protection from environmental stressors such as drought, pests, and overgrazing to the plant, making the relationship between the plant and the endophyte truly mutualistic (Siegel et al.,
1984; Bacon et al., 1986). It is estimated that 90% of the 15 million hectares of U.S. tall fescue are endophyte-infected with *E. coenophiala* (Young et al., 2014).

The fitness benefits observed in *E. coenophila*-infected tall fescue are a result of bioactive alkaloid production from the endophyte (Siegel et al., 1996; Strickland et al., 2011; Young et al., 2014). Alkaloids produced by *Epichloë* species in infected tall fescue include peramine, lolines, indole-diterpenes, and ergot alkaloids (Siegel et al., 1996). Peramine has been reported as an insect feeding deterrent. Loline has been reported as an insect toxicant. Lolitrem B and ergot alkaloids are also insect toxicants, but they have shown additional negative effects on cattle, sheep, and horses (Bacon et al., 1986; Klotz and Nicol, 2016).

### 1.1.3 Ergot Alkaloids

Alkaloids are naturally occurring, nitrogen containing, organic compounds that are predominately produced in plants. Ergot alkaloids are within the peptide alkaloid class and contain a tetracyclic ring structure (Strickland et al., 2011). Three separate subclasses exist within ergot alkaloids, including: 1) clavine alkaloids, 2) lysergic acid amides, and 3) ergopeptines (Bush and Fannin, 2009). Ergot alkaloids can be found throughout the tall fescue plant. In general, alkaloid concentration is greatest in seed and the seedhead, followed by the crown, stems, leaves, and roots (Rottinghaus et al., 1991). Concentration of ergot alkaloids in tall fescue fluctuates during the year. For the southeast, a peak occurs in late spring and again in early autumn (Bush and Fannin, 2009).

Ergovaline, an ergot alkaloid, has received the most attention and credit for fescue toxicosis symptoms since Lyons et al. (1986) reported it to have the highest concentration of the five ergot alkaloids detected in tall fescue. Animals grazing tall fescue infected with endophytes that did not produce ergovaline demonstrated similar performance to animals grazing non-
infected tall fescue (Parish et al., 2003; Watson et al., 2004). The structure of ergovaline and other ergot alkaloids is very similar to biogenic amines (e.g. dopamine), and it can agonize or antagonize the action of a neurotransmitter, eliciting a neurological effect (i.e. toxicosis) (Levin and York, 1978; Klotz and Nicol, 2016). Other alkaloids and alkaloid metabolites are likely to contribute to the symptoms seen in cattle grazing wild-type, endophyte-infected tall fescue, but ergovaline has been the major peptide investigated and reported to date (Hill et al., 2001, Klotz and Nicol, 2016).

1.1.4 Measuring infection and alkaloids

After discovery of the wild-type, fungal endophyte in tall fescue, researchers focused on developing techniques to identify and quantify infection levels in tall fescue pastures. Infection frequency is traditionally measured as the presence or absence of the endophyte from the tiller or seed of a single plant. A representative sample is collected from a field to determine that field’s infection frequency and presented as a percentage (%) (Barker et al., 2009). Initially the endophyte was identified using a microscope (Clark et al., 1983), but a monoclonal antibody kit produced commercially starting in 2000 has become the preferred method because of the increased reliability, faster results, and decreased operator bias (Hill et al., 2002).

With an improvement in the understanding of fescue toxicosis, quantification of the ergot alkaloids concentration in the plant became necessary to better manage wild-type, endophyte-infected tall fescue pastures. High-performance liquid chromatography can test singularly for several of the ergot alkaloids identified in tall fescue (Rottinghaus et al., 1991). Enzyme-linked immunosorbent assay methods are also available, providing a quantification of total ergot alkaloid concentration (Barker et al., 2009). Other methods are available, but the two previously mentioned are the most common methods in practice.
1.2 Fescue Toxicosis

Tall fescue is the base forage species for pasture in the transition zone of the U.S. humid region (Poore, 2010). As previously mentioned, this plant persists in a range of environments principally because of its enhanced vigor endowed by *E. coenophila*. The ergot alkaloids produced by this fungus are believed to cause the symptoms associated with fescue toxicosis, such as reduced weight gain, reduced reproductive performance, heat intolerance, and vasoconstriction. The chronic exposure to alkaloids and subsequent decrease in livestock productivity is estimated to cost U.S. beef cattle farmers $1 billion annually (Kallenbach, 2015; Klotz, 2015). The next sections of this review will focus on poor animal performance and animal welfare symptoms associated with fescue toxicosis, as well as research findings on methods to mitigate these symptoms.

1.2.1 Animal performance

The damaging effects on cattle performance as a result of consumption of wild-type, endophyte-infected tall fescue have been thoroughly documented (Parish et al., 2003; Watson et al., 2004; Klotz, 2015). Liveweight gain is economically important in animal production agriculture. Early research utilized steers to examine the effects of wild-type, endophyte-infected tall fescue consumption on liveweight gain (Waller, 2009). More recently, the impact of wild-type, endophyte-infected tall fescue consumption on the reproductive performance of cattle has been studied to better understand the direct and indirect effects of ergot alkaloid exposure (Klotz, 2015; Poole et al., 2018).

Average daily gain

Average daily gain in cattle consuming tall fescue infested with *E. coenophila* has been shown to be less than that of cattle consuming non-infested tall fescue (Bacon et al., 1977;
Chestnut et al., 1991). Hoveland et al. (1983) saw improvement in the gain of steers grazing non-infected tall fescue in a four-year grazing study with the non-infected treatment group averaging 0.83 kg/d and the fungus-infected group averaging 0.50 kg/d. Read and Camp (1986) observed an improvement in average daily gain similar to Hoveland et al. (1983) in low-level (<5%) infected tall fescue compared to high-level (>90%) infected tall fescue, furthering the theory of the fungus being the causal agent of the symptoms. Paterson et al. (1995) summarized the results from several southeast states and showed a uniform decrease in weight gain of steers grazing infected tall fescue from 30-100% less than steers grazing non-infected tall fescue. Prior to the identification of ergot alkaloids in tall fescue, farmers were advised to expect a 0.045 kg/d decrease in weight gain with every 10% increase in infection level (Paterson et al., 1995). This early research took place during the summer months, and more recently information of animal performance on stockpiled tall fescue has become available.

Drewnoski et al. (2009a) showed no difference in average daily gain of steers and heifers grazing stockpiled tall fescue with varying levels of endophyte infection during the winter months in the southeastern U.S. Further, Lyons et al. (2016) observed similar gains for heifers grazing stockpiled wild-type, endophyte-infected tall fescue. Ergot alkaloids are known to interact with serotonergic receptors, which are important in regulating gut motility, and it is speculated that these alkaloids have a negative impact on passage rate, and thereby voluntary feed intake (Klotz, 2015). Further, an interaction between ergot alkaloid consumption and elevated ambient temperatures can reduce animal intake (Hemken et al., 1981; Aldrich et al., 1993). Ergot alkaloid concentrations have been shown to dramatically decrease from December to March (Kallenbach et al., 2003; Drewnoski et al., 2007). On the same experimental plots as Drewnoski et al. (2009a), Drewnoski et al. (2009b) observed a decrease in average daily gain for
heifers grazing wild-type, endophyte-infected tall fescue in comparison to novel endophyte-infected and endophyte free tall fescue from April to June. The increase in ambient air temperatures and ergot alkaloid concentration during this time of year was likely the factor in differences observed for this study.

**Reproductive performance**

Reproductive performance of beef cattle has been shown to improve with the decrease of wild-type, endophyte-infected tall fescue plants in pastures (Boiling, 1985; Gay et al., 1988; Porter and Thompson, 1992). Schmidt et al. (1986) observed a 96% conception rate of beef cows grazing low infested tall fescue pastures and 55% for beef cows grazing highly infested tall fescue pastures. In an examination of impact of breeding dates on calving rates for cows grazing wild-type, endophyte-infected tall fescue, Caldwell et al. (2013) showed a dramatic difference in calving rates for a fall calving herd (90%) in comparison to a spring calving herd (44%). For the fall calving herd, breeding occurred in December when mean ergot alkaloid concentrations were 402 µg/kg for their respective pasture, whereas the spring calving herd was bred at the end of May where pastures averaged 799 µg/kg total ergot alkaloids. In contrast, Drewnoski et al. (2009) found no difference in pregnancy rate of heifers consuming wild-type, endophyte infected tall fescue, endophyte free tall fescue and novel endophyte-infected tall fescue that were bred in late March. The author speculated the difference observed in calving rates could have been a result of differences in ergot alkaloid concentrations within pasture at the time of breeding and (or) ambient temperature differences at time of breeding.

As previously mentioned, ergot alkaloids have a structure similar to biogenic amines and can act on their receptors (Larson et al., 1999). Similar to animal performance, the mechanisms involved in the broad disruption of reproduction is not clear. Poole et al. (2018) showed reduced
vessel diameter and potential blood flow to reproductive tissues due to no change in blood pressure in cattle fed wild-type, endophyte-infected tall fescue seed, indicating that vasoconstriction plays an important role in the impact. Furthermore, reduction in dry matter intake and digestible nutrients also negatively impacts maintenance and growth of beef heifers. These findings show some of the causes of the reproductive challenges with wild-type, endophyte-infected tall fescue, but further research is needed to better understand the mechanisms responsible for these symptoms.

1.2.2 Animal Welfare

Animals exhibiting fescue toxicosis typically retain their winter hair coat, have elevated core body temperature, increased respiration rate, and excessive salivation in the summer months (Oliver, 2005). In extreme cases, cattle consuming wild-type, endophyte infected tall fescue may slough off hooves, tail, and ear tips during the winter months. Cattle may exhibit lameness initially, followed by an occasional tremor, and finally, necrosis in extreme cases (Bush et al., 1979). The general effect of vasoconstriction by ergot alkaloids contributes to many of these symptoms, except for retained winter hair coat, which further disrupts thermoregulation in the summer months (Klotz, 2015). As the importance of animal welfare and transparency in animal production agriculture increases, long-term solutions to decreasing these symptoms are needed.

1.2.3 Heat Stress

It is critical for production animals to maintain normal body temperatures for metabolic processes. Heat stress is defined as elevation of body temperature sufficient to elicit a disruption in animal performance and physiology (Fuquay, 1981). Cattle dissipate 85% of their total heat production via sweating and the remaining 15% via the respiratory tract (i.e. panting). With vasoconstriction caused by the ergot alkaloids ultimately decreasing heat dissipation via
evaporative cooling, animals rely more heavily on panting to dissipate heat (McClanahan et al., 2008). Separating the effects of heat stress and ergot alkaloid exposure is difficult, and many of the signs overlap. However, Osborn (1988) observed increased respiration rate and rectal temperature, along with decreased intake in cattle consuming wild-type, endophyte-infected tall fescue in high ambient temperatures compared to cattle consuming the endophyte free tall fescue diet, indicating that heat stress is intensified when combined with ergot alkaloid exposure.

1.3 Mitigation of Fescue Toxicosis

1.3.1 Genetics

The incorporation of *Bos indicus* (i.e. Brahman) genetics into *Bos taurus* (i.e. Angus and Hereford) cow herds pastured on wild-type, endophyte-infected tall fescue has been shown to alleviate some symptoms associated with fescue toxicosis (Goetsch et al., 1988; McMurphy et al., 1990). Brahman cattle have greater skin surface area to dissipate heat compared to Angus and Hereford cattle, therefore lessening the impact of heat stress (Finch, 1986; Gaughan et al., 1999). Morrison et al. (1988) saw liveweight gains decrease more severely in British-breed steers grazing wild-type, endophyte-infected tall fescue pastures compared to Brahman crossbred steers. The acceptability of Brahman cattle by beef cattle farmers in the transition zone of the eastern U.S. is limited because of the breed’s reputation for poor carcass quality, temperament, and decreased marketability (Hammond et al., 1996). More recently, research regarding body temperature regulation in *Bos taurus* cattle developed in the American tropics (i.e. Senepol) has shown some alleviation of fescue toxicosis symptoms. These improvements in animal performance are attributed to a specific genetic mutation in the Senepol breed and other Criollo breeds that results in a slick hair type (Porta-Neto et al., 2018). Browning (2004) found no difference in growth rate of Senepol steers fed orchardgrass hay or wild-type, endophyte-infected
tall fescue hay over a two-year period, and a decrease in respiration rate compared to Hereford steers fed the same diets. Poole et al., (2019) reported lower surface temperatures and respiration rates for cattle that contained the slick hair genetic trait in comparison to those that did not while consuming wild-type, endophyte-infected tall fescue in a total mixed ration. Senepol production traits align more closely with the traditional British influenced breeds in the U.S. than Brahman cattle, improving the probability of farmer acceptance. More research into incorporation of this slick hair coat trait, which is dominant and heritable is needed to further assess this practice as another management strategy for producers dealing with fescue toxicosis.

1.3.2 Supplemental Feeding

Providing access to forages other than wild-type, endophyte-infected tall fescue or providing grain concentrates or protein supplementation can improve the performance of cattle pastured on wild-type, endophyte-infected tall fescue through intake substitution and increasing the net energy of the diet (Stokes, et al. 1988). Steers grazing wild-type, endophyte-infected tall fescue and supplemented with ground corn at 0.65 % BW showed a two-fold improvement in liveweight gain compared to steers not receiving a corn supplement (Stokes et al., 1988). Beck et al. (2006) reported 0.11 kg/d improvement in steers supplemented with corn or crude protein in comparison to steers not supplemented while grazing wild-type, endophyte-infected tall fescue pasture. Similarly, Aiken et al. (1998) observed that feeding a free-choice corn-broiler litter mixture to steers that were grazing wild-type, endophyte-infected tall fescue pasture increased liveweight gain. Additionally, Aiken et al. (2008) observed a 0.2 kg/d gain increase in steers supplemented with soybean hulls at 1% BW in comparison to steers receiving no supplement while grazing wild-type, endophyte-infected tall fescue pasture. Lyons et al. (2016) reported 0.11 kg/d improvement in heifers given access to a 34% protein tub. Finally, Poore et al. (2006)
reported an improvement in heifer liveweight gain when fed whole cottonseed, indicating concentrate by-products can also reduce the severity of fescue toxicosis. However, concentrate supplement costs directly impact the probability of obtaining profitable weight gains on wild-type, endophyte-infected tall fescue pasture (Aiken et al., 2008). In a review of supplementation strategies used to mitigate fescue toxicosis, Gadberry et al. (2015) reported that fibrous energy sources supplemented up to 1% BW had an estimated feed conversion of 6:1 and could be a cost-effective strategy for farmers to use when managing fescue toxicosis.

1.3.3 Pasture Management

The incorporation of legumes into tall fescue pasture has had a long history of improving cattle performance. Fergus (1952) recommended incorporating legumes into tall fescue plantings to decrease commercial nitrogen usage and improve pasture nutritive value. Blaser et al. (1956) observed an increase in gain in steers grazing a tall fescue-clover pasture compared to tall fescue alone. Additionally, the tall fescue pastures received 242 kg/ha of nitrogen whereas the tall fescue-clover pasture received no nitrogen. McMurphy et al. (1990) reported a 0.64 kg/d gain increase in Angus steers pastured on wild-type, endophyte-infected tall fescue interseeded with clover. Andrae et al. (2006) and Beck et al. (2008) reported more moderate increases at 0.2 kg/d for steers grazing wild-type, endophyte-infected tall fescue pastures interseeded with clover. In all studies, gain per hectare was not affected by treatment, and grazing days were decreased with incorporation of clovers. Finally, when studies examine the incorporation of legumes into endophyte free tall fescue pastures, an improvement of liveweight gain is observed (Chestnut et al., 1991; Thompson et al., 1993), indicating the legumes provide an additive effect across forage species.
1.3.4 Stockpiling

Stockpiling tall fescue consists of conserving standing forage for deferred grazing and usually takes place in autumn (Roberts et al., 2009). Concentrations of ergovaline, the putative causative alkaloid in fescue toxicosis, drastically decrease in the winter months in the U.S. Kallenbach et al. (2003) observed an 85% ergovaline decrease in stockpiled tall fescue from December to March in Mt. Vernon, MO. Additionally, stockpiled tall fescue retains adequate nutritive value, therefore providing an opportunity to extend the grazing season for many beef cattle producers (Poore et al., 2000). However, cattle must be removed from the pasture to accumulate the forage, and gains may not be adequate for growing animals (Poore et al., 2010). Finally, with tall fescue being the base forage species on southern beef cattle farms, it would be difficult to only graze wild-type, endophyte-infected tall fescue during the months in which ergot alkaloid concentrations are the lowest.

1.3.5 Seedhead suppression

Tall fescue seeds contain the highest ergot alkaloid levels within the plant (Bush and Fannin, 2009). Rogers et al. (2011) showed that monthly clipping, beginning in the spring, reduced total ergot alkaloid content by delaying plant maturity and seedhead formation. Spraying tall fescue with a plant growth regulator delays seedhead development, causing the plant to stay in the vegetative state and delaying maturity and the subsequent decline in nutritive value (Turner et al., 1990). Furthermore, delaying maturity limits seedhead formation and reduces total alkaloid concentrations in wild-type, endophyte-infected tall fescue pastures (Aiken et al., 2012). Turner et al. (1990) observed a 20% improvement in average daily gain in cattle grazing wild-type, endophyte-infected tall fescue pastures treated with the plant growth regulator metfluidide (N-2,4(dimethyl – 5 – [{trifluoromethyl}sulfonyl]amino]-phenylacetamide). However, this
product is not labeled for use in pastures. Aiken et al. (2012) reported similar results to Turner et al. (1990) with Chaparral herbicide, which contains (2-pyridine carboxylic acid, 4-amino-3,6-dichloro-) and metsulfuron-methyl {Methyl 2-[[[(4-methoxy-6-methyl-1,3,5-tiazin-2-yl)-amino]carbonyl] amino]sulfonyl]benzoate}. Goff et al. (2014) observed an 80% reduction in seedhead density with minimal plant injury in tall fescue pastures treated with Chaparral at 2 oz per acre in April in Kentucky. However, timing of application, herbicide usage rates, and rainfall immediately following application can affect success rates of seedhead suppression and may limit the adoption of this practice.

1.4 Non-toxic tall fescue

Replacing wild-type, endophyte-infected tall fescue pastures with endophyte free or novel, endophyte-infected tall fescue is an option for farmers. If successfully completed, this option eliminates fescue toxicosis, while all of the other options discussed to this point only reduce the severity of the issue (Bouton et al., 2002). Cultivars that are endophyte-free and produce no ergot alkaloids, or cultivars that have introduced endophytes that produce no, or nil amounts of alkaloids are available to farmers. Early research focused on endophyte-free tall fescue as the answer for fescue toxicosis, but lack of plant persistence has shifted research to ‘novel’ endophyte-infected tall fescue. The next sections of this review will focus on the development of endophyte-free and ‘novel’ endophyte-infected tall fescue cultivars and the limited information available on replacing wild-type, endophyte-infected tall fescue pastures.

1.4.1 Endophyte-free Tall Fescue

When *E. coenophila* was first suspected as the causative agent for fescue toxicosis, researchers did not know of the fitness benefits the fungus provided to the plant (Hoveland et al., 1983; Fribourg et al., 1988). During this time, the knowledge of *E. coenophila* and its role in
fescue toxicosis was limited to a report from Robbins and staff showing improved animal performance on tall fescue pastures with low endophyte levels (Bacon et al., 1977). Hoveland et al. (1983) reported a 0.33 kg/d improvement in steers grazing low endophyte level (<5%) tall fescue pastures. This information, along with other grazing trials, prompted plant breeders to remove the endophyte from tall fescue. Pederson and Sleper (1988) suggested that prior to the evaluation of any new tall fescue line, the endophyte should be removed. However, stand persistence, insect pressure, and drought tolerance issues were reported in endophyte-free fields (Siegel et al., 1984; Read and Camp, 1986). Nevertheless, plant breeders believed that a proper plant breeding program could address many of the issues observed in the endophyte-free fields (Pederson and Sleper, 1988).

As endophyte-free tall fescue cultivars were being marketed and sold, farmers were reporting issues of stand loss (West et al., 1993). Siegel et al. (1987) reported that *E. coenophila* must be a mutualistic symbiont after comparing reports of plant (host) fitness and fitness of the fungus living independently to the two living in association. This information stimulated researchers to investigate this mutualistic relationship in more detail and explore other host endophytic relationships such as those seen in perennial ryegrass (Latch et al., 1993).

1.4.2 Novel-endophyte Tall Fescue

With a better understanding of the benefits that *E. coenophila* provides to the tall fescue plant, researchers focused their efforts on the heritability of alkaloid production within plants, genetic manipulation of endophytes to reduce ergot alkaloid production, and identification of naturally occurring, nontoxic endophytes (Bouton et al., 2002). Adcock et al. (1996) reduced alkaloid concentration by 86% after two generations of selection from a low-alkaloid producing tall fescue population. Disruption of the enzymes responsible for synthesizing ergot alkaloids
was also achieved (Schardl, 1996), but was not further pursued because the methodology at the
time was very new and underdeveloped. The most promising approach was the identification of
naturally occurring, nontoxic strains as a result of the previous identification of similar strains in
perennial ryegrass and the availability of tall fescue strains in New Zealand (Bouton et al., 2002).
These strains were transferred into improved endophyte-free tall fescue cultivars, resulting in a
plant with an introduced, non-toxic endophyte.

Bouton et al. (2002) examined two previously released tall fescue cultivars, Georgia 5
and Jesup, after reinfection with five ‘novel’ endophytes for infection levels and total ergot
alkaloid production, followed by agronomic performance and animal performance on selected
tall fescue-endophyte combinations. Endophytes were obtained from AgResearch (AR)
Grasslanz, Palmerston North, New Zealand (Latch et al., 2000). Georgia 5 infected with
endophyte AR542 and Jesup (AR542) possessed survival qualities equal to their wild-type,
endophyte-infected versions two years after planting and were further examined for yield and
animal performance (Bouton et al., 2002). Dry matter yields for Jesup (AR542) and Georgia5
(Ar542) were no different from their respective wild-type, endophyte-infected versions, and
their average daily gains were comparable to their endophyte-free versions (Bouton et al., 2002).
Finally, Bouton et al. (2002) showed that infection transmission and maintenance of endophyte-
plant relationship was greatest for Jesup (AR542), solidifying this combination of plant and
endophyte as the best option for replacement of wild-type, endophyte-infected tall fescue. It was
later trademarked as Jesup MaxQ and made commercially available by Pennington Seed,
Madison, GA.

Since the release of Jesup MaxQ, several studies have examined the agronomic and
animal performance of differing novel endophyte-infected tall fescue associations. Positive
agronomic and animal performance observations were made for AR542 in association with Jesup tall fescue for several studies across the southeast U.S. (Watson et al., 2004; Hopkins and Alison, 2006; Vibart et al., 2008; Franzluebbers et al., 2009; Drewnoski et al., 2009b). In an examination of HiMag4, a tall fescue infected ‘strain 4’ endophyte, directly compared to wild-type, endophyte-infected tall fescue, Nihsen et al. (2004) and Lomas et al. (2011) reported greater ADG for cattle consuming the novel endophyte-infected tall fescue. Further, Parish et al. (2013b) examined the association of AR584, a novel endophyte, with three different endophyte free cultivars in comparison to Jesup MaxQ and wild-type, endophyte-infected tall fescue for ADG and herbage mass. No differences were observed for herbage mass produced between treatments. Animal performance was superior for AGRFA 150, which was ‘KYFA 9301’ tall fescue infected with AR584, in comparison to other novel endophyte-infected tall fescues and the control. When examining stand persistence and animal performance for BarOptima Plus E34, a soft-leaf tall fescue infected with the novel endophyte E34 that does produce greater levels of ergot alkaloids in comparison to other novel varieties (Beck et al. 2009), stand density did not differ between BarOptima Plus E34 and toxic endophyte-infected tall fescue during the two-year grazing study. Both were greater in comparison to endophyte-free tall fescue. Further, animal performance was improved for BarOptima Plus E34 and endophyte-free tall fescue in comparison to the control leading Beck et al. (2009) to suggest the boost in performance could provide producers with an incentive to renovate toxic pastures and plant novel endophyte infected tall fescue.

1.4.3 Establishment

Current information about replacing toxic tall fescue and establishing non-toxic tall fescue is based on small plot studies or unpublished trials, while no information has been provided on a large-scale renovation study. Nonetheless, a detailed plan should be developed for
establishment of non-toxic tall fescue in old toxic tall fescue pastures (Fribourg et al., 1988). Many systems have been developed to kill toxic tall fescue pastures and establish non-toxic tall fescue, and in general, follow the approach of: i) inhibiting toxic tall fescue seedhead formation prior to replacement, ii) mechanically or chemically destroying existing tall fescue, iii) leaving ground fallow or planting a ‘smother crop’ prior to planting non-toxic tall fescue, and iv) planting non-toxic tall fescue. In regions where summer drought is possible, a fall seeding at least 2 weeks prior to the first hard freeze is the best option for establishing tall fescue (Fribourg et al., 1988).

1.4.4 Controlling Seedhead

Producers should control tall fescue seed production in the spring of the year that tall fescue is planted. Hill et al. (2010) reported tall fescue seeds averaging 25% germination and 33% endophyte infection after laying at the soil surface from seed harvest to October 1 in Watkinsville, GA. Additionally, tall fescue seeds on the soil surface or buried in the soil can survive up to 1 year (Pederson et al., 1984). Therefore, seed head formation must be prevented to limit this infestation mode in newly renovated pastures (Fribourg et al., 1988). As previously mentioned, Rogers et al. (2011) observed a reduction in seedhead formation by clipping vegetative tall fescue in the spring. Similarly, Jung et al. (1996) showed that grazing cool-season grasses in the spring can result in a reduction in seedhead formation and increase tillering. Finally, Goff et al. (2014) observed an 80% reduction in seedhead density after applying Chapparal herbicide. Use of Chapparal or similar residual herbicides can increase the waiting period for planting new seedlings up to 12 months (Fribourg et al., 1988). Thus, it is recommended to control seedhead formation via clipping or grazing in the spring in order to maximize success of establishing non-toxic tall fescue.
1.4.5 Eradicating Tall Fescue

Tillage should not be used in most cases to destroy toxic tall fescue because of the high soil erodibility of many tall fescue pastures sites (Fribourg et al., 1988; Smith, 1989). Therefore, herbicides that can adequately kill tall fescue, and a subsequent sod seeding, are recommended to replace toxic tall fescue (Washburn and Barnes, 2000). Fall applications of paraquat [1,1’-dimethuyl-4,4’-bipyridinium ion] at 0.3 kg ai/ha or glyphosate at 1.3 kg ai/ha controlled 80% to 100% of toxic tall fescue. Spring applications of paraquat at 0.3 kg ai/ha resulted in only a 60% control of tall fescue for a single application, whereas glyphosate applied at 1.1 kg ai/ha resulted in 90% control. Additionally, Washburn and Barnes (2000) observed an 88% reduction in tall fescue cover after a spring application of glyphosate at 2.2 kg ai/ha. Similarly, Bagegni et al. (1994) reported a spring application of glyphosate at 1.7 kg ai/ha and paraquat application of 0.6 kg ai/ha resulted in a 97% and 64% control of tall fescue, respectively. Finally, only a 10-day interval after a glyphosate application is needed for successful seeding of grasses (Campbell, 1976). With this information in mind, and the fact that paraquat is now registered as a restricted-use herbicide, glyphosate should be the recommended herbicide for tall fescue control.

1.4.6 Interim Cropping

Planting one or more annual forage crops after application of glyphosate on preexisting toxic tall fescue prior to planting non-toxic tall fescue could help achieve complete eradication of toxic tall fescue and offset the costs of the renovation (Bagegni et al., 1994). Fribourg et al. (1988) suggested that grain crops, annual forages, and even alfalfa could be used in the interim to compete with tall fescue and provide income during the process. Tripplett et al. (2001) observed 95% to 100% control of tall fescue plants when using corn and soybean varieties tolerant to glyphosate applications. However, results of infestation of toxic tall fescue in non-toxic plantings
have not been reported from these studies. Further, access to the equipment needed to plant and harvest grain crops may be a limiting factor for farmers in the southeast with smaller operations that focus on livestock production (McBride and Mathews, 2011). Therefore, annual forage crops could be more attractive for farmers wanting to renovate toxic tall fescue pasture. However, research on agronomic and animal performance on annual forages is limited. Furthermore, evidence on the performance of these forages in renovation systems is non-existent.

Current recommendations for interim cropping during renovations are based on agronomic performance and yield trials. Research that provides agronomic and animal performance data for annual forages used during renovation systems is needed. This section of the review will provide information on agronomic and animal performance for warm-season and cool-season annual forages and insight as to where these forages might fit in the renovation system.

Warm-season annual forage crops

Warm-season annual forage crops are known for rapid growth that results in high yields and the ability to withstand drought stress during the summer months (Fribourg, 1985). Sorghum [Sorghum bicolor (L.)], sudangrass [Sorghum vulgare (Pers.)], sorghum-sudangrass hybrid, and pearl millet (Pennisetum glaucum L.R.) are frequently recommended warm-season annual forages (Dillard et al., 2018). At maturity, these forages have high fiber and lignin concentrations, resulting in low digestibility (Cowan and Lowe, 1998). However, brown-midrib and brachytic dwarf varieties have lower lignin content and greater leaf-to-stem ratios, respectively. These improvements, in addition to high yields, make warm-season annual forages an attractive option for interim cropping in renovation systems.
Sorghum-sudangrass

Sorghum-sudangrass is capable of producing high tonnage in a short growing season. Beck et al. (2007b) reported sorghum-sudangrass yield of 7.4 Mg DM/ha in only 63 days after planting in Arkansas. Similarly, Casler et al. (2003) reported an average yield of 10.3 Mg DM/ha for sorghum-sudangrass with a 96% ground cover at harvest in Nebraska. This competition (including shading) with tall fescue plants that may have escaped desiccation from a spring glyphosate application can improve overall tall fescue control during the renovation (Fribourg et al., 1988). Income can be generated from harvested hay or improved animal performance while grazing warm-season annual forages during the ‘summer slump,’ but animal performance data are limited for sorghum-sudangrass and other warm-season grasses. Parish et al. (2013b) reported live-weight gains of steers grazing sudangrass from 0.80 to 0.83 kg/d. In a cow-calf system, Tracy et al. (2010) found that 235-kg calves had an average daily gain of 0.87 kg/d while grazing sorghum-sudangrass forage.

Pearl Millet

Improved pearl millet varieties for grazing systems in the U.S. were developed in Tifton, GA under the direction of Dr. G.W. Burton and W.W. Hanna. This forage is known for extensive tillering and can be more tolerant to grazing than sorghum-sudangrass forage (Dillard et al., 2018). Small plot trials in Athens, GA have shown pearl millet on dryland produced from 6.0 to 7.3 Mg/ha of DM during the 2018 growing season (Gassett et al., 2018a). In Lexington, KY during 2018, pearl millet yield averaged 14.6 Mg/ha. Harvey and Burns (1988) reported ADG ranging from 0.96 kg/d to 1.07 kg/d for cattle creep-grazing pearl millet during a three-year trial in Laurel Springs, NC. In a forage-finishing trial, Duckett et al. (2013) reported ADG of 1.61 kg/d for steers grazing pearl millet in South Carolina. Franzluebbers and Stuedemann (2007)
reported adequate gains of 0.73 and 0.83 kg/d for steers grazing pearl millet as a summer cover crop in no-till and conventional tillage cropping systems. These data show that pearl millet is capable of producing high tonnage and satisfactory animal weight gains during the summer months.

**Warm-season Annual Forage Mixtures**

Incorporating legumes into warm-season annual forage plantings can reduce the need for nitrogen fertilization and improve nutritive value (Dillard et al., 2018). Additionally, incorporating forage brassicas into mixtures has the potential to increase overall DM digestibility of the sward (Barry, 2013). Finally, yields from polyculture plantings of pearl millet and sorghum-sudangrass or forage sorghum and sorghum-sudangrass were greater than yields from monoculture plantings of the same variety of forages (Tuetsch, 2017). Creamer et al. (2000) reported a sorghum-sudangrass and cowpea mixture biomass of 8.0 Mg/ha in North Carolina. Still, information on agronomic and animal performance is limited for many of the recommended warm-season mixtures, and research is needed to validate claims made by seed and distribution companies.

**Cool-season Annual Forage Crops**

Cool-season annual forage crops provide bimodal forage production during the fall and early spring in the southeastern U.S. (Dillard et al., 2018). Cereal grains such as oat (*Avena sativa* L.), rye (*Secale cereal* L.), wheat (*Triticum aestivum* L.), and triticale (*x Triticosecale Wittm. Ex A. Camus [Secale x Triticum]*) can be grown in monocultures or mixtures. The ability to extend the grazing season depends largely on planting date, weather, and planting method. Rouquette (2017) noted that sod-seeded cereal grain DM yield could be reduced up to 60% in comparison to small grains sown in a prepared seedbed. This decreased yield could negatively
impact the economic viability of utilizing sod-seeded cereal grains, and more research is needed to examine the agronomic and animal performance of cereal grains. Research examining monocultures of cool-season annual forages, mixtures of cereal grains, and cereal grains with annual ryegrass exist, yet data for incorporating legumes and brassicas into mixtures are limited.

**Rye, Wheat, Oat, and Triticale**

Rye, wheat, oat, and triticale are viable options for farmers to extend the grazing season and reduce stored feeding costs (Dillard et al., 2018). In general, rye will provide adequate forage DM earliest in the season, followed by triticale, wheat, and oats. Small plot trials in Athens, GA during the 2018 growing season showed that dryland wheat produced an average of 9.1 Mg/ha of DM, triticale averaged 9.5 Mg/ha, rye averaged 11.3 Mg/ha, and oats averaged 7.2 Mg/ha (Gassett et al., 2018b). Olson et al. (2018) observed lower yields in cereal grain trials in Lexington, KY, reporting average yields of 4.3 Mg/ha DM for triticale, 7.1 Mg/ha for rye, and 7.5 Mg/ha for wheat. The difference in yields may have been the result of location difference and a seven-day delay in planting time for the Lexington trials. Beck et al. (2005) reported that oats, rye, wheat, and cereal mixture pastures allowed ADG of 1.07 kg/d or greater during a three-year grazing trial. Similarly, Marchant et al. (2019) observed an average ADG of 1.44 kg/d for steers grazing triticale, wheat, and annual ryegrass mixtures. Further, Mullenix et al. (2014) reported ADG of 1.12 kg/d for steers grazing monoculture plantings of triticale, annual ryegrass and wheat. Overall, cereal crops can produce adequate DM to extend the grazing season and produce favorable liveweight gains.

**Cool-season Annual Forage Mixtures**

In general, it has been observed that mixtures of cereal grains and cereal grains mixed with annual ryegrass can improve yield distribution over the growing season (Dillard et al.,
2018). In Arkansas, Beck et al. (2007a) reported a higher ADG in the spring grazing season with annual ryegrass incorporated into oats, rye, wheat, or triticale in comparison to the fall grazing season for the same mixtures. As previously mentioned, legumes can alleviate some nitrogen costs and improve nutritive quality. To see these improvements in cool-season forage mixtures, Burns and Standaert (1985) suggest that legumes should make up at least 20% of the above-ground biomass. Redmon et al. (1998) observed no difference in DM yield for wheat, wheat and vetch, or wheat and winter pea but saw an improvement in crude protein of DM for both legume mixtures compared to wheat alone. Creamer and Bennett (1997) observed above-ground biomass for cool-season forage mixtures in Ohio to range from 3,631 to 13,642 kg/ha. Additionally, nitrogen from the above-ground biomass ranged from 74 to 269 kg/ha. Franzluebbers and Stuedemann (2014) reported 4,440 and 5,890 kg/ha for rye and clover, and rye and ryegrass, respectively. Animal performance with the addition of cool-season legumes to cereal grains or annual ryegrass largely showed no improvement in average daily gain (Butler et al., 2012; Franzluebbers and Stuedemann, 2014; Rouquette, 2017). Butler et al. (2012) found no difference in average daily gain for cattle grazing rye and annual ryegrass mixture vs these forages with arrowleaf clover [Trifolium vesiculosum Savi], field pea [Pisum sativum L.], and hairy vetch [Vicia villosa Roth] (RR-Leg) (1.06 kg/d vs 1.07 kg/d; respectively). However, when Hoveland et al. (1978) examined overseeding dormant bermudgrass (Cynodon dactylon (L.) Pers.), an improvement in ADG (0.87 kg/d vs 0.80 kg/d) was reported for cattle that grazed a rye and clover mixture compared to ryegrass alone. The majority of animal performance data available for cool-season forage mixtures is limited to two or three mixtures. Commercially available seed mixtures can contain up to ten forage species. Research is needed to provide animal performance
data for cool-season forage mixtures so that producers can have a better understanding of the realities and limitations of cool-season forage mixtures.

1.5 Soil Health

Pastureland of states located within the ‘fescue belt’ (GA, SC, NC, VA, WV, KY, MO, AR, MS, AL) amounts to 9.2 Mha (USDA NASS, 2017). Not all pasturelands reported are in tall fescue, but this forage dominates the pasture landscape in the reported states. In addition to playing an important role in grazing systems, perennial forages have been identified as one management strategy to sequester carbon (C) to mitigate greenhouse gas emission (Bolinder et al., 2002; Franzluebbers, 2005). This may be largely due to root biomass quantity and distribution and reduced incidence of tillage in pastureland systems (Paustian et al., 1997). Hafenrichter et al. (1968) reported root mass for a 6-yr old stand growing in a Palouse sit loam soil of 7.8 Mg/ha at 0-20 cm depth. In the same study, clipping at three-week intervals reduced root biomass to 5.6 Mg/ha. In Canada, Bolinder et al. (2002) reported tall fescue root biomass of 19.3 Mg/ha at 0-45 cm depth. For all forages examined in this study, 70 to 90% of total root biomass was accounted for at 0-30 cm depth. Further, Nie et al. (2008) noted half of tall fescue’s root biomass was located at 0-20 cm depth.

Management practices, weather, and topography in pasture-based livestock operations can alter a perennial forage’s carbon sequestration potential (Chaubey et al., 2010; Franzluebbers et al., 2012; Endale et al., 2013). Land converted from conventionally tilled cropland to perennial pasture has the ability to sequester significant quantity of soil organic carbon (SOC) (Franzluebbers, 2005; Causarano et al., 2006; Franzluebbers and Stuedemann, 2008). Franzluebbers et al. (2000) reported 31% greater SOC in a 20-year-old tall fescue-bermudagrass pasture in comparison to 24-year-old conservation-tillage cropland. However, pasture
establishment or renovation can create opportunities to gain or lose SOC (Franzluebbers, 2005). Eradicating tall fescue stands and examining the changes to SOC fractions could provide insight into the impact renovation has on the ability of pasture land to sequester C during renovation. Franzluebbers and Stuedemann (2008) observed a tillage treatment effect on SOC three years after killing tall fescue and implementing a no-till or conventional grain production system with grazed cover crops during the break season. In this study, SOC was dramatically reduced at the near surface soil depth for conventional tillage in comparison to no-till. Total organic C was not different when cattle grazed cover crops in comparison to non-grazed cover crops.

In a multi-state study of nitrogen (N) response in stockpiled tall fescue, Franzluebbers et al. (2018) observed strong correlations between physical (i.e. bulk density), chemical (i.e. total organic C), and biological (soil microbial biomass C, flush of CO$_2$ following rewetting of dried soil during 3 d) soil properties. Specifically, the flush of CO$_2$, which can be a general indicator of organic matter resources, had a strong relation with plant available N. Reduction in inorganic N fertilization of stockpiled tall fescue and improved economic outcomes for farmers could be attained with this information. Also, in a review of the flush of CO$_2$, Franzluebbers (2018) observed strong relationship for C mineralization in 24 d and net N mineralization with the flush of CO$_2$ during 3 d ($r^2 = 0.98$ for C mineralization in 24 d and $r^2 = 0.62$ for net N mineralization) across sites in the western and eastern U.S. and the tropics of Brazil and Guam. These strong correlations for the flush of CO$_2$ with other soil properties, in combination with it having a short reliable analysis could make this test a valuable indicator of soil health. Franzluebbers (2016) reported that soil indicators must be sensitive to variations in management and climate to provide proper insight into soil function and health. With renovation periods typically lasting no longer
than 2 years, it will be important to measure soil responses that are sensitive to management change.

1.6 Economic Analysis

Net returns for converting toxic tall fescue pastures to non-toxic tall fescue are highly dependent on pasture production and severity of fescue toxicosis (Bouton, 2007). Nonetheless, there is need to quantify the costs and potential gains a farmer can expect when converting a pasture. Andrae and Lacy (2004) indicated that if a farmer improved breeding efficiency by 20% by converting to ‘novel’ tall fescue, it would take 3.5 years to recoup conversion costs. Beck et al. (2008), utilizing steer performance data, reported a 4-year break-even period for converting toxic tall fescue pastures to novel endophyte pastures. The limited research providing economic analysis on replacing toxic tall fescue suggests a cost range of $988/ha (Gunter and Beck, 2004) to $1205/ha (Zhuang et al., 2005).

Gunter and Beck (2004) provided a thorough scenario assessing conversion of established toxic tall fescue pastures to a novel tall fescue pasture. Agronomic costs included two, 336 kg/ha applications of 17-17-17 totaling $151/ha as well as three, 56 kg/ha applications of ammonium nitrate for the smother crop totaling $117/ha. There may be opportunity to reduce fertilizer inputs on some farms that are adequate in phosphorus and/or potassium or that incorporate legumes into smother crops. Zhuang et al. (2005) examined a reestablishment strategy that utilized grain corn as the interim crop. Pasture rent was an additional factor since cattle were unable to graze the pasture during the conversion period. The net renewal cost of this method was $1205/ha. This strategy may be unrealistic for many farmers with toxic tall fescue, as these are traditionally small-scale farmers without the equipment necessary to successfully plant and harvest grain crops.
Finally, the literature provides some estimation, but is specific to unique conditions of the trials, and there is currently no published research that provides the actual cost of renovating toxic tall pastures in a replicated field trial. With <3% of toxic tall fescue pastures having been converted to non-toxic fescue (Chris Agee, personal communication), it seems that farmers are reluctant to renovate. Economic factors are frequently associated with farmer’s reluctance to adopt new practices or make major changes to their farms (Rodriguez et al., 2009). Research that addresses the economics of conversion within the context of a replicated conversion strategy is needed to provide relevant information to farmers interested in alleviating fescue toxicosis on their farm.

1.7 Conclusions and Research Objectives

Tall fescue is the dominant cool-season pasture grass in the transition zone of the humid U.S. region and serves as the main forage for beef cow-calf production in the region. Pasture-based livestock systems have a role in improving C sequestration, and many of these systems use tall fescue forage. Fescue toxicosis has a large negative impact on beef cattle, and beef cattle farmers and should be alleviated to help ensure the sustainability of beef cattle production. Many strategies have been successful in partial mitigation of fescue toxicosis, while eradication of toxic fescue has been shown to eliminate fescue toxicosis. However, limited information on changes in soil characteristics, agronomic and animal performance during conversion, and the economic costs has hampered conversion.

The following chapters will report changes to the entire production system including agronomic, animal, soil, and economic changes during various conversion strategies of toxic tall fescue to novel tall fescue and provide context for how each strategy may fit a farmer’s goal(s) during conversion.
Literature Cited


Limbu, S. P. 017. Fall stockpiled tall fescue response to nitrogen fertilization as affected by soil biological quality [master’s thesis]. Raleigh: North Carolina State University.


Vinall, H. N. 1909. Meadow fescue; its culture and uses. USDA Farmers Bull. 361.


CHAPTER 2: Soil changes during the replacement of wild-type endophyte-infected tall fescue.

2.1 Introduction

Agricultural soils provide food, feed, fiber and fuel to the human population (Lal, 2008). Additionally, soils serve as a large source and sink of greenhouse gases such as CO₂ (Franzluebbers, 2010). Agricultural practices can determine whether a soil is a net source or sink of greenhouse gases. Properly managed pastureland has the potential to store a large quantity of soil organic C and total soil N in comparison to other agricultural land uses (Franzluebbers and Stuedemann, 2010). Tall fescue \([Lolium arundinaceum\) (Schreb.) Darbysh.] is the base forage species for pasture in the transition zone of the U.S. humid region (Poore, 2010), and total U.S. hectares of tall fescue is estimated at 14 million (Bouton, 2007). The majority of tall fescue pastures are infested with a wild-type endophyte, \(Epichloë coenophiala\) (Young et al., 2014), which gives the plant good agronomic performance and ability to withstand animal grazing (Franzluebbers et al., 2009). However, undesirable animal responses (i.e., reduced weight gain, poor reproductive performance, heat stress) are also associated with wild-type, endophyte-infected tall fescue (Thompson et al., 1993; Poole et al., 2019).

Replacement of wild-type, endophyte-infected tall fescue with a novel, endophyte-infected tall fescue improves animal performance while maintaining the positive agronomic characteristics of wild-type, endophyte-infected tall fescue (Parish et al., 2003). Killing a wild-type, endophyte-infected tall fescue pasture in the spring with an application of glyphosate, \(N\) (phosphonomethyl)glycine, followed by no-till seeding annual forages in summer, and no-till seeding novel endophyte-infected tall fescue in fall is a strategy that will effectively establish a novel endophyte-infected tall fescue pasture and has become a common recommendation (Roberts and Andrae, 2004). Annual forage crops used as “smother crops” during replacement
can help eliminate residual wild-type, endophyte-infected tall fescue plants, improve animal performance and offset costs of replacement (Fribourg et al., 1988; Bagegni et al., 1994). Additionally, annual forages used as cover crops in grain cropping systems have been shown to provide substantial C input at the soil surface and belowground with living and decaying roots (Franzluebbers, 2010). Further, grazing of cover crops had little impact on the biologically active soil C and N for a no-till cropping system in Georgia (Franzluebbers and Stuedemann, 2015).

Multi-species cover crops have been shown to improve cover crop biomass production and plant diversity in comparison to single species cover crops (Creamer and Baldwin, 2000; Wortman et al., 2010). Further, multi-species cover crops have been proposed to improve functional capabilities of the soil, reduce risk of cover crop failure from poor establishment or pest pressure and optimize C-to-N ratio (Wendling, 2019). However, an examination of change in soil properties with grazing of single-species versus multi-species annual forages used as smother crops during the replacement of wild-type, endophyte-infected tall fescue to novel endophyte-infected tall fescue is non-existent. Further, it is not understood if using smother crops beyond one season could alter soil properties.

We hypothesized the use of annual forages as a smother crop beyond one season could improve soil C input. We also hypothesized that a multi-species smother crop could improve soil biological diversity and soil function. Therefore, our objectives were to characterize physical, chemical, and biological soil properties at the beginning of wild-type, endophyte-infected tall fescue replacement and at planting of novel endophyte-infected tall fescue during the course of (a) one season using a single species smother crop, (b) three seasons using a single species smother crop, and (c) three seasons using a multi-species smother crop that included grasses, legumes and brassicas.
2.2 Materials and Methods

The experiment was conducted during 2017, 2018 and 2019 at the Butner Beef Cattle Field Laboratory (36°17’ N; 78°80’ W) near Bahama, NC. Sixteen, 0.8-ha experimental plots, established in Kentucky-31 tall fescue in October 2007, were used in a randomized complete block design for this experiment. Pastures in 2015 had an average infection rate of 63% with *E. coenophiala*, as determined from molecular analyses (Takach and Young, 2014). Treatments included: wild-type, endophyte-infected tall fescue (C), one season single species smother crop (1-SM), three season single species smother crop (3-SM), and three season complex mixture smother crop (3-CM). Soil was classified as Georgeville silt loam (clayey, kaolinitic, thermic Typic Hapludults). Total rainfall and average air temperature for the months of the experiment and the 30-yr average are presented in Figure 1 and Table 1, respectively, as recorded at the North Carolina Department of Agriculture and Consumer Services Oxford Tobacco Research Station (36°30’ N; 78°61’ W), which was 30 km to the northeast of the site.

2.2.1 Data Collection

Soil samples were collected for each plot on 8 Mar 2017 (initiation at 0-10, 10-20, and 20-30 cm) and on 3 Oct 2018 (1 wk post-planting of novel-endophyte tall fescue at 0-10 and 10-20 cm). Samples were collected from eight random locations and composited within each plot with a push probe with 4-cm inside diameter (mounted on all-terrain vehicle with hydraulics in 2017 and using a t-bar hand probe in 2018). At two random sites within each plot, surface residue was collected within a 30-cm-diameter ring by clipping all material below ~4-cm height to ground level with hand shears (Franzluebbers et al., 2000). Surface residue was oven-dried (55 °C, 72 h) and weighed, then ground to pass a 1-mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ). A 1-g subsample of surface residue was analyzed for total C and N
using a Leco TruMac CN analyzer. Soil was oven-dried (55 °C, 72 h) and weighed to determine bulk density from dry weight and known sampling volume (1005 cm³). Soil was sieved to pass a 4.75-mm screen by lightly crushing with a ceramic pestle. Stones and organic debris larger than 4.75 mm were removed. Soil was stored dried at ambient conditions and thoroughly mixed before taking sub-samples for subsequent analyses. A 100-g subsample from each experimental unit and depth was sent to Soil Testing Services of North Carolina Department of Agriculture and Consumer Services for routine soil analysis.

Total organic C and total N were determined with dry combustion from a 1-g subsample that was ball-milled for 2 min to a fine powder. Particulate organic C and N were also determined with dry combustion from a 1-g subsample of the sand fraction that was ball milled. Sand was isolated by dispersion with 0.1 M Na₄P₂O₇, shaking overnight, followed by collection of the material retained on a screen with 0.053-mm openings, and drying and weighing (Franzluebbers and Stuedemann, 2008).

Using the <4.75 mm sieved soil as a starting point, two 50-g subsamples were weighed into 60-mL glass jars, wetted to 50% water-filled pore space, and placed in a 1-L canning jar that contained 10 mL of 1 M NaOH to trap CO₂, and one vial of water to maintain humidity. Samples were incubated at 25 °C for up to 24 d. The NaOH traps were removed and replaced at 3 d and 10 d. Determination of CO₂-C took place at 3, 10, and 24 d by titration as described by Franzluebbers and Stuedemann (2008). Potential C mineralization was calculated as the sum of CO₂ evolved over 24 d incubation. Basal soil respiration was calculated from the linear rate of C mineralization during the 10 to 24 d incubation (Franzluebbers et al., 1999). One subsample, removed at 10 d, was fumigated with CHCl₃ for 1 d under vacuum and then placed in a new 1-L canning jar with a NaOH trap to incubate at 25 °C for an additional 10 d to determine soil
microbial biomass C (Voroney and Paul, 1984; Franzluebbers et al., 1999). Net N mineralization was calculated as the difference in inorganic N at the beginning of incubation and at the end of 24 d of incubation. Inorganic N (NH₄-N + NO₂-N + NO₃-N) was determined from a 10-g dried and sieved subsample of soil that was shaken with 20 mL of 2 M KCl for 30 min. The filtered extract was analyzed for inorganic N using salicylate-nitroprusside and hydrazine-reduction autoanalyzer techniques (Bundy and Meisinger, 1994; Franzluebbers and Stuedemann, 2008).

2.2.2 Statistical Analysis

Mean initial concentration (8 Mar 2018) and mean final concentration across treatments (3 Oct 2018) for soil properties were analyzed using the TTEST procedure and PAIRED statement of SAS Version 9.3 (SAS Institute Inc., Cary, NC). Final concentration (3 Oct 2018) of soil properties for each treatment were analyzed as a randomized complete block design using the MIXED procedure with values being reported as least square means. Pasture was considered the experimental unit for all data. Differences among results were considered significant at $P < 0.05$.

2.3 Results and Discussion

Initial mean soil bulk density was less than final mean soil bulk density at depths of 0-10 cm (1.11 vs. 1.38 Mg m⁻³ $P < 0.01$) and 10-20 cm (1.42 vs. 1.59 Mg m⁻³, $P < 0.01$). This difference in compaction could be attributed to equipment traffic (chemical application, fertilizer application, planting, and harvesting) on plots during the study. However, we would not expect bulk density values this high in just three seasons post-tall fescue pasture. After 12 years of haying, Franzluebbers and Stuedemann (2010) reported a cumulative soil bulk density value to a depth of 20 cm (1.49 Mg m⁻³) for tall fescue/bermudagrass ($Cynodon dactylon$ L.) fields in Georgia. Achieving a sampling depth of 20 cm in our study was not always possible across the
experimental plots due to dry soil conditions and may have contributed to greater than normal
soil bulk density values in the end of experiment samples.

Final soil bulk density at a depth of 0-10 cm was lowest for the control plots in
comparison to all other treatments but did not differ at 10-20 cm (Table 2). The control plots
only received equipment traffic for fertilizer applications and haying in the spring, in comparison
to fertilizer application, multiple herbicide applications, and multiple planting events for
renovation treatment plots throughout the experimental period.

Soil chemical response variables as analyzed by the Soil Testing Services of North
Carolina Department of Agriculture and Consumer Services are summarized in Table 3. Initial
mean pH did not differ from final mean pH at depths of 0-10 cm (5.8 vs. 5.8, \( P = 0.39 \)) and 10-
20 cm (6.5 vs. 6.4, \( P = 0.08 \)). Final soil pH did not differ among treatments at a depth of 0-10
cm. However, final soil pH at 10-20 cm soil depth, was greater for 3-CM in comparison to the
control and 1-SM, but did not differ from 3-SM. Initial Cation Exchange Capacity (CEC) did not
differ from the final CEC at depths of 0-10 cm (10.8 vs. 10.5 cmol c kg\(^{-1}\), \( P = 0.14 \)) and 10-20 cm
(8.4 vs. 8.9 cmol c kg\(^{-1}\), \( P = 0.41 \)). Final CEC did not differ among treatments at depth of 0-10 cm
and 10-20 cm. Initial mean base saturation (BS) did not differ from the final mean BS at depths
of 0-10 cm (84 vs. 85\%, \( P = 0.10 \)) and 10-20 cm (90 vs. 90\%, \( P = 0.26 \)). Final BS did not differ
among treatments at 0-10 cm depth. Final BS at 10-20 cm soil depth, was greater for 3-SM and
3-CM in comparison to 1-SM, and was similar to the control. Initial mean phosphorus
concentration was greater than final mean concentration at depths of 0-10 cm (63 vs. 48 mg dm\(^{-3}\),
\( P < 0.01 \)) and 10-20 cm (11 vs. 8 mg dm\(^{-3}\), \( P = 0.04 \)). Final phosphorus concentration did not
differ among treatments at depth of 0-10 cm and 10-20 cm. Initial mean potassium concentration
was similar to final mean potassium concentration at depths of 0-10 cm (74 vs. 69 mg dm\(^{-3}\), \( P =
\( P = 0.10 \)) and 10-20 cm (90 vs. 90\%, \( P = 0.26 \)). Final BS did not differ among treatments at 0-10 cm depth. Final BS at 10-20 cm soil depth, was greater for 3-SM and
3-CM in comparison to 1-SM, and was similar to the control. Initial mean phosphorus
concentration was greater than final mean concentration at depths of 0-10 cm (63 vs. 48 mg dm\(^{-3}\),
\( P < 0.01 \)) and 10-20 cm (11 vs. 8 mg dm\(^{-3}\), \( P = 0.04 \)). Final phosphorus concentration did not
differ among treatments at depth of 0-10 cm and 10-20 cm. Initial mean potassium concentration
was similar to final mean potassium concentration at depths of 0-10 cm (74 vs. 69 mg dm\(^{-3}\), \( P =
\( P = 0.10 \)) and 10-20 cm (90 vs. 90\%, \( P = 0.26 \)). Final BS did not differ among treatments at 0-10 cm depth. Final BS at 10-20 cm soil depth, was greater for 3-SM and
3-CM in comparison to 1-SM, and was similar to the control. Initial mean phosphorus
concentration was greater than final mean concentration at depths of 0-10 cm (63 vs. 48 mg dm\(^{-3}\),
\( P < 0.01 \)) and 10-20 cm (11 vs. 8 mg dm\(^{-3}\), \( P = 0.04 \)). Final phosphorus concentration did not
differ among treatments at depth of 0-10 cm and 10-20 cm. Initial mean potassium concentration
was similar to final mean potassium concentration at depths of 0-10 cm (74 vs. 69 mg dm\(^{-3}\), \( P =
\( P = 0.10 \)) and 10-20 cm (90 vs. 90\%, \( P = 0.26 \)). Final BS did not differ among treatments at 0-10 cm depth. Final BS at 10-20 cm soil depth, was greater for 3-SM and
3-CM in comparison to 1-SM, and was similar to the control. Initial mean phosphorus
concentration was greater than final mean concentration at depths of 0-10 cm (63 vs. 48 mg dm\(^{-3}\),
\( P < 0.01 \)) and 10-20 cm (11 vs. 8 mg dm\(^{-3}\), \( P = 0.04 \)). Final phosphorus concentration did not
differ among treatments at depth of 0-10 cm and 10-20 cm. Initial mean potassium concentration
was similar to final mean potassium concentration at depths of 0-10 cm (74 vs. 69 mg dm\(^{-3}\), \( P =
0.30) and 10-20 cm (30 vs. 32 mg dm\(^{-3}\), \(P = 0.66\)). Final potassium concentrations were similar among treatments at depths of 0-10 cm and 10-20 cm. Initial mean calcium concentration was similar to final calcium concentration at depths of 0-10 cm (1228 vs. 1203 mg dm\(^{-3}\), \(P = 0.28\)) and 10-20 cm (1026 vs. 1092 mg dm\(^{-3}\), \(P = 0.40\)). Final calcium concentrations were similar among treatments at depths of 0-10 cm and 10-20 cm. Initial mean magnesium concentration was similar to final mean magnesium concentration at depths of 0-10 cm (341 vs. 334 mg dm\(^{-3}\), \(P = 0.43\)) and 10-20 cm (281 vs. 307 mg dm\(^{-3}\), \(P = 0.36\)). Final magnesium concentrations were similar among treatments at depths of 0-10 cm and 10-20 cm. Mean initial soil chemical concentrations at a depth of 0-10 cm analyzed by the Soil Testing Services of North Carolina Department of Agriculture and Consumer Services were generally lower than values reported from stockpiled tall fescue pastures in the Piedmont region of North Carolina (Franzluebbers et al., 2018). Specifically, initial mean soil pH at 0-10 cm soil depth was lower than the recommended pH (6.0) for tall fescue pastures (Castillo, 2016). However, herbage mass from the control (data are shown in Chapter 3) was similar to previous studies examining tall fescue pastures across the southeast (Bouton et al., 2002; Franzluebbers et al., 2009; Parish et al., 2013). Acidification of soils takes place over time with the application of N fertilizers, but 3-CM did not receive inorganic N fertilization, and this could explain differences observed in soil pH at 10-20 cm soil depth. Base saturation is the percentage of soil exchange sites occupied by basic cations, which directly affects calculated soil pH (inverse log of H\(^+\)). Therefore, similar differences observed in BS and pH at the 10-20 cm can be attributed to the relationship between the two calculations.

Soil and residue chemical response variables as analyzed in the Soil Ecology and Management Lab at North Carolina State University are summarized in Table 4 and 5. Initial
mean total organic C (TOC) concentration was greater than final mean TOC concentration at a depth of 0-10 cm (25 vs. 22 g kg⁻¹, $P < 0.01$) and concentration was similar at 10-20 cm (7.7 vs. 7.7 g kg⁻¹, $P = 0.98$). Final TOC concentrations were similar among treatments at depths of 0-10 cm and 10-20 cm. This depth distribution pattern for TOC is similar to other tall fescue pastures in the southeast (Causarano et al., 2008). Initial mean TOC at 0-10 cm soil depth, was lower than TOC reported in long-term tall fescue pasture study in Georgia at a depth of 15 cm (Franzluebbers et al., 1999), but similar to average TOC at 10 cm depth (24.3 g kg⁻¹) for stockpiled tall fescue pastures sampled across the piedmont region of the southeast U.S. (Franzluebbers et al., 2018). Franzluebbers and Stuedemann (2008) reported a decrease in TOC when cover crops were grazed by cattle in varying cropping systems. Further, experimental units were harvested for hay in May 2017 and could have reduced residue C input, therefore, leading to a reduction in TOC. Initial mean particulate organic C (POC) concentration was similar to final mean POC concentration at depths of 0-10 cm (5.8 vs. 5.7 g kg⁻¹, $P = 0.71$) and 10-20 cm (1.6 vs. 1.4 g kg⁻¹, $P = 0.54$). Final POC concentrations were similar among treatments at depths of 0-10 cm and 10-20 cm. These values at initiation were lower than those reported after 3-yr of no-till grain production (Franzluebbers and Stuedemann, 2008). It is not well understood why these values were lower than previous reports of POC, but it assumed that there is a direct relation to the degradation of decomposing roots and residues. Initial mean total N concentration was greater than final mean total N concentration at a depth of 0-10 cm (2.19 vs. 1.94 g kg⁻¹, $P < 0.01$) and concentrations were similar at 10-20 cm (0.68 vs. 0.62 g kg⁻¹, $P = 0.23$). Final total N concentrations did not differ among treatments at depths of 0-10 cm and 10-20 cm. The TN concentration at 0-10 cm depth was similar to values reported at a soil depth of 15 cm in tall fescue pasture in Georgia (Franzluebbers et al., 1999), and the piedmont region sampling sites
from the multi-state study conducted by Franzluebbers et al. (2018). Summation of TN (0-20 cm) for this study generated values similar to TN reported at 0-30 cm for cattle grazing tall fescue in Georgia (Franzluebbers et al., 2000). Initial mean particulate organic N (PON) concentration was similar to final mean PON concentration at depths of 0-10 cm (0.32 vs. 0.33 g kg\(^{-1}\), \(P = 0.77\)) and 10-20 cm (0.08 vs. 0.06 g kg\(^{-1}\), \(P = 0.12\)). Final PON concentrations were similar among treatments at depths of 0-10 cm and 10-20 cm. Initial mean inorganic N concentration was lower than final mean concentration at depths of 0-10 cm (13 vs. 24 g kg\(^{-1}\), \(P < 0.01\)) and 10-20 cm (6 vs. 8 g kg\(^{-1}\), \(P < 0.01\)). An N application was made just prior to final sampling in October and is likely the reason for the dramatic difference in values. Final mean inorganic N concentration at a depth of 0-10 cm was greater for 1-SM in comparison to 3-SM and the control, and was similar to 3-CM. Final inorganic N concentration was similar among treatments at 10-20 cm.

Initial mean surface residue amount, and surface residue C and N content were greater than final mean surface residue amount, and surface residue C and N content (3.1 vs. 2.0 Mg ha\(^{-1}\), \(P < 0.01\); 1.7 vs. 1.0 Mg ha\(^{-1}\), \(P < 0.0001\); 83 vs. 47 kg/ha, \(P < 0.0001\), respectively). Initial mean surface residue C-to-N ratio was lower than final mean surface residue C-to-N ratio (20 vs. 24, \(P < 0.01\)). Final surface residue amount, surface residue C and N content and surface residue C-to-N ratio were similar (\(P = 0.09\); 0.09; 0.31; 0.98, respectively) among treatments. Initial residue samples were collected in productive wild-type, endophyte-infected tall fescue pasture (Lyons et al., 2016), whereas final samples were taken at planting of novel endophyte-infected tall fescue. Further, cattle consumed smother crop forage and likely reduced the amount of herbage left to decompose on the soil surface.

Soil biological response variables as analyzed in the Soil Ecology and Management Lab at North Carolina State University are summarized in Table 6. Initial soil microbial biomass C
(SMBC) concentration was greater than final mean SMBC concentration at depths of 0-10 cm
(1197 vs. 773 mg kg$^{-1}$, $P < 0.01$) and 10-20 cm (306 vs. 204 mg kg$^{-1}$, $P < 0.01$). Final SMBC concentrations were similar among treatments at depths of 0-10 cm and 10-20 cm and are in agreement with SMBC values (708 mg kg$^{-1}$) reported for a grazed summer cover crop and winter grain crop system in Georgia (Franzluebbers and Stuedemann, 2008). Initial mean concentration of the flush of CO$_2$ following rewetting of dried soil over 3 d was greater than final mean concentration at a depth of 0-10 cm (462 vs. 361 mg CO$_2$-C kg$^{-1}$ soil, $P < 0.01$) and mean concentrations were similar at 10-20 cm (103 vs. 91 mg CO$_2$-C kg$^{-1}$ soil, $P < 0.09$). Final concentrations of the flush of CO$_2$ following rewetting of dried soil over 3 d did not differ among treatments at depths of 0-10 cm and 10-20 cm. Flush of CO$_2$ following rewetting of dried soil summed to a 20 cm soil depth was similar to a multi-state pasture study in the southern Piedmont and Coastal plain examining soil organic carbon fractions (Causarano et al., 2008) and a long-term pasture study in Georgia (Franzluebbers and Stuedemann, 2002). The initial mean potential C mineralization was greater than the final mean concentration at depths of 0-10 cm (1182 vs. 922 mg CO$_2$-C kg$^{-1}$ soil, $P < 0.01$) and 10-20 cm (269 vs. 229 mg CO$_2$-C kg$^{-1}$ soil, $P = 0.02$). Final concentration of potential C mineralization was similar among treatments at depths of 0-10 cm and 10-20 cm. Initial mean basal soil respiration rate (BSR) was greater than the final BSR at a depth of 0-10 cm (29 vs. 21 mg CO$_2$-C kg$^{-1}$ soil d$^{-1}$, $P < 0.01$), and were similar at 10-20 cm (6.2 vs. 5.2 mg CO$_2$-C kg$^{-1}$ soil d$^{-1}$, $P = 0.12$). Final BSR were similar among treatments at depths of 0-10 cm and 10-20 cm. Initial mean net N mineralization concentration was similar to final mean net N mineralization concentration at depths of 0-10 cm (122 vs. 111 mg kg$^{-1}$ soil, $P = 0.13$) and 10-20 cm (18 vs. 23 mg kg$^{-1}$ soil, $P = 0.13$). Final net N mineralization values were similar among treatments at depths of 0-10 cm and 10-20 cm. The activity of labile soil C and N
is seasonally dependent and relies heavily on root growth (Franzluebbers et al., 1995). Franzluebbers et al. (1995) observed a peak in the flush of CO$_2$ (~30 g CO$_2$-C m$^{-2}$) during the peak of the growing season of wheat. In the present study, soil was sampled 1 wk post-planting of novel endophyte-infected tall fescue and it is assumed root growth was lower during this time in comparison to peak smother crop production.

2.4 Summary

In the short term, equipment used in renovating established wild-type, endophyte-infected tall fescue pastures may increase soil bulk density near the soil surface. Final soil bulk density values near the soil surface for the renovation treatments were approaching values that could limit forage root growth. However, moisture content at the time of the two samplings influenced the ability to achieve the proper sampling depth for accurate estimate of soil bulk density. Further, human bias could have influenced sampling points within experimental units to be in more open, compacted areas of the pasture (i.e. space absent of tall fescue or in between two tall fescue plants). Further sampling over time of experimental units would be ideal to validate if differences in bulk density were real. However, with novel endophyte-infected tall fescue established, equipment traffic should decrease on the pastures. Whether renovation treatment was multi-species or single-species, one season or three, made little difference in the progressive evolution of soil chemical properties routinely analyzed by a soil testing laboratory. The general reduction in active soil C and N across treatments showed a general dependence on season of sampling, as well as a strong dependency on TOC and TN. Time of sampling, may have been a more important factor than treatment in this short-term experiment.

With forage production maintaining or improving in comparison to the control (Chapter 4), and one of the major C inputs decreasing (surface residue) for a pasture, grazing of cover
crops could reduce TOC. Residual forage target (Chapter 4) may have been too low to maintain sufficient residue contribution to the soil surface. Setting conservative smother crop residual forage targets that achieve adequate animal performance and surface residue input should be a primary focus for farmers interested in renovation of wild-type, endophyte-infected tall fescue. Our hypothesis that extending the renovation period would improve soil C input was not proven. Further, our second hypothesis that multi-species smother crops would improve soil function and biodiversity was not supported, due to a lack of difference in SMBC and a general reduction in active soil C and N pools. Reports of improvement in soil C input and soil function tend to be in conventional grain cropping systems transitioning to no till production. In the present study, a perennial pasture with high concentration of TOC and TN, and high soil biological activity was likely the reason why we did not see evidence to support our hypotheses. This also highlights the importance of properly managed perennial forage systems in maintaining soil health.

Further research is needed to examine soil properties during the first few years of establishing novel endophyte-infected tall fescue pastures to better understand subtle changes, if any, in overall soil health.
Tables and Figures

Figure 2.1 Monthly rainfall at the North Carolina Department of Agriculture and Consumer Services Oxford Tobacco Research Station, Oxford, NC, for 2017, 2018, 2019, and 30 yr average.
Table 2.1 Average air temperature (°C) summary for 2017, 2018, 2019 and 30 yr-average at the North Carolina Department of Agriculture and Consumer Services Oxford Tobacco Research Station, Oxford, NC.

<table>
<thead>
<tr>
<th>Month</th>
<th>30 yr-avg.</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>4.7</td>
<td>6.7</td>
<td>2.6</td>
<td>4.9</td>
</tr>
<tr>
<td>Feb.</td>
<td>6.3</td>
<td>10.7</td>
<td>10.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Mar.</td>
<td>9.9</td>
<td>10.2</td>
<td>7.0</td>
<td>8.8</td>
</tr>
<tr>
<td>Apr.</td>
<td>15.2</td>
<td>17.8</td>
<td>13.7</td>
<td>16.4</td>
</tr>
<tr>
<td>May</td>
<td>19.6</td>
<td>19.5</td>
<td>22.3</td>
<td>-</td>
</tr>
<tr>
<td>June</td>
<td>23.8</td>
<td>23.1</td>
<td>24.6</td>
<td>-</td>
</tr>
<tr>
<td>July</td>
<td>25.4</td>
<td>26.2</td>
<td>24.9</td>
<td>-</td>
</tr>
<tr>
<td>Aug.</td>
<td>24.7</td>
<td>24.3</td>
<td>24.8</td>
<td>-</td>
</tr>
<tr>
<td>Sept.</td>
<td>21.2</td>
<td>21.2</td>
<td>23.6</td>
<td>-</td>
</tr>
<tr>
<td>Oct.</td>
<td>15.6</td>
<td>17.0</td>
<td>16.2</td>
<td>-</td>
</tr>
<tr>
<td>Nov.</td>
<td>9.9</td>
<td>9.5</td>
<td>8.4</td>
<td>-</td>
</tr>
<tr>
<td>Dec.</td>
<td>6.2</td>
<td>4.9</td>
<td>6.9</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 2.2 Mean bulk density across treatments at initiation (March 2017) and final bulk density for each treatment at planting of novel-endophyte tall fescue (October 2018).

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>March 2017</th>
<th>October 2018&lt;sup&gt;1&lt;/sup&gt;</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C 1-SM 3-SM 3-CM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>1.11</td>
<td>1.25&lt;sup&gt;a&lt;/sup&gt; 1.40&lt;sup&gt;b&lt;/sup&gt; 1.40&lt;sup&gt;b&lt;/sup&gt; 1.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>10-20</td>
<td>1.42</td>
<td>1.67 1.53 1.56 1.59</td>
<td>0.08</td>
<td>0.74</td>
</tr>
<tr>
<td>20-30</td>
<td>1.43</td>
<td>- - - -</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Means within a row with unlike superscripts differ ($P < 0.05$).

<sup>1</sup> C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.
Table 2.3 Mean initial concentration of routinely analyzed soil chemical properties across treatments at three soil depths (March 2017) and final concentration at two depths for each treatment at planting of novel-endophyte tall fescue (October 2018).

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>March 2017</th>
<th>October 2018</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>March 2017</td>
<td>October 2018</td>
<td>SEM</td>
<td>P-value</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C 1-SM 3-SM 3-CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>0-10</td>
<td>5.8</td>
<td>5.8</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>6.5</td>
<td>6.3b</td>
<td>6.3b</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>6.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEC (cmol·kg⁻¹)</td>
<td>0-10</td>
<td>10.8</td>
<td>10.8</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>8.4</td>
<td>7.8</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>10.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BS (%)</td>
<td>0-10</td>
<td>84</td>
<td>86</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>90</td>
<td>90ab</td>
<td>89b</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P (mg dm⁻³)</td>
<td>0-10</td>
<td>63</td>
<td>49</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>11</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K (mg dm⁻³)</td>
<td>0-10</td>
<td>74</td>
<td>57</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>30</td>
<td>33</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>20-30</td>
<td>33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2.3 (continued).

<table>
<thead>
<tr>
<th></th>
<th>Ca (mg dm$^{-3}$)</th>
<th></th>
<th>Mg (mg dm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-10</td>
<td>10-20</td>
<td>20-30</td>
</tr>
<tr>
<td>Ca</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>1228</td>
<td>1245</td>
<td>1206</td>
</tr>
<tr>
<td>10-20</td>
<td>1220</td>
<td>1142</td>
<td>62</td>
</tr>
<tr>
<td>20-30</td>
<td>1129</td>
<td>98</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Means within a row with unlike superscripts differ ($P < 0.05$).

1. C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.

2. pH = -log[H$^+$].

3. CEC, cation exchange capacity; BS, base saturation.
Table 2.4 Mean initial concentration of soil chemical properties across treatments at three soil depths (March 2017) and final concentration at two depths for each treatment at planting of novel-endophyte tall fescue (October 2018).

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Treatment$^1$</th>
<th>Mean</th>
<th>C</th>
<th>1-SM</th>
<th>3-SM</th>
<th>3-CM</th>
<th>SEM</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total organic C (g kg$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td></td>
<td>25.1</td>
<td>23.4</td>
<td>22.3</td>
<td>21.3</td>
<td>19.9</td>
<td>1.20</td>
<td>0.21</td>
</tr>
<tr>
<td>10-20</td>
<td></td>
<td>7.7</td>
<td>7.6</td>
<td>7.2</td>
<td>8.4</td>
<td>7.9</td>
<td>0.65</td>
<td>0.61</td>
</tr>
<tr>
<td>20-30</td>
<td></td>
<td>5.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particulate organic C (g kg$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td></td>
<td>5.8</td>
<td>6.2</td>
<td>6.2</td>
<td>5.5</td>
<td>4.8</td>
<td>0.4</td>
<td>0.09</td>
</tr>
<tr>
<td>10-20</td>
<td></td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.4</td>
<td>1.5</td>
<td>0.1</td>
<td>0.97</td>
</tr>
<tr>
<td>20-30</td>
<td></td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total N (g kg$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td></td>
<td>2.19</td>
<td>2.09</td>
<td>1.96</td>
<td>1.92</td>
<td>1.80</td>
<td>0.12</td>
<td>0.41</td>
</tr>
<tr>
<td>10-20</td>
<td></td>
<td>0.68</td>
<td>0.67</td>
<td>0.63</td>
<td>0.60</td>
<td>0.58</td>
<td>0.07</td>
<td>0.45</td>
</tr>
<tr>
<td>20-30</td>
<td></td>
<td>0.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particulate organic N (g kg$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td></td>
<td>0.32</td>
<td>0.36</td>
<td>0.35</td>
<td>0.33</td>
<td>0.29</td>
<td>0.03</td>
<td>0.20</td>
</tr>
<tr>
<td>10-20</td>
<td></td>
<td>0.08</td>
<td>0.07</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
<td>0.01</td>
<td>0.35</td>
</tr>
<tr>
<td>20-30</td>
<td></td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inorganic N (g kg$^{-1}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td></td>
<td>13</td>
<td>19$^c$</td>
<td>29$^a$</td>
<td>22$^{bc}$</td>
<td>25$^{ab}$</td>
<td>1.0</td>
<td>0.01</td>
</tr>
<tr>
<td>10-20</td>
<td></td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>0.6</td>
<td>0.75</td>
</tr>
<tr>
<td>20-30</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

$^1$ C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.
Table 2.5 Mean initial surface residue, C and N content, and C-to N ratio across treatments (March 2017) and final residue amount, C and N content, and C-to-N ratio for each treatment at planting of novel-endophyte tall fescue (October 2018).

<table>
<thead>
<tr>
<th>Item</th>
<th>March 2017</th>
<th>October 2018&lt;sup&gt;1&lt;/sup&gt;</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>1-SM</td>
<td>3-SM</td>
</tr>
<tr>
<td>Surface residue (Mg ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.1</td>
<td>2.4</td>
<td>1.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Surface residue C (Mg ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>1.7</td>
<td>1.3</td>
<td>0.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Surface residue N (kg ha&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>83</td>
<td>57</td>
<td>34</td>
<td>62</td>
</tr>
<tr>
<td>Surface residue C-to-N ratio</td>
<td>20</td>
<td>23</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Means within a row with unlike superscripts differ (P < 0.05).

<sup>1</sup> C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.
Table 2.6 Mean initial concentration of soil biological properties across treatments at three soil depths (March 2017) and final concentration at two depths for each treatment at planting of novel-endophyte tall fescue (October 2018).

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>March 2017</th>
<th>October 2018</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C 1-SM 3-SM 3-CM</td>
<td>C 1-SM 3-SM 3-CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soilmicrobial biomass C (mg kg(^{-1}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>1197 876 754 746 716</td>
<td>77</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>10-20</td>
<td>306 184 169 227 230</td>
<td>25</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>149</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flush of CO(_2) following rewetting of dried soil (mg CO(_2)-C kg(^{-1}) soil)(^{0-3 \text{ d}})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>462 387 379 349 327</td>
<td>28</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>10-20</td>
<td>103 86 88 99 91</td>
<td>8</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>53</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential C mineralization (mg CO(_2)-C kg(^{-1}) soil)(^{0-24 \text{ d}})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>1182 1014 967 885 820</td>
<td>63</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>10-20</td>
<td>269 206 213 242 254</td>
<td>25</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>141</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basal soil respiration (mg CO(_2)-C kg(^{-1}) soil d(^{-1}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>29 23 21 19 18</td>
<td>2</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>10-20</td>
<td>6 5 5 5 7</td>
<td>1</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net N mineralization (mg kg(^{-1}) soil)(^{0-24 \text{ d}})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>122 125 106 105 108</td>
<td>13</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>10-20</td>
<td>18 21 22 26 25</td>
<td>4</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a row with unlike superscripts differ (P < 0.05).

\(^{1}\) C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.
Acknowledgements

I would like to thank Dr. Alan Franzlubbers, Ellen Leonard, and Erin Silva for their support during the collection, processing, analyzing and interpretation of soil data.
Literature Cited


Takach, J. E., C. A. Young. 2014. Alkaloid genotype diversity of tall fescue endophytes. Crop Sci. 54:667-678. doi:10.2135/cropsci2013.06.0423


CHAPTER 3: Agronomic performance of smother crops during the replacement of wild-type endophyte-infected tall fescue.

3.1 Introduction

Tall fescue \([Lolium arundinaceum\) (Schreb.) Darbysh.] infected with a wild-type endophyte, \(Epichloë coenophiala\), is prevalent in beef cattle pastures located in the transition zone of the U.S. humid region (Poore, 2010). This cool-season perennial grass is adapted to a wide range of soils and can be grazed for much of the year (Franzluebbers et al., 2009). However, ergot alkaloids produced by \(E. coenophiala\) and consumed by cattle grazing wild-type, endophyte-infected tall fescue can elicit reduced weight gain, heat stress, and reduced reproductive performance (Thompson et al, 1993; Poole et al., 2019). This reduction in animal performance is estimated to cost beef cattle producers $600 million annually (Bouton, 2007).

Novel endophyte-infected tall fescue cultivars that produce nil amounts of ergot alkaloids are available to beef cattle farmers who seek improved animal performance and the agronomic benefits of wild-type, endophyte-infected tall fescue.

The replacement strategy termed, ‘spray-smother-spray’, in which wild-type, endophyte-infected tall fescue is killed in the spring with an application of glyphosate, annual forages are no-till seeded in the summer, and novel endophyte-infected tall fescue is no-till seeded after a second application of glyphosate in the fall, can successfully replace wild-type, endophyte-infected tall fescue (Roberts and Andrae, 2004; Hill et al., 2010). However, new wild-type, endophyte-infected tall fescue plants from the existing seedbank or plants that survive glyphosate applications can be an issue. Parish et al. (2013) used 3 separate applications of glyphosate to establish ‘Jesup MaxQ’ in wild-type, endophyte-infected tall fescue pastures and observed a 30% contamination of wild-type tall fescue within the plots. This competition could
result in failure to create a novel endophyte-infected pasture (Fribourg et al., 1988). Further, ergot alkaloid production could still be detrimental to livestock (Parish et al., 2013).

Warm-season annual forages used as a ‘smother crop’ have good yield potential during a period when cool-season perennial forages begin to decline in yield (Dillard et al., 2018; Parish et al., 2013). Sorghum-sudanagrass [*Sorghum bicolor* (L.) x *Sorghum vulgare* (Pers.)] and pearl millet [*Pennisetum glaucum* (L.) R. Br.] are two warm-season annual grasses that can be highly productive during the summer months (Casler et al., 2003; Beck et al., 2007; McGlaughlin et al., 2004) and are commonly recommended as the ‘smother crop’ in a spray-smother-spray renovation strategy (Roberts and Andrae, 2004). Annual forage mixtures containing a combination of grasses, legumes and forbs grown for forage production have recently gained popularity among some beef cattle farmers (Omokanye et al., 2019). These mixtures have been proposed to reduce risk of crop failure due to poor establishment or pest pressure and improve soil function and nutritive value in comparison to monoculture plantings (Creamer and Baldwin, 2000; Wortman et al., 2010; Wendling, 2019). However, data related to productivity and nutritive value for annual forage mixtures is non-existent. Beef cattle producers need this information when making the decision to plant monoculture or polyculture forage crops.

We hypothesized that: (i) smother crops would produce more herbage mass in comparison to wild-type, endophyte-infected tall fescue, (ii) extending the renovation period would eliminate wild-type, endophyte-infected tall fescue escapes in the newly established novel endophyte-infected tall fescue, (iii) a multi-species smother crop, containing grasses, legumes and forbs would have greater nutritive value in comparison to a single species smother crop. Therefore, our objectives were to measure herbage mass, botanical composition, and nutritive value for a single species smother crop and a multi-species smother crop during the replacement
of wild-type, endophyte-infected tall fescue with novel endophyte-infected tall fescue over three seasons.

3.2 Materials and Methods

3.2.1 Experimental Site

The experiment was conducted on established wild-type, endophyte-infected tall fescue pastures near Bahama, NC (36°17’ N; 78°80’ W) as described in Chapter 2. Total rainfall and average air temperature for the months of the experimental period and the 30-yr average are presented in Figure 2.1 and Table 2.1

3.2.2 Treatments and Experimental Design

There were a total of four treatments. The treatments were set up so that renovation from ‘Kentucky 31’ to ‘Texoma MaxQ II’ (Pennington Seed, Inc.) tall fescue occurred in the Fall of 2018 for all treatments. The treatments were: (i) Control (continuation of wild-type, endophyte-infected tall fescue pastures), (ii) one-season single species smother crop, (iii) three-season single species smother crop, and (iv) three-season complex mixture smother crop as presented in Table 1. Treatment (ii) was employed as a positive control plot to examine the control of escape wild-type, endophyte-infected tall fescue plants for the three-season treatments compared to a single season treatment. Within the three-season treatments, a smother crop containing a mixture of grasses, legumes and forbs was employed to examine the nutritive value, soil health (Chapter 2), and economic costs (Chapter 5) of this mixture in comparison to a single species smother crop. The experimental design was a randomized complete block with treatments replicated four times, for a total of 16 experimental units. The area of an experimental unit was 0.8 ha. All experimental units were planted with a no-till drill (Model 1590, Deere and Company, Inc. Moline, IL).
3.2.3 Plot Establishments and Management

Control plots maintained as ‘Kentucky 31’ tall fescue (Table 1) and were fertilized with 45 kg N ha\(^{-1}\) in the spring and fall of 2017 and 2018. Hay was harvested on control plots in May 2017-2019.

The 1-SM treatment was maintained in the same manner as the control until Summer 2018. On 4 May 2018, 1-SM experimental units received an application of glyphosate at 2.2 kg ai (active ingredient) ha\(^{-1}\) to kill the existing tall fescue stand. On 10 May 2018, 45 kg N ha\(^{-1}\) was applied to 1-SM experimental units and then planted with pearl millet at 19 kg ha\(^{-1}\) on 11 May 2018.

On 22 May 2017, 3-SM experimental units received an application of glyphosate, at 2.2 kg ai ha\(^{-1}\) to kill the existing tall fescue stand. On 9 Jun 2017, 3-SM experimental units were planted in sorghum-sudangrass at 44 kg ha\(^{-1}\) and fertilized with 45 kg N ha\(^{-1}\). On 28 Sep 2017, 3-SM experimental units were rotary mowed to a 15 cm stubble height and sprayed with glyphosate at 2.2 kg ai ha\(^{-1}\). On 3 Oct 2017, 3-SM experimental units received 45 kg N ha\(^{-1}\) and were then planted with triticale (\(x\)Triticosecale) at 111 kg ha\(^{-1}\). The 3-SM experimental units received the same protocol as 1-SM in Summer 2018, with an application of glyphosate, nitrogen and planting of pearl millet occurring on 4 May 2018, 10 May 2018, and 11 May 2018, respectively.

The 3-CM experimental units received an application of glyphosate at 2.2 kg ai ha\(^{-1}\) on 22 May 2017 to kill the existing tall fescue stand. On 9 Jun 2017, 3-CM experimental units were planted with a mixture of grasses, legumes, and forbs at 70 kg ha\(^{-1}\). On 28 Sep 2017, 3-SM experimental units were rotary mowed to a 15-cm stubble height and sprayed with glyphosate at 2.2 kg ai ha\(^{-1}\). On 9 Oct 2017, a mixture of cereal grains, grass, legumes, and forbs was planted at
a rate of 44 kg ha\textsuperscript{-1} in 3-CM experimental units. On 4 May 2018, an application of glyphosate at 2.2 kg ai ha\textsuperscript{-1} was made to 3-CM experimental units followed by planting the same mixture of grasses, legumes and forbs as was used in 2017, at 51 kg ha\textsuperscript{-1}.

On 10 Sep 2018, 1-SM, 3-SM, and 3-CM experimental units were rotary mowed to a 15 cm stubble height and received an application of glyphosate at 2.2 kg ai ha\textsuperscript{-1}. On the same day, C plots were fertilized with 45 kg N ha\textsuperscript{-1} and forage growth was allowed to accumulate. On 27 Sep 2018, Texoma MaxQII (Pennington Seed, Inc.) was planted at 26 kg ha\textsuperscript{-1} in 1-SM, 3-SM, and 3-CM plots and fertilized with 45 kg N ha\textsuperscript{-1}.

3.2.4 Defoliation Management

The 0.8-ha experimental units were subdivided into four 0.2-ha sub-paddocks. Thirty-two Angus and Angus-cross tester steers (425.3 ± 4.7, 297.6 ± 6.1, 381.8 ± 7.7 kg for Summer 2017, Winter 2018 and Summer 2018; respectively) were randomly assigned to one of four treatments and rotationally stocked. Put-and-take animals similar to the tester animals were used to manage forage allowance in each grazing period. The grazing period was 7 d and the resting period was 21 days in Summer 2017 and Summer 2018; consequently; the grazing cycle was 28 d. In Winter 2018, the grazing period for 3-SM and 3-CM experimental units was 7 d, whereas steers on the control experimental units were moved to the next subpaddock to maintain a target residue height of 5 cm. Initial DM herbage mass was used to determine the stocking rate for the beginning of the grazing cycle with a 30% DM residual herbage mass target for each subpaddock. Adjustments in stocking rate were made for each experimental unit following the calculation of DM herbage mass from 2-wk interval sample collections. The mean stocking rate for the control, 1-SM, 3-SM, and 3-CM in Summer 2017; and Summer 2018 were 1793, 1915, 1701, 1482 ± 72 kg BW ha\textsuperscript{-1}; and 1676, 1592, 1508, and 1574 ± 116 kg BW ha\textsuperscript{-1}, respectively.
The mean stocking rate for the control, 3-SM, and 3-CM in Winter 2018 were 1681, 1409, 1476 ± 85 kg BW ha⁻¹, respectively. In Summer 2017 and Summer 2018, two grazing cycles were completed for all treatments.

Due to unfavorable environmental conditions in Fall 2017 and Winter 2018 (Figure 2.1 and Table 2.1), a later planting date and the need to plant Summer 2018 smother crops in early May, grazing cycles for Winter 2018 were shortened. In Winter 2018, a 1 and ½ grazing cycle was completed for 3-SM (42 d) and a ¾ grazing cycle was completed for 3-CM (21 d). Herbage mass was available in the 4th subpaddock of 3-CM, but it was determined to remove cattle and begin preparation for Summer 2018 planting. Total grazing days for the control experimental units were 23 d.

3.2.5 Response Variables

Herbage mass

Since cattle were rotationally stocked on the four subpaddocks for 7 d and sampling took place every 14 d, forage sampling took place in subpaddocks (1) and (3). Herbage mass was determined by clipping and combining four random, 1.4 m² quadrats in 1-SM (Summer 2018 only), 3-SM, and 3-CM subpaddocks within the experimental unit to a 5-cm stubble height using hand shears. The uniform stubble height was selected to account for herbage mass produced and not necessarily forage remaining after grazing by cattle. Herbage mass was weighed fresh, and then herbage was chopped into 10-cm pieces, thoroughly mixed and then carefully divided into subsamples to be used to determine dry matter, botanical composition, and nutritive value. One of the subsamples was dried at 60°C until constant weight to determine dry matter concentration.

A 0.25 m² falling plate meter was used to determine herbage mass (Lyons et al., 2016) in the control subpaddocks for the entire experiment, and for the 1-SM subpaddocks during the
summer of 2017. Within the control subpaddocks, five 0.25 m² quadrats, selected to capture the range in forage mass present in the paddock, were clipped to a 5-cm stubble height and dried at 60º C until constant weight to determine dry matter concentration. Herbage mass from the five clipped quadrats was related to the corresponding plate meter readings using linear regression to develop a calibration equation (R² of 0.86; 0.92; 0.61; and 0.94 for Summer 2017; Winter 2018; Summer 2018; and Winter 2019, respectively). These equations were used to determine herbage mass in the control experimental units for each sampling date from the average of 25 random falling plate meter readings.

**Botanical Composition**

Hand-sheared samples, to a 5 cm stubble height, from 25 randomly chosen sites from the control subpaddocks throughout the experimental period and 1-SM subpaddocks for Summer 2017 were collected, thoroughly mixed and then carefully divided into subsamples to be used to determine botanical composition. One subsample from the thoroughly mixed herbage in 1-SM (Summer 2018 only), 3-SM, 3-CM subpaddocks, described in the previous section, was separated into desirable and non-desirable species and dried to 60º C until constant weight to determine dry matter concentration. Total desirable species consisted of maintained or planted species (Table 1), and non-planted desirable species, crabgrass (*Digitaria spp.*) and johnsongrass (*Sorghum halepense*).

**Nutritive Value**

One subsample for each experimental unit on each sampling date was packaged and shipped to North Carolina Department of Agriculture and Consumer Services Forage Testing Services for analysis for dry matter, neutral detergent fiber, acid detergent fiber, crude protein, total digestible nutrients, and minerals.
**Pasture Stand Score and Hay Yield**

Thirty randomly selected 0.25 m² points within each of the 1-SM, 3-SM, and 3-CM experimental units were used to assign a pasture stand score (Table A.1), and identify wild-type, endophyte-infected tall fescue escape plants on 3 Apr 2019 by two trained individuals. Pasture stand score was calculated by averaging the two individuals’ stand scores within experimental unit. Wild-type, endophyte-infected tall fescue escape plants were differentiated from Texoma MaxQII plants by size and location of the plants. Presumed escape plants were larger and located between rows and were recorded when present.

On 13 May 2019, all plots were harvested for hay. Round bales were weighed for each individual plot and eight core samples were pulled from each bale using an HMC hay probe (Hart Machine Company, Madras, OR). A 10-g subsample was oven-dried (105°C, 24 h) and weighed hot to determine DM yield for each plot.

**3.2.6 Statistical Analysis**

Data were analyzed using PROC MIXED of SAS Version 9.3 (SAS Institute Inc., Cary, NC). Replicate and its interaction with treatment were considered random. Herbage mass, botanical composition and nutritive value data were analyzed by date within grazing period for Summer 2017 and Summer 2018. Sampling dates did not align among all treatments for Winter 2018, therefor data were analyzed as average values for the season. Least square means are reported and compared using the PDIFF option of SAS. Treatments were considered different at \( P < 0.05 \).

**3.3 Results and Discussion**

Herbage mass (HM) for each grazing period is summarized in Table 2. For Summer 2017, HM was greater for 3-SM on the first two sampling dates in comparison to all other
treatments. For the last sampling date, HM was similar between the control, 1-SM, and 3-CM, and the control and 1-SM were greater than 3-SM. Differences in HM between 3-SM and the two experimental units maintained in wild-type, endophyte-infected tall fescue for the first two sampling dates is expected when comparing a warm-season annual grass to a cool-season annual grass in the summer months (Dillard et al., 2018). Observed HM values for 3-SM for the first two sampling dates were greater than herbage accumulation values (3,130 kg ha⁻¹) prior to the initiation of grazing reported by McCuiston et al. (2011) for a study examining stocker cattle performance for a similar brown mid-rib and photoperiod sensitive sorghum-sudangrass. Differences in forage production can occur among sorghum-sudangrass varieties (Chaugool et al., 2013) and because of environmental factors, and these are likely the cause for the observed differences between the present study and McCuiston et al. (2011). The similarity of HM values between 3-CM, the control and 1-SM was not expected. However, with cowpea accounting for 60.45% of the total seed (by weight) planted in 3-CM experimental units in Summer 2017 and monoculture cowpea herbage mass values of approximately 2 Mg ha⁻¹ being reported in replicated field trial in Florida 6 wk post-planting (Foster et al., 2009), the observed values for 3-CM are not surprising. Herbage mass values were similar between the control and 1-SM, greater than 3-SM, and did not differ from 3-CM on the last sampling date. Individual animal performance (Chapter 4) was negative for the control and 1-SM, and positive for 3-SM and 3-CM. This could explain the general similarities of herbage mass across sampling dates for the control and 1-SM, and why the values were greater than one of the annual forage treatments at the end of the grazing period. Lomas et al. (2011) reported similar forage productivity (3363 kg ha⁻¹) for wild-type, endophyte-infected tall fescue when examining the effect of wild-type, novel and endophyte-free cultivars of tall fescue on animal performance from March until November.
From this study, it was suggested a reduced intake from cattle grazing wild-type, endophyte-infected tall fescue contributed to the observed greater available forage for this treatment throughout the season in comparison to novel endophyte-infected and endophyte-free tall fescue.

Winter 2018 HM values were similar between the control and 1-SM and greater than 3-SM and 3-CM. The HM values for the control and 1-SM are in general agreement with reported average values from a three-yr stockpiled tall fescue study in Raleigh, North Carolina (1660 kg ha\(^{-1}\)) (Burns and Chamblee, 2000). Drewnoski et al. (2007) reported greater herbage mass values (3979 kg ha\(^{-1}\)) in comparison to the present study during a five-yr study in Bahama, North Carolina (Drewnoski et al., 2007). Stockpiling of tall fescue began in early to mid-September for the study in Bahama, NC in comparison to September 1 for study Raleigh and the current study. However, Drewnoski et al. (2007) observed a treatment by year interaction with 2964 kg ha\(^{-1}\) observed in year five when stockpiling started in early October, and 2534 kg ha\(^{-1}\) in yr 2 when weather was drier than normal. The low herbage mass in the study of Burns and Chamblee (2000) was likely due to lower than average rainfall during the autumn months, which is also consistent with 2017 in the current study. It is clear from these studies that yield of winter stockpiled tall fescue is dramatically influenced by the date of initiation and the amount of rainfall realized during the autumn months.

For 3-SM, HM values were greater than reported HM from a three-yr grazing study in Alabama (1,464 kg ha\(^{-1}\)) (Mullenix et al., 2014) and a two-yr study in the same state (1,093 kg ha\(^{-1}\)) (Marchant et al., 2019). Marchant et al. (2019) reported low temperatures in January (5 ºC) of the experimental period and proposed this to be a factor in the low herbage mass.

In Summer 2018, HM values were similar among treatments for three of the four sampling dates. The observations over the first two sampling dates, no differences observed
during the first sampling date and 1-SM and 3-SM not differing from the control on the sampling
date, contradict reasoning for the observed differences in the first two sampling dates in Summer
2017. However, three days post-planting of 1-SM, 3-SM, and 3-CM, heavy rainfall (146 mm)
occcurred over 4 d and likely caused issues with seed placement and emergence. Franzluebbers
and Stuedemann (2007) reported an estimated 34% reduction in pearl millet plant population for
no-till in comparison to conventional seedbed preparation. It was proposed issues of poor seed-
to-soil contact led to reduced plant populations with the no-till treatment because of the need to
place this small seed within the surface residue layer. With two smother crops previous to this
planting in Summer 2018, the surface residue could have also caused issues in achieving a
satisfactory stand of pearl millet. Further, the botanical composition of herbage mass, shown
later in this chapter, highlights the issues with achieving a good forage stand for renovation
treatments in May 2018. On the second sampling date, 3-CM herbage mass was greater than the
control and 3-SM and similar to 1-SM. However, the sampling protocol for the grazing periods
limits characterization to only half of the experimental unit for the entire grazing period and one-
quarter of the experimental unit on a given date. Therefore, although we observed a difference in
values for this sampling date, data should be interpreted with caution.

Botanical composition of planted desirable species for the experimental period is
presented in Table 3. Planted desirable species in Summer 2017 were similar among treatments
for three of the four sampling dates. For the third sampling date, the control and 1-SM planted
desirable species were greater than 3-CM planted desirable species and similar to 3-SM planted
desirable species. With the control and 1-SM being established wild-type, endophyte-infected
tall fescue, and the assumption that intake of cattle was reduced on these treatments, it is
reasonable that greater values would be observed in these paddocks in comparison to 3-SM and
3-CM. However, limitations of the sampling protocol as described previously, warrant cautious interpretation of the differences observed for this sampling date.

For Winter 2018, all percentages of planted desirable species were higher than 90% for the grazing period. Weed encroachment [chickweed \((Stellaria\ media)\) and henbit \((Lamium\ amplexicaule)\)] lowered planted desirable species percentage for 3-CM in comparison to the control and 3-SM. These results suggest that even with less than ideal environmental conditions (Table 2.1 and Figure 2.1), winter annual forages can make up the majority of herbage mass using no-till.

For Summer 2018, desirable species (primarily wild-type, endophyte-infected tall fescue) within the control were greater than planted desirable species for all other treatments on three of the four sampling dates. On the first sampling date, the control desirable species were greater than 1-SM and 3-SM planted species and similar to 3-CM planted species. The general low percentage of planted desirable species for all renovation treatments across sampling dates in Summer 2018 provides confirmation that difficult conditions arose at planting in May.

Table 4 summarizes the total desirable species across treatments, which included crabgrass and johnsongrass in addition to planted or maintained (in the case of control) desirable species, for the experimental period. Both crabgrass and johnsongrass have the capability to produce high amounts of forage and high nutritive value (Dillard et al., 2012; Harmon, 2017). Further, animal performance during the Summer 2018 grazing period (Chapter 4) was as expected for planted desirable species when crabgrass and johnsongrass actually made up the majority of the herbage mass. Therefore, both forages were included in total desirable species for the experimental period. Total undesirable species included Carolina horse nettle \((Solanum\ stapfianum)\).
carolinense), yellow foxtail (Setaria glauca), broad leaf signal grass (Brachiaria platyphylla) and a variety of other broadleaf weeds.

Total desirable species were similar between the control, 3-SM, and 3-CM, and 3-SM and 3-CM were greater than 1-SM for three of the four sampling dates. Total desirable species was above 90% across sampling dates for 3-SM and 3-CM, with crabgrass and johnsongrass making notable contributions to total desirable species in Summer 2017. Crabgrass and johnsongrass contribution to total desirable species for the control and 1-SM were low. Fertilization schedule of control and 1-SM experimental units prior to this study (Lyons et al., 2016) and during the study promoted tall fescue growth and is likely a factor in the low percentage of crabgrass and johnsongrass contributing to total desirable species. Total desirable species for Winter 2018 did not change from planted/maintained desirable species because no non-planted desirable species were identified during this grazing period. Fortunately, in Summer 2018, crabgrass and johnsongrass contribution to total desirable species for renovation treatments was high and alleviated initial concerns about stand establishment in relation to animal performance. This poor stand establishment can be an issue with annual forage crops (Beck et al., 2008) and risks associated with annual forages should be made clear to producers interested in incorporating annual forages into their production system. However, in a renovation process, it is clear that non-planted desirable species can make a positive contribution to the overall outcome. Yet, it is unfortunate to have planted species composition be low when trying to compare different planted desirable species.

Nutritive value of HM for each grazing period is summarized in Tables, 5-7. Chemical composition of the control for Summer 2017 and Summer 2018 were similar to reported concentrations for wild-type, endophyte-infected tall fescue during a 3-yr grazing study that took
place from mid-April to June of tall fescue in North Carolina (Drewnoski et al., 2009). Crude protein (CP) concentration was generally less for 3-SM in comparison to all other treatments at the beginning and end of Summer 2017. These values were expected when comparing a warm-season grass to a cool-season grass and a warm-season mixture containing a legume (Burns and Standaert, 1985; Grabber et al., 1992). Further, harvesting sorghum-sudangrass to a 5 cm stubble height incorporates a majority of the plant, including the lower stalk which is generally lower in CP concentration in comparison to the leaf (Burns, 2009). For the first sampling date in Summer 2018, CP concentration was similar between the control, 1-SM and 3-CM, and the control was greater than 3-SM. On the second sampling date, CP concentration was similar between the control and 3-CM and greater than 1-SM and 3-SM. Crude protein concentration was greater for the control in comparison to all other treatments on the third sampling date. Finally, on the fourth sampling date, CP concentration for the control was greater than 1-SM and 3-SM, and similar to 3-CM.

For NDF concentrations in summer 2017, 3-CM was lower in NDF in comparison to all other treatments on three of the four sampling dates. On the last sampling date, NDF values for 3-CM were similar to the control and greater than 1-SM and 3-SM. The leguminous component of 3-CM was likely a factor in the observed differences among treatments. For Winter 2018, NDF values were similar between 3-SM and 3-CM and lower than the control. The observed NDF concentrations for the control were higher than the average NDF concentration (52.6%) reported by Lyons et al. (2016) when examining the nutritive value of stockpiled wild-type, endophyte-infected tall fescue during the months of November and December on these same plots. However, concentrations from the current study were similar to the average NDF concentration (58.8%) reported by Drewnoski et al. (2009) for stockpiled wild-type, endophyte-
infected tall fescue in a 5-yr grazing study that took place from December to March. It has been shown that delaying sampling of accumulated tall fescue from October to December can increase NDF concentration (Burns, 2009).

Mullenix et al. (2014) reported similar NDF values (48.4) when examining triticale under continuous stocking from late fall to early spring over three years in Alabama. The NDF values observed in the present study for 3-CM were lower than NDF concentration (22%) observed by Villalobos and Brummer (2017) who examined a mixture of triticale, brassica, Austrian winter pea, and hairy vetch in Colorado. Brassicas have been reported to reduce overall NDF concentrations of the sward when representing more than 50% of the sward (Hansen et al., 2015). In the present study, brassicas represented less than 5% (data not shown) of the sward, whereas Villalobos and Brummer reported brassicas representing 80% of the sward. This difference in botanical composition, specifically brassica, explains the differences observed in NDF concentration. For Summer 2018, NDF concentration was similar between 1-SM, 3-SM and 3-CM for all sampling dates. On the third sampling date, NDF concentration was lower for the control in comparison to all other treatments. On the last sampling date, control NDF concentration was higher than 3-SM, and similar to 1-SM and 3-CM.

For the first sampling date in Summer 2017, ADF concentration was lower for 3-CM in comparison to all other treatments. For the third sampling date, ADF concentration was similar between the control, 3-SM, and 3-CM, and 3-CM ADF concentration was lower than 1-SM. For the last sampling date, ADF concentration was similar between the control, 1-SM, and 3-CM, and the control and 1-SM ADF concentrations were lower than 3-SM. For Winter 2018, ADF concentrations differences were similar to observed NDF concentrations differences with 3-SM
and 3-CM ADF concentrations being lower than the control. These concentrations observed in 3-SM are in agreement with triticale ADF concentration (26.6%) reported by Mullenix et al. (2014). For the first sampling date in Summer 2018, ADF concentration was similar between the control, 1-SM, and 3-SM, and 3-SM ADF concentration was lower than 3-CM. For the last sampling date, ADF concentration for the control was lower than all other treatments. The contribution of non-planted desirable species for all renovation treatments likely influenced the general lack of differences observed for ADF concentrations for Summer 2018. Although these contributing non-planted desirable species allowed for good animal performance (Chapter 4), overall nutritive value data for renovation treatments may be more indicative to crabgrass and johnsongrass rather than pearl millet and a mixture containing grasses, legumes, and forbs.

Tall fescue hay was harvested in the Spring of 2018 and 2019 and yield is presented in Table 8. Yield was greater for 1-SM in comparison to the control for Spring 2018. The 1-SM experimental units were not grazed during the Winter 2018 to maintain similar management of 3-SM and 3-CM prior to initiation of renovation and therefore the fall accumulated growth of 1-SM likely contributed to the differences observed. No difference was observed among treatments for yield in the Spring 2019 season. These data will be used in the economic analysis (Chapter 5) to give more information on the opportunity cost of converting toxic endophyte-infected tall fescue pasture. Pasture scores (Table A.1) did not differ with scores averaging 4.6, 4.6, and 4.5 for 1-SM, 3-SM and 3-CM, respectively. Further, escape wild-type, endophyte-infected tall fescue was only observed once within row spacing in a 3-CM experimental unit. These pasture scores show that all renovation treatments were successful in establishing novel endophyte-infected tall fescue and initially, length renovation or smother crop choice will not have an effect on pasture scores. In addition, lack of wild-type, endophyte-infected tall fescue escapes in 1-SM
does not support our hypothesis that extending the renovation period would decrease the risk of escape plants.

### 3.4 Summary

Grazing experiments can provide valuable information on plant-animal interactions (Sollenberger and Burns, 2001). Great effort must be made to accurately characterize these complex interactions, with factors such as stocking rate, herbage mass, stubble height, nutritive value and botanical composition playing key roles in the success of a grazing study.

In this study, because of the rotational stocking strategy and the need to control labor and other costs associated with frequent sampling, forage characterization was limited to one-quarter of the experimental unit for sampling date and one-half of the experimental unit over the whole grazing period. Thus, the entire experimental unit was not fully characterized as would have been the case if we made measurements every week. However, animal grazing days, as reported in Chapter 4, represents “effective yield” from the whole experimental unit and is the appropriate value to use in the economic analysis to determine the cost and benefit of tall fescue renovation from Kentucky 31 tall fescue to novel endophyte-infected tall fescue.

Finally, stand establishment issues in Summer 2018 compromised the interpretation of differences among treatment with non-planted species making up a large portion of the total herbage mass. However, key information was still gained about the agronomic performance of planted and non-planted species during the renovation of wild-type, endophyte-infected tall fescue. The use of summer annual forages, either single species or a mixture of grasses, legumes, and forbs, can be as productive as wild-type, endophyte-infected tall fescue. Nutritive value (especially crude protein) may be lower in annuals during a renovation, but animal performance is likely to improve (Chapter 4). Further, challenges with environmental conditions and surface
residue may arise when planting annual forages, but if crabgrass and johnsongrass are within the seed bank of pastures to be renovated, farmers will still improve animal performance and succeed in smothering out wild-type, endophyte-infected tall fescue.
### Table 3.1 Forage species maintained or planted across treatments for experimental period.

<table>
<thead>
<tr>
<th>Crop Season</th>
<th>Treatment $^\dagger$</th>
<th>C</th>
<th>1-SM</th>
<th>3-SM</th>
<th>3-CM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer 2017</td>
<td>Kentucky 31 tall fescue</td>
<td>Kentucky 31 tall fescue</td>
<td>98.5% AS 6501 sorghum-sudangrass, 1.4% inert matter, 0.1% other crop seed</td>
<td>60.45% Iron &amp; Clay cowpea, 11.05% AS 6501 sorghum-sudangrass, 7.45% Daikon radish, 7.33% Tifleaf III pearl millet, 5.52% AS 6401 sorghum-sudangrass, 3.71% Peredovik sunflower, 2.76% T-raptor hybrid brassica, 1.03% inert matter, 0.36% other crop seed, 0.32% weed seed</td>
<td></td>
</tr>
<tr>
<td>Winter 2018</td>
<td>Kentucky 31 tall fescue</td>
<td>Kentucky 31 tall fescue</td>
<td>98% TriCal 815 triticale, 1.4% inert matter, 0.5% other crop seed, 0.1% weed seed</td>
<td>23.26% Austrian winter pea, 19.97% Reeves oat, 19.30% TriCal 815 Triticale, 12.48% Hairy vetch, 11.18% crimson clover, 7.13% ryegrass, 2.50% rape, 2.49% radish, 1.06% inert matter, 0.43% other crop seed, 0.18% weed seed</td>
<td></td>
</tr>
<tr>
<td>Summer 2018</td>
<td>Kentucky 31 tall fescue</td>
<td>Wonderleaf pearl millet, 1.5 % inert matter, 0.4% other crop seed, 0.1% weed seed</td>
<td>98% Wonderleaf pearl millet, 1.5 % inert matter, 0.4% other crop seed, 0.1% weed seed</td>
<td>61.25% Iron &amp; Clay cowpea, 8.0% AS 6501 sorghum-sudangrass, 8.0% AS 6401 sorghum-sudangrass, 6.74% Wonderleaf pearl millet, 6.23% Daikon radish, 6.13% Peredovik sunflower, 1.87% T-Raptor hybrid brassica, 1.69% inert matter, 0.06% other crop seed, 0.03% weed seed</td>
<td></td>
</tr>
</tbody>
</table>

$^\dagger$ C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.

$^2$ As presented on seed tag.
Table 3.2 Herbage mass (HM) across treatments for each grazing period.

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Treatment</th>
<th>Treatment</th>
<th>Treatment</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>1-SM</td>
<td>3-SM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer 2017</td>
<td>HM kg ha(^{-1})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Aug</td>
<td>2673(^b)</td>
<td>2922(^b)</td>
<td>4511(^a)</td>
<td>3275(^b)</td>
<td>323</td>
</tr>
<tr>
<td>15 Aug</td>
<td>3278(^b)</td>
<td>3397(^b)</td>
<td>4611(^a)</td>
<td>3763(^b)</td>
<td>169</td>
</tr>
<tr>
<td>29 Aug</td>
<td>3367</td>
<td>3638</td>
<td>3422</td>
<td>3141</td>
<td>211</td>
</tr>
<tr>
<td>12 Sep</td>
<td>3219(^a)</td>
<td>3280(^a)</td>
<td>2135(^b)</td>
<td>2932(^ab)</td>
<td>280</td>
</tr>
<tr>
<td>Winter 2018(^\dagger)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1999(^a)</td>
<td>1979(^a)</td>
<td>1297(^b)</td>
<td>1508(^b)</td>
<td>112</td>
</tr>
<tr>
<td>Summer 2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Jul</td>
<td>3247</td>
<td>3235</td>
<td>2464</td>
<td>3511</td>
<td>277</td>
</tr>
<tr>
<td>19 Jul</td>
<td>3576(^b)</td>
<td>4561(^ab)</td>
<td>3260(^b)</td>
<td>5253(^a)</td>
<td>419</td>
</tr>
<tr>
<td>2 Aug</td>
<td>3017</td>
<td>3586</td>
<td>2825</td>
<td>3653</td>
<td>392</td>
</tr>
<tr>
<td>16 Aug</td>
<td>2442</td>
<td>2604</td>
<td>2685</td>
<td>3398</td>
<td>293</td>
</tr>
<tr>
<td>Winter 2019</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2033</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^a\)\(^c\) Means within a row with unlike superscripts differ \((P < 0.05)\)

\(^1\) C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.

\(^\dagger\) Average herbage mass for Winter 2018 presented for treatments as sampling dates did not align for all treatments.
Table 3.3 Percentage of planted desirable species by weight across treatments for all sampling dates in the grazing period (2017-2019).

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Treatment¹</th>
<th>C</th>
<th>1-SM</th>
<th>3-SM</th>
<th>3-CM</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer 2017</strong></td>
<td>Planted† desirable species (% DM)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Aug</td>
<td>79</td>
<td>66</td>
<td>86</td>
<td>69</td>
<td>7.2</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>15 Aug</td>
<td>79</td>
<td>63</td>
<td>69</td>
<td>67</td>
<td>11</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>29 Aug</td>
<td>89ᵃ</td>
<td>89ᵃ</td>
<td>75ᵇ</td>
<td>58ᵇ</td>
<td>8</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>12 Sep</td>
<td>78</td>
<td>58</td>
<td>51</td>
<td>62</td>
<td>13.5</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td><strong>Winter 2018</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>98ᵃ</td>
<td>-</td>
<td>99ᵃ</td>
<td>91ᵇ</td>
<td>1</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td><strong>Summer 2018</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Jul</td>
<td>54ᵃ</td>
<td>27ᵇ</td>
<td>18ᵇ</td>
<td>33ᵇ</td>
<td>7</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>19 Jul</td>
<td>80ᵃ</td>
<td>22ᵇ</td>
<td>28ᵇ</td>
<td>41ᵇ</td>
<td>10</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>2 Aug</td>
<td>85ᵃ</td>
<td>26ᵇ</td>
<td>20ᵇ</td>
<td>36ᵇ</td>
<td>8</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>16 Aug</td>
<td>91ᵃ</td>
<td>16ᵇ</td>
<td>19ᵇ</td>
<td>35ᵇ</td>
<td>11</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td><strong>Winter 2019</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>99</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

ᵃᵇᶜ Means within a row with unlike superscripts differ (P < 0.05)

¹C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.

†Planted/maintained desirable species for Summer 2017 in C and 1-SM: (Tall fescue); 3-SM: (Sorghum-sudangrass); 3-CM: (Cowpea + sorghum-sudangrass + pearl millet + radish + hybrid brassica + sunflower), for Winter 2018 in C and 1-SM: (Tall fescue); 3-SM: (Triticale); 3-CM: (Winter pea + oat + triticale + hairy vetch + crimson clover + ryegrass + rape + radish), for Summer 2018 in C: (Tall fescue); 1-SM and 3-SM: (Pearl millet); 3-CM: (Cowpea + sorghum-sudangrass + pearl millet + radish + hybrid brassica + sunflower).

‡average planted desirable species for Winter 2018 presented for treatments as sampling dates did not align for all treatments.
Table 3.4 Percentage of total desirable species by weight across treatments for all sampling dates in the grazing period (2017-2019).

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Treatment¹</th>
<th>C</th>
<th>1-SM</th>
<th>3-SM</th>
<th>3-CM</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer 2017</strong></td>
<td><strong>Total† desirable species (% DM)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Aug</td>
<td>87&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>75&lt;sup&gt;b&lt;/sup&gt;</td>
<td>99&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.2</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>15 Aug</td>
<td>87&lt;sup&gt;a&lt;/sup&gt;</td>
<td>71&lt;sup&gt;b&lt;/sup&gt;</td>
<td>98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.6</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>29 Aug</td>
<td>91</td>
<td>93</td>
<td>96</td>
<td>91</td>
<td>3</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>12 Sep</td>
<td>79&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>61&lt;sup&gt;b&lt;/sup&gt;</td>
<td>98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.2</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td><strong>Winter 2018‡</strong></td>
<td></td>
<td>98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>99&lt;sup&gt;a&lt;/sup&gt;</td>
<td>91&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td><strong>Summer 2018</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Jul</td>
<td>54&lt;sup&gt;b&lt;/sup&gt;</td>
<td>89&lt;sup&gt;a&lt;/sup&gt;</td>
<td>93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>19 Jul</td>
<td>80</td>
<td>78</td>
<td>96</td>
<td>89</td>
<td>7</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>2 Aug</td>
<td>85</td>
<td>82</td>
<td>95</td>
<td>89</td>
<td>5</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>16 Aug</td>
<td>91&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>75&lt;sup&gt;b&lt;/sup&gt;</td>
<td>99&lt;sup&gt;a&lt;/sup&gt;</td>
<td>98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td><strong>Winter 2019</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a-d</sup> Means within a row with unlike superscripts differ (P < 0.05)

<sup>¹</sup>C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.

<sup>†</sup>Total desirable species for Summer 2017 in C and 1-SM: (Tall fescue + crabgrass + johnsongrass); 3-SM: (Sorghum-sudangrass + crabgrass + johnsongrass); 3-CM: (Cowpea + sorghum-sudangrass + pearl millet + radish + hybrid brassica + sunflower + crabgrass + johnsongrass), for Winter 2018 in C and 1-SM: (Tall fescue); 3-SM: (Triticale); 3-CM: (Winter pea + oat + triticale + hairy vetch + crimson clover + ryegrass + rape + radish), for Summer 2018 in C: (Tall fescue + crabgrass + johnsongrass); 1-SM and 3-SM: (Pearl millet + crabgrass + johnsongrass); 3-CM: (Cowpea + sorghum-sudangrass + pearl millet + radish + hybrid brassica + sunflower + crabgrass + johnsongrass).

<sup>‡</sup>Average total desirable species for Winter 2018 presented for treatments as sampling dates did not align for all treatments.
Table 3.5 Crude Protein (CP) composition across treatments for all sampling dates in the grazing period (2017-2019).

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Treatment</th>
<th>CP %</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>1-SM</td>
<td>3-SM</td>
<td>3-CM</td>
</tr>
<tr>
<td>Summer 2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Aug</td>
<td>10.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>15 Aug</td>
<td>9.2</td>
<td>9.9</td>
<td>8.4</td>
<td>11.0</td>
</tr>
<tr>
<td>29 Aug</td>
<td>11.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>11.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>9.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>12 Sep</td>
<td>13.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Winter 2018†</td>
<td>13.7</td>
<td>-</td>
<td>12.9</td>
<td>18.6</td>
</tr>
<tr>
<td>Summer 2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Jul</td>
<td>11.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>8.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.9&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>19 Jul</td>
<td>11.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2 Aug</td>
<td>12.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>16 Aug</td>
<td>14.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.1&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Winter 2019</td>
<td>13.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a row with unlike superscripts differ (P < 0.05)

<sup>1</sup>C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.

<sup>†</sup>Average CP concentration for Winter 2018 presented for treatments as sampling dates did not align for all treatments.
Table 3.6 Neutral detergent fiber (NDF) composition of herbage mass across treatments for all sampling dates in the grazing period (2017-2019).

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Treatment</th>
<th>NDF %</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer 2017</td>
<td>C</td>
<td>56.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>1-SM</td>
<td>55.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3-SM</td>
<td>54.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3-CM</td>
<td>44.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Aug</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Aug</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29 Aug</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Sep</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter 2018‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>64.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.4</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Summer 2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Jul</td>
<td></td>
<td>59.7</td>
<td>1.6</td>
<td>0.36</td>
</tr>
<tr>
<td>19 Jul</td>
<td></td>
<td>60.2</td>
<td>1.4</td>
<td>0.17</td>
</tr>
<tr>
<td>2 Aug</td>
<td></td>
<td>59.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.2</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>16 Aug</td>
<td></td>
<td>60.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.3</td>
<td>0.04</td>
</tr>
<tr>
<td>Winter 2019</td>
<td></td>
<td>58.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a row with unlike superscripts differ (P < 0.05)
<sup>1</sup> C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.
<sup>‡</sup>average NDF concentration for Winter 2018 presented for treatments as sampling dates did not align for all treatments.
Table 3.7 Acid detergent fiber (ADF) composition of herbage mass across treatments for all sampling dates in the grazing period (2017-2019).

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Treatment¹</th>
<th>C</th>
<th>1-SM</th>
<th>3-SM</th>
<th>3-CM</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer 2017</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Aug</td>
<td></td>
<td>33.1ᵇ</td>
<td>33.1ᵇ</td>
<td>32.9ᵇ</td>
<td>27.6ᵃ</td>
<td>0.9</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>15 Aug</td>
<td></td>
<td>34.4</td>
<td>34.0</td>
<td>32.1</td>
<td>31.0</td>
<td>1.1</td>
<td>0.17</td>
</tr>
<tr>
<td>29 Aug</td>
<td></td>
<td>33.2ᵃᵇ</td>
<td>34.2ᵇ</td>
<td>32.6ᵃᵇ</td>
<td>30.1ᵃ</td>
<td>0.9</td>
<td>0.03</td>
</tr>
<tr>
<td>12 Sep</td>
<td></td>
<td>36.5ᵃ</td>
<td>37.2ᵃ</td>
<td>42.6ᵇ</td>
<td>38.9ᵃᵇ</td>
<td>1.2</td>
<td>0.01</td>
</tr>
<tr>
<td>Winter 2018²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>38.4ᵇ</td>
<td>-</td>
<td>26.7ᵃ</td>
<td>22.7ᵃ</td>
<td>1.7</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Summer 2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Jul</td>
<td></td>
<td>35.7ᵃᵇ</td>
<td>35.9ᵃᵇ</td>
<td>33.7ᵃ</td>
<td>36.9ᵇ</td>
<td>0.7</td>
<td>0.05</td>
</tr>
<tr>
<td>19 Jul</td>
<td></td>
<td>36.9</td>
<td>38.4</td>
<td>36.6</td>
<td>38.0</td>
<td>0.7</td>
<td>0.35</td>
</tr>
<tr>
<td>2 Aug</td>
<td></td>
<td>35.6</td>
<td>40.1</td>
<td>39.0</td>
<td>38.9</td>
<td>1.0</td>
<td>0.06</td>
</tr>
<tr>
<td>16 Aug</td>
<td></td>
<td>34.1ᵃ</td>
<td>40.5ᵇ</td>
<td>41.9ᵇ</td>
<td>39.3ᵇ</td>
<td>0.8</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Winter 2019</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>33.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

ᵃᵇᶜ Means within a row with unlike superscripts differ (P < 0.05)
¹C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.
²Average ADF concentration for Winter 2018 presented for treatments as sampling dates did not align for all treatments.
Table 3.8 Harvested hay yield for C and 1-SM (2018) and all treatments (2019).

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment(^1)</th>
<th>C</th>
<th>1-SM</th>
<th>3-SM</th>
<th>3-CM</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spring 2018</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yield, kg/ha</td>
<td>1987(^{b}) 2757(^{a})</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>76</td>
<td>76</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td><strong>Spring 2019</strong></td>
<td></td>
<td>2456</td>
<td>1742</td>
<td>1550</td>
<td>1947</td>
<td>255</td>
<td>0.07</td>
</tr>
</tbody>
</table>

\(^{a-b}\) Means within a row with unlike superscripts differ \((P < 0.05)\)

\(^1\) C, toxic endophyte infected tall fescue; 1-SM, one season simple mixture; 3-SM, three season simple mixture; and 3-CM, three season complex mixture.
Literature Cited


CHAPTER 4: Animal performance on smother crops during the replacement of wild-type endophyte-infected tall fescue.

4.1 Introduction

Fescue toxicosis is prevalent in cattle grazing wild-type, endophyte-infected tall fescue and conservative estimates suggest this issue costs cattle farmers $600 million annually (Bouton, 2007). Replacement of this grass with novel endophyte-infected tall fescue is an option for farmers who seek improved animal performance and similar plant persistence in comparison to wild-type, endophyte-infected tall fescue (Roberts and Andrae, 2004). The use of annual forages as smother crops can help eliminate residual wild-type, endophyte-infected tall fescue plants and improve animal performance during the transition to novel endophyte-infected tall fescue (Bagegni et al., 1994). Extending the renovation period past one season has been proposed to better control wild-type, endophyte-infected escape plants, improve farmer confidence in using a no-till drill prior to planting novel endophyte-infected tall fescue, and recoup renovation costs at time of planting novel endophyte-infected tall fescue through improved animal performance. In addition, annual forage mixtures containing grasses, legumes and forbs have been proposed to have a higher nutritive value than single-species annual grasses to improve animal performance. However, animal performance data during the replacement of wild-type, endophyte-infected tall fescue with novel endophyte tall fescue using annual forages and annual forage mixtures as smother crops are non-existent.

We hypothesized that smother crops will improve animal performance in comparison to wild-type, endophyte-infected tall fescue in one season and over three seasons. We also hypothesized that the complex mixture smother crop could improve animal performance in comparison to a single species smother crop. Our objectives were to compare animal performance from four systems: (1) continuation of wild-type, endophyte-infected tall fescue, (2)
replacement of wild-type, endophyte-infected tall fescue with novel endophyte-infected tall fescue intervened by one season using a single species smother crop, (3) replacement of wild-type, endophyte-infected tall fescue with novel endophyte-infected tall fescue intervened by three seasons using a single species smother crop, and (4) replacement of wild-type, endophyte-infected tall fescue with novel endophyte-infected tall fescue intervened by three seasons using a multi-species smother crop that included grasses, legumes, and brassicas.

4.2 Materials and Methods

All cattle care, handling, and sampling procedures were approved by the North Carolina State University Animal Care and Use Committee. The Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999) was used for animal care during these three experiments, and the protocol was approved by the Institutional Animal Care and Use Committee (IACUC protocol # 13-124-A and 16-212-A).

4.2.1 Treatments and Experimental Design

The experiment took place on wild-type, endophyte-infected tall fescue pastures located at the Butner Beef Cattle Field Laboratory (36°17’ N; 78°80’ W) near Bahama, NC in 2017, 2018, and 2019. Pastures in 2015 had an average infection rate of 63% with *E. coenophiala*, as determined from molecular analyses (Takah and Young, 2014). Average air temperature and total rainfall for the months of the experiment and the 30 yr average are presented in Chapter 2 as recorded at the North Carolina Department of Agriculture and Consumer Services Oxford Tobacco Research Station (36°30’ N; 78°61’ W).

Treatments were: (i) Control (continuation of wild-type, endophyte-infected tall fescue pastures), (ii) one season single species smother crop renovation (renovated over one season from wild-type, endophyte-infected tall fescue to novel endophyte-infected tall fescue beginning
in May 2018 using pearl millet [\textit{Pennisetum glaucum} (L.) R. Br.], (iii) three-season single species smother crop renovation over three seasons from wild-type, endophyte-infected tall fescue to novel endophyte-infected tall fescue beginning in May 2017 with sorghum-sudangrass [\textit{Sorghum bicolor} (L.) x \textit{Sorghum vulgare} (Pers.)], triticale (\textit{xTriticosecale}), and pearl millet as the smother crop for Summer 2017, Winter 2018, and Summer 2018, respectively), and (iv) three-season complex mixture smother crop renovation over three seasons from wild-type, endophyte-infected tall fescue to novel endophyte-infected tall fescue beginning in May 2017 using a mixture of grasses, legumes and forbs as the smother crop for Summer 2017, Winter 2018, and Summer 2018 as presented in Chapter 3. The four treatments were replicated four times in a randomized complete block design for a total of 16 experimental units. Area of an experimental unit was 0.8-ha.

\textbf{Stocking Management}

All plots were divided into four 0.2-ha subpaddocks for each grazing period using temporary electric fence. Cattle were rotationally stocked on subpaddocks for 7 d, with each subpaddock having a 21-d rest period before cattle grazed forage within that subpaddock for a second time during the summer grazing periods. Initial DM measurements were used to determine stocking rate for each grazing period with 30\% residual forage target for each subpaddock. Adjustments in stocking rate were made for each plot following calculation of DM biomass from 2-wk interval sample collections.

For the control treatment in Winter 2018 and 2019, cattle were set stocked in subpaddocks to graze stockpiled tall fescue from the first of January to late February with target post-graze height of 5 cm (Drewnoski et al., 2007). With a limited number of cattle available, cattle were moved when post-target height was reached rather than moving every 7 d.
4.2.2 Response Variables

**Bodyweight Gain**

Prior to each grazing period, all cattle were vaccinated at weaning with Bovishield Gold FP5VL5 (Zoetis US, Parsippany, NJ) and One Shot Ultra 7 (Zoetis US, Parsippany, NJ), and grazed on a mix of cool-season perennial grass pastures that included wild-type, endophyte-infected, and novel endophyte-infected tall fescue. For each grazing period, 32 Angus and Angus-cross tester steers (425 ± 5, 298 ± 6, and 382 ± 8 kg for Summer 2017, Winter 2018 and Summer 2018, respectively) were blocked by BW after being weighed two consecutive days and randomly assigned to one of four treatments. Two tester steers were assigned to each plot and allowed to graze the plot for the entire grazing period. Put-and-take stocking was used to manage forage allowance in each grazing period, and presence of these cattle were used to determine gain per hectare and animal unit grazing days. All cattle had access to a mineral mix, water, and shade. Final BW was recorded at the end of each grazing period to determine ADG for each treatment.

**Bodyweight Gain Per Hectare**

For each grazing period, BW gain per hectare was calculated by: the average of ADG of the tester steers x total days grazed by testers and “puts-and takes” / total area grazed. Animal unit (AU) grazing days were collected for each grazing period and were calculated by: initial animal weight/454 kg (1 AU) x length of grazing period / total area of plot.

4.2.3 Statistical Analysis

All statistical analysis was performed in SAS version 9.3 (SAS Institute Inc., Cary, NC). Animal response variables were analyzed as a randomized complete block design using the MIXED procedure with values being reported as least square means. Pasture was considered the
experimental unit for BW gain per hectare, AU grazing days and pasture rating and animal was considered the sampling unit for average daily gain. Because BW gain per hectare, AU grazing days, and pasture ratings were means of plots, data were analyzed using the GLM procedure of SAS. Differences among results were considered significant at $P < 0.05$.

4.3 Results and Discussion

Final BW, ADG, and BW gain per hectare for Summer 2017 (Table 1) were similar between 3-SM and 3-CM, and greater than the control and 1-SM. The negative rate of gain observed for steers grazing the wild-type, endophyte-infected tall fescue control and 1-SM, (which was still in wild-type, endophyte-infected tall fescue during Summer 2017) is not consistent with other reported ADG for cattle grazing wild-type, endophyte-infected tall fescue. Franzluebbers and Stuedemann (2009) observed 0.45 kg/d for steers grazing wild-type, endophyte-infected tall fescue in Georgia during the summer, and Drewnoski et al. (2009a) reported 0.25 kg/d for heifers grazing wild-type, endophyte-infected tall fescue from mid-April to August. Rottinghaus et al. (1991) reported low ergovaline concentrations for June, July and August regrowth of wild-type, endophyte-infected tall fescue, however, concentrations began to rise in September and peaked in early October. Steers grazed the control and 1-SM experimental units from August to the end of September, it is possible ergot alkaloid concentrations began to rise during the grazing period and elicited this negative rate of gain. The ADG values for steers grazing 3-SM (sorghum-sudangrass) for Summer 2017 were similar to gains (0.83 kg/d) reported by Parish et al. (2013) for cattle grazing sudangrass in Mississippi and to gains (0.86 kg/d) reported by Harmon et al. (2017) for yearling steers grazing sorghum-sudangrass in Georgia. Average daily gain values for 3-CM for Summer 2017 were in general agreement with ADG (0.7 kg/d) reported by Vendramini et al. (2012) for cattle grazing bahiagrass interseeded with
cowpea. The BW gain per hectare values for 3-SM were greater than values (89 kg/ha) reported by Parish et al. (2013). With ADG not differing between the present experiment and Parish et al. (2013), stocking rate is likely the factor for the observed differences in BW gain per hectare. Animal unit grazing days per hectare did not differ among treatment for Summer 2017.

In Winter 2018, final BW and ADG were not different between 3-SM and 3-CM, but greater than in the control. Steer ADG for stockpiled wild-type, endophyte-infected tall fescue in Winter 2018 was greater than previously reported ADG (0.35; 0.51 kg/d) for heifers grazing stockpiled wild-type, endophyte-infected tall fescue by Poore et al. (2006) and Drewnoski et al. (2009b), respectively. Conversely, BW gain per hectare for stockpiled wild-type, endophyte-infected tall fescue was less than values (223; 257 kg/ha) reported by Poore et al. (2006) and Drewnoski et al. (2009b), respectively. It is possible that in the current study pastures were slightly understocked (data not shown) and individual animal performance was at its maximum, whereas Poore et al. (2006), Drewnoski et al. (2009b), and Lyons et al. (2016) achieved greater gains per hectare with higher stocking rates and with a compromise of individual animal performance. The ADG values observed for 3-SM (triticale) were greater than ADG values (1.23; 1.45 kg/d) reported in Alabama for steers grazing triticale and triticale + annual ryegrass (Mullenix et al., 2012; Marchant et al., 2019, respectively). However, the BW gain per ha (293 kg/ha) was less than reported by Marchant et al. (2019) (542 kg/ha). Similar to the control, it is possible individual animal performance was maximized with a low stocking rate (data not shown) but gain per ha was not and this led to greater ADG values observed in this study than previous studies. Finally, 3-SM had greater AU grazing days per hectare in comparison to the control and 3-CM, and the control AU grazing days were greater than 3-CM. The AU grazing days approximately one-quarter of the 3-yr mean (459) grazing days reported by Mullenix et al.
(2012). Many cool-season annual forage studies begin grazing in January and end in May (Beck et al., 2013). In the present study, we began grazing in March and terminated in April to prepare for the next smother crop. If the grazing period was extended for 3-SM and 3-CM, BW gain per hectare and AU grazing days may have improved.

In Summer 2018, Final BW values were similar between 3-SM (pearl millet) and 3-CM, whereas 3-SM values were greater than in 1-SM (pearl millet) and the control, and 3-CM values were greater than the control. Further, ADG and BW gain per hectare values were greater for both 3-SM and 3-CM in comparison to 1-SM and the control, and 1-SM was greater than the control. The difference in 1-SM and 3-SM ADG and BW gain per hectare values were surprising because the forage nutritive values for 3-SM and 1-SM were similar (Chapter 4) and the same grasses were planted in 3-SM and 1-SM pastures (Chapter 3). However, total desirable species (Chapter 3) for 3-SM was approximately 75% crabgrass (data not shown) whereas crabgrass only contributed ~30% to total desirable species for 1-SM. Although information is limited on the performance of cattle grazing predominantly crabgrass pastures, Harmon (2017) observed similar gains (0.97kg/d) to the present study for yearling steers grazing a mixture of crabgrass and pearl millet. Steer ADG was positive for the control in Summer 2018 and is in agreement with the other studies previously mentioned that examined grazing of tall fescue in early summer. Steer initial BW in Summer 2018 was lower than in Summer 2017 and these steers could have had a higher growth potential than those in Summer 2018 (Short et al., 1999).

Further, the grazing period for Summer 2018 was during July and August, when ergot alkaloids in regrowth of wild-type, endophyte-infected tall fescue concentrations decline (Rottinghaus et al., 1991).
4.4 Summary

Renovation treatments improved individual animal performance and BW gain per ha in comparison to wild-type, endophyte-infected tall fescue for all grazing periods. These data confirm our first hypothesis and highlight the benefits of moving cattle off wild-type, endophyte-infected tall fescue during the summer. Data did not support our second hypothesis that a mixture of grasses, legumes, and forbs would improve animal performance, compared to a single species. With poor stand establishment in Summer 2018, crabgrass and johnsongrass percentages of total herbage mass were high across renovation treatments and limit interpretation of treatment effect during this grazing period. Yet, planted species were 60% for 3-SM and 3-CM (Chapter 3) in Summer 2017, and animal performance still did not differ. Legume and brassica contribution to the total herbage mass may not have been high enough to elicit a change in animal performance (Villalobos and Brummer, 2017). Although positive gains were observed for the control in Summer 2018, these values were half to one-third of observed gains on the smother crop treatments. Further, in Summer 2018, following poor stand establishment, non-planted species of crabgrass and johnsongrass made up the majority of the total herbage and cattle still performed well. This information should give producers some comfort in knowing that even if the establishment of annual forages is less than optimal, cattle will likely perform better on the non-planted species that germinate in the pasture in comparison to wild-type, endophyte-infected tall fescue. Finally, this improvement in animal performance will generate economic returns not realized for wild-type, endophyte-infected tall fescue (Chapter 5) and should entice farmers to consider renovating a portion of their wild-type, endophyte-infected tall fescue pastures.
### Tables and Figures

**Table 4.1** Effects of treatment on cattle BW and performance (2017-2019).

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th>C</th>
<th>1-SM</th>
<th>3-SM</th>
<th>3-CM</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer 2017</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td></td>
<td>424</td>
<td>425</td>
<td>423</td>
<td>429</td>
<td>10</td>
<td>0.31</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td></td>
<td>420&lt;sup&gt;b&lt;/sup&gt;</td>
<td>417&lt;sup&gt;b&lt;/sup&gt;</td>
<td>469&lt;sup&gt;a&lt;/sup&gt;</td>
<td>475&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>ADG, kg</td>
<td></td>
<td>-0.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.79&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.1</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>BW gain per hectare, kg</td>
<td></td>
<td>-16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>166&lt;sup&gt;a&lt;/sup&gt;</td>
<td>165&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>AU grazing days/ha</td>
<td></td>
<td>221</td>
<td>215</td>
<td>210</td>
<td>183</td>
<td>12</td>
<td>0.20</td>
</tr>
<tr>
<td><strong>Winter 2018</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td></td>
<td>289&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>-</td>
<td>284&lt;sup&gt;b&lt;/sup&gt;</td>
<td>320&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10</td>
<td>0.05</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td></td>
<td>307&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td>348&lt;sup&gt;a&lt;/sup&gt;</td>
<td>369&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9</td>
<td>0.03</td>
</tr>
<tr>
<td>ADG, kg</td>
<td></td>
<td>0.79&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td>1.85&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.2</td>
<td>0.01</td>
</tr>
<tr>
<td>BW gain per hectare, kg</td>
<td></td>
<td>109&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-</td>
<td>293&lt;sup&gt;a&lt;/sup&gt;</td>
<td>214&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19</td>
<td>0.01</td>
</tr>
<tr>
<td>AU grazing days/ha</td>
<td></td>
<td>92&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
<td>110&lt;sup&gt;a&lt;/sup&gt;</td>
<td>63&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td><strong>Summer 2018</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td></td>
<td>380</td>
<td>385</td>
<td>384</td>
<td>379</td>
<td>16</td>
<td>0.37</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td></td>
<td>399&lt;sup&gt;c&lt;/sup&gt;</td>
<td>423&lt;sup&gt;b&lt;/sup&gt;</td>
<td>443&lt;sup&gt;a&lt;/sup&gt;</td>
<td>437&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>19</td>
<td>0.01</td>
</tr>
<tr>
<td>ADG, kg</td>
<td></td>
<td>0.33&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.68&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.04&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.1</td>
<td>0.01</td>
</tr>
<tr>
<td>BW gain per hectare, kg</td>
<td></td>
<td>90&lt;sup&gt;c&lt;/sup&gt;</td>
<td>156&lt;sup&gt;b&lt;/sup&gt;</td>
<td>213&lt;sup&gt;a&lt;/sup&gt;</td>
<td>223&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>AU grazing days/ha</td>
<td></td>
<td>207</td>
<td>197</td>
<td>186</td>
<td>194</td>
<td>7</td>
<td>0.78</td>
</tr>
<tr>
<td><strong>Winter 2019</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td></td>
<td>297</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Final BW, kg</td>
<td></td>
<td>313</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ADG, kg</td>
<td></td>
<td>0.71</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>BW gain per hectare, kg</td>
<td></td>
<td>125.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>AU grazing days/ha</td>
<td></td>
<td>81</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<sup>a</sup>d Means within a row with unlike superscripts differ (*P* < 0.05).

<sup>1</sup> C, wild-type, endophyte-infected tall fescue; 1-SM, one season single species; 3-SM, three season single species; and 3-CM, three season complex mixture.
Literature Cited


CHAPTER 5: Economic analysis of three strategies to replace wild-type endophyte-infected tall fescue with novel endophyte-infected tall fescue.

5.1 Introduction

Wild-type, endophyte-infected tall fescue is the base forage species for pasture in the transition zone of the U.S. humid region (Poore, 2010). The ergot alkaloids produced by the wild-type, endophyte, *Epichloë coenophiala*, have been linked with undesirable animal responses (i.e., reduced weight gain, poor reproductive performance, heat stress) (Thompson et al., 1993; Poole et al., 2019). These issues, collectively termed *fescue toxicosis*, are estimated to cost livestock farmers (cattle, sheep and goats, and equine) an estimated $1 billion annually (Strickland et al., 2011). Replacement of wild-type, endophyte-infected tall fescue with novel endophyte-infected tall fescue using a smoother crop over one season is an option for farmers (Roberts and Andrae, 2004). However, less than 3% of wild-type, endophyte-infected tall fescue pastures have been converted to novel endophyte-infected tall fescue (Chris Agee, personal communication).

The limited research providing economic analysis on replacing wild-type, endophyte-infected tall fescue suggests a net cost range of $371/ha (Gunter and Beck, 2004) to $1206/ha (Zhuang et al., 2005). Further, both studies were only model scenarios and to date, no information is available to the farmer based on a replicated field trial examining the economics of conversion of pasture from wild-type, endophyte-infected tall fescue to novel endophyte-infected tall fescue. Also, no study has examined the economic benefit of utilizing legumes in smoother crops which can offset the need for inorganic N applications (Phelan et al., 2015).

We hypothesized that smoother crops would improve animal performance and value of gain for renovation strategies in comparison to wild-type, endophyte-infected tall fescue and thereby partially offset the cost of renovating. We also hypothesized that extending the
renovation period past one season to three seasons would have a greater offset of renovation cost. Finally, we hypothesized using a complex annual forage mix including a legume as a smother crop and therefore eliminating inorganic N applications, could reduce renovation costs. Our objectives were to compare the economic costs and returns for grazing steers on: wild-type, endophyte-infected tall fescue; a single species smother crop for one season; a single species smother crop for three seasons; and on a complex forage mixture smother crop for three seasons.

5.2 Materials and Methods

5.2.1 Treatments and Experimental Design

The experiment took place on established wild-type, endophyte-infected tall fescue pastures located at the Butner Beef Cattle Field Laboratory (36°17’ N; 78°80’ W) near Bahama, NC in 2017, 2018, and 2019. Pastures in 2015 had an average infection rate of 63% with *E. coenophiala*, as determined from molecular analyses (Takah and Young, 2014). Average air temperature and total rainfall for the months of the experiment and the 30 yr average are presented in Figure 2.1 and Table 2.1.

Treatments were described in detail in Chapter 3. Briefly, they were (i) Control (wild-type, endophyte-infected tall fescue pastures), (ii) one season single species smother crop renovation beginning in May 2018, (iii) three season single species smother crop renovation beginning in May 2017, and (iv) three season complex mixture smother crop renovation beginning in May 2017. The four treatments were replicated four times in a randomized complete block design for a total of 16 experimental units. The area of an experimental unit was 0.8-ha. The treatments were set up so that renovation from ‘Kentucky 31’ to ‘Texoma MaxQ II’ (Pennington Seed, Inc.) tall fescue occurred in the Fall of 2018 for all treatments.
5.2.2 Response Variables

Agronomic costs

Costs for establishing novel endophyte tall fescue and maintaining wild-type tall fescue for this study (Table 1) were based on the “Economics of Conversion to Novel Fescue” enterprise budget developed by Joe Horner (Agricultural Economics Department, University of Missouri, Columbia, MO). Herbicide costs included: glyphosate, $5.68/kg ai (active ingredient); Dicamba + 2,4-D, $13.73/kg ai; and pendimethalin, $25.56/kg ai. A custom herbicide application rate of $24.71/ha was used for all herbicide applications throughout the experiment. The cost of the pendimethalin + 43.8 kg N/ha application in Spring 2019, was set at $24.71/ha. Seed (Table 3.1) costs included: Summer 2017, Sorghum-sudangrass, $2.58/kg PLS; complex mixture, $3.37/kg PLS; Fall 2017, triticale, $1.06/kg PLS; complex mixture, $2.82/kg PLS; Summer 2018, pearl millet, $3.59/kg PLS; complex mixture, $3.02/kg PLS, and Fall 2018, Texoma MaxQII, $8.38/kg PLS. A custom planting rate of $49.42/ha was used for all plantings throughout the experiment. Fertilizer costs included a custom fertilizer application rate of $14.83/ha for all N applications throughout the experiment. A 5-yr prorated cost of $7.40/ton for dolomitic lime was added to the agronomic cost each year for each treatment and included the cost and application of the lime.

Returns

Returns from BW gain per hectare and yield from hay cutting are summarized in Table 2. Net Returns were calculated as: (Total Cost – Total Returns = Net Returns). Value of gain was set at $1.98/kg for calculating return from BW gain per hectare and was based on communication with University of Florida livestock economist, Chris Prevatt, where the annual average for value gain was estimated at $1.98/kg from 2007-2016. The value of hay was set at $0.033/kg, similar
to the value set by Beck et al. (2008) and took into account machinery and labor costs for harvesting hay.

5.2.3 Statistical Analysis

Economic return data were analyzed using the GLM procedure of SAS Version 9.3 (SAS Institute Inc., Cary, NC). Differences among results were considered significant at $P < 0.05$.

5.3 Results and Discussion

Returns for Summer 2017 were similar between 3-SM and 3-CM, and greater than the control and 1-SM which were negative. Although added costs were incurred with seed and herbicide for 3-SM and 3-CM, the dramatic improvement in animal performance in comparison to the control and 1-SM (Chapter 4) provided greater returns for these treatments. For Winter 2018, 3-SM returns were greater in comparison to 3-CM and the control, and 3-CM returns were greater than the control. With 3-SM having a longer grazing period and higher BW gain per hectare (Chapter 4), a greater return during this grazing period is expected. In Summer 2018, returns were similar between 3-SM and 3-CM, and greater than 1-SM and the control, and 1-SM returns were greater than the control. Once again, the added costs of seed and herbicide for renovation treatments in Summer 2018 were returned with improved animal performance in comparison to cattle grazing wild-type, endophyte-infected tall fescue. Return values for the control in Winter 2019, were reported as means and because no animals grazed the newly established novel-endophyte infected tall fescue, no values were reported for 1-SM, 3-SM and 3-CM. For Spring 2019, returns from hay yield were similar across treatments, although the greatest numerical return was observed in the control and is expected when comparing the value of hay yielded in an established field to a newly established field.
Total Return reported is the summation of treatment returns across seasons within the experimental period and Net Return is the Total Cost subtracted from the Total Return. This Net Return calculation, which could be viewed as net cost for renovation treatments, rendered a positive net return for the control and negative net returns for 1-SM, 3-SM, and 3-CM.

5.4 Summary

Despite good performance by the cattle on smother crops (Chapter 4), there will still be a net cost to farmers to renovate wild-type, endophyte-infected tall fescue to the point of termination of this study. However, all net returns (or more accurately net costs) for renovation treatments were lower than previously reported values ($1206/ha) by Zhunag et al. (2005) which examined a one season renovation strategy utilizing grain corn as the smother crop, and 3-SM and 3-CM net costs were lower than values ($371/ha) reported by Gunter and Beck (2004) which examined a one season renovation strategy that utilized pearl millet harvested for hay as the smother. Gunter and Beck (2004) reported estimated hay yield (6,719 kg/ha) and returns ($222/ha) for novel endophyte-infected tall fescue over the entire 1st year of establishment in their model whereas the current study only reported returns for the first hay cutting in May 2019. This difference in 1st year value of hay is likely the contributing factor for the higher one season renovation net cost for the current study in comparison to Gunter and Beck (2004). Measuring yield for the first season across renovation treatments in the current study should provide a more robust analysis of potential returns of newly established novel endophyte-infected tall fescue than previously model derived estimates. Further, we know that the animal performance improvement for novel endophyte-infected tall fescue (Parish et al., 2003; Beck et al., 2009; Drewnoski et al., 2009), is the main driver for recouping any costs of the renovation. Therefore, an examination of the payback period that includes animal performance will be beneficial when
discussing the potential economic implications of each treatment to farmers and will take place for these pastures over the next few years. This ‘complete picture’ will provide information, from an unbiased source, that is not currently available to farmers and help convey the message that renovation is a viable option for many farmers that have wild-type, endophyte-infected tall fescue pasture.
Tables and Figures

**Table 5.1** Agronomic costs for each season within the experiment.

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th>C</th>
<th>1-SM</th>
<th>3-SM</th>
<th>3-CM</th>
</tr>
</thead>
<tbody>
<tr>
<td><em><em>Agronomic costs</em>, $/ha</em>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Summer 2017</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glyphosate ($5.68/kg ai)</td>
<td></td>
<td>-</td>
<td>12.73</td>
<td>12.73</td>
<td></td>
</tr>
<tr>
<td>Glyphosate Application</td>
<td></td>
<td>-</td>
<td>24.71</td>
<td>24.71</td>
<td></td>
</tr>
<tr>
<td>Seed ($2.58/kg PLS, 3-SM; $3.37/kg PLS, 3-CM)</td>
<td></td>
<td>-</td>
<td>112.75</td>
<td>234.40</td>
<td></td>
</tr>
<tr>
<td>Seed Planting</td>
<td></td>
<td>-</td>
<td>49.42</td>
<td>49.42</td>
<td></td>
</tr>
<tr>
<td>Nitrogen ($1.43/kg)</td>
<td></td>
<td>62.64</td>
<td>62.24</td>
<td>62.64</td>
<td>-</td>
</tr>
<tr>
<td>Nitrogen Application</td>
<td></td>
<td>14.83</td>
<td>14.83</td>
<td>14.83</td>
<td>-</td>
</tr>
<tr>
<td>5-yr pro-rated lime application ($7.40/ton)</td>
<td></td>
<td>18.29</td>
<td>18.29</td>
<td>18.29</td>
<td>18.29</td>
</tr>
<tr>
<td>Rotary Mowing</td>
<td></td>
<td>-</td>
<td>37.78</td>
<td>37.78</td>
<td></td>
</tr>
<tr>
<td><strong>Season Total</strong></td>
<td></td>
<td><strong>95.75</strong></td>
<td><strong>95.75</strong></td>
<td><strong>333.15</strong></td>
<td><strong>377.33</strong></td>
</tr>
<tr>
<td><strong>Fall 2017</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glyphosate ($5.68/kg ai)</td>
<td></td>
<td>-</td>
<td>12.73</td>
<td>12.73</td>
<td></td>
</tr>
<tr>
<td>Glyphosate Application</td>
<td></td>
<td>-</td>
<td>24.71</td>
<td>24.71</td>
<td></td>
</tr>
<tr>
<td>Seed ($1.06/kg PLS, 3-SM; $2.82/kg PLS, 3-CM)</td>
<td></td>
<td>-</td>
<td>117.42</td>
<td>123.35</td>
<td></td>
</tr>
<tr>
<td>Seed Planting</td>
<td></td>
<td>-</td>
<td>49.42</td>
<td>49.42</td>
<td></td>
</tr>
<tr>
<td>Nitrogen ($1.43/kg)</td>
<td></td>
<td>62.64</td>
<td>62.64</td>
<td>62.64</td>
<td>-</td>
</tr>
<tr>
<td>Nitrogen Application</td>
<td></td>
<td>14.83</td>
<td>14.83</td>
<td>14.83</td>
<td>-</td>
</tr>
<tr>
<td><strong>Season Total</strong></td>
<td></td>
<td><strong>77.47</strong></td>
<td><strong>77.47</strong></td>
<td><strong>281.75</strong></td>
<td><strong>210.21</strong></td>
</tr>
</tbody>
</table>
Table 5.1 (continued).

<table>
<thead>
<tr>
<th></th>
<th>Summer 2018</th>
<th></th>
<th></th>
<th>Fall 2018</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>12.73</td>
<td>12.73</td>
<td>12.73</td>
<td>12.73</td>
<td>12.73</td>
</tr>
<tr>
<td>Glyphosate ($5.68/kg ai)</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glyphosate Application</td>
<td>-</td>
<td>24.71</td>
<td>24.71</td>
<td>24.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed ($3.59/kg PLS, 1-SM &amp; 3-SM; $3.02/kg PLS, 3-CM)</td>
<td>-</td>
<td>68.47</td>
<td>68.47</td>
<td>152.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed Planting</td>
<td>-</td>
<td>49.42</td>
<td>49.42</td>
<td>49.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen ($1.43/kg)</td>
<td>62.64</td>
<td>62.64</td>
<td>62.64</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen Application</td>
<td>14.83</td>
<td>14.83</td>
<td>14.83</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-yr pro-rated lime application ($7.40/ton)</td>
<td>18.29</td>
<td>18.29</td>
<td>18.29</td>
<td>18.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotary Mowing</td>
<td>-</td>
<td>37.78</td>
<td>37.78</td>
<td>37.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season Total</td>
<td><strong>95.75</strong></td>
<td><strong>288.87</strong></td>
<td><strong>288.87</strong></td>
<td><strong>295.27</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fall 2018</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.73</td>
<td>12.73</td>
<td>12.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glyphosate ($5.68/kg ai)</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glyphosate Application</td>
<td>-</td>
<td>24.71</td>
<td>24.71</td>
<td>24.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Novel-endophyte tall fescue seed ($8.38/kg PLS)</td>
<td>-</td>
<td>215.97</td>
<td>215.97</td>
<td>215.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed Planting</td>
<td>-</td>
<td>49.42</td>
<td>49.42</td>
<td>49.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen ($1.43/kg)</td>
<td>62.64</td>
<td>62.64</td>
<td>62.64</td>
<td>62.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,4-D + Dicamba ($13.73/ kg ai)</td>
<td>-</td>
<td>14.83</td>
<td>14.83</td>
<td>14.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,4-D + Dicamba Application</td>
<td>-</td>
<td>24.71</td>
<td>24.71</td>
<td>24.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Season Total</td>
<td><strong>77.47</strong></td>
<td><strong>419.83</strong></td>
<td><strong>419.83</strong></td>
<td><strong>419.83</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5.1 (continued).

<table>
<thead>
<tr>
<th></th>
<th>Winter 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendimethalin ($25.56/kg ai)</td>
<td>-        81.55  81.55  81.55</td>
</tr>
<tr>
<td>Nitrogen ($1.43/kg)</td>
<td>62.64  62.64  62.64  62.64</td>
</tr>
<tr>
<td>Chemical and/or Nitrogen Application</td>
<td>14.83  24.71  24.71  24.71</td>
</tr>
<tr>
<td>Season Total</td>
<td>77.47  168.90  168.90  168.90</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>423.91  877.60  1492.50  1471.54</td>
</tr>
</tbody>
</table>

*adapted from “Economics of Conversion to Novel Fescue” enterprise budget developed by Joe Horner (Agricultural Economics Department, University of Missouri, Columbia, MO).
### Table 5.2 Agronomic cost, return and, net return for each treatment (2017-2019).

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment1</th>
<th></th>
<th></th>
<th></th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agronomic costs, $/ha</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer 2017</td>
<td>95.75</td>
<td>95.75</td>
<td>333.15</td>
<td>377.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall 2017</td>
<td>77.47</td>
<td>77.47</td>
<td>281.75</td>
<td>210.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer 2018</td>
<td>95.75</td>
<td>288.87</td>
<td>288.87</td>
<td>295.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fall 2018</td>
<td>77.47</td>
<td>419.83</td>
<td>419.83</td>
<td>419.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter 2019</td>
<td>77.47</td>
<td>168.90</td>
<td>168.90</td>
<td>168.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Cost, $/ha</strong></td>
<td>423.91</td>
<td>1050.82</td>
<td>1492.50</td>
<td>1471.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Return*, $/ha</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer 2017</td>
<td>-30.78b</td>
<td>-79.21b</td>
<td>329.80a</td>
<td>327.25a</td>
<td>52.00</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Fall 2017/Winter 2018</td>
<td>216.27c</td>
<td>90.98d</td>
<td>580.01a</td>
<td>423.55b</td>
<td>53.57</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Summer 2018</td>
<td>179.46c</td>
<td>310.16b</td>
<td>423.30a</td>
<td>441.54a</td>
<td>29.59</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Fall 2018/Winter 2019</td>
<td>248.13</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring 2019</td>
<td>84.09</td>
<td>57.48</td>
<td>51.16</td>
<td>67.10</td>
<td>5.04</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Total Return, $/ha</strong></td>
<td>758.08</td>
<td>379.41</td>
<td>1383.29</td>
<td>1224.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Net Return, $/ha</strong></td>
<td>334.17</td>
<td>-671.41</td>
<td>-109.21</td>
<td>-247.47</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Means within a row with unlike superscripts differ (P < 0.05).
1C, toxic endophyte infected tall fescue; 1-SM, one season simple mixture; 3-SM, three season simple mixture; and 3-CM, three season complex mixture.
*Based on calf value of gain at $1.98/kg, or value of hay at $0.033/kg.
Literature Cited


CHAPTER 6: ‘From the Ground Up’: What to expect during the renovation of KY-31 tall fescue pastures.

6.1 Introduction

Kentucky-31: The Wonder Grass

Believe it or not, it is thought that tall fescue was first introduced into the U.S. by mistake as a contaminant in other cool-season grass seed. However, folks quickly took notice of this cool-season perennial grass and it now dominates most beef cattle pastures in the transition zone of the U.S. humid region. This area, now known as the fescue belt, extends roughly from central Ohio to central Alabama and from eastern Oklahoma to eastern Virginia and pastures over 8 million beef cattle. The most widely grown tall fescue cultivar is Kentucky 31, which was first noticed by Dr. E.N. Fergus on William Suiter’s farm in Kentucky during the fall of 1931. After several years of testing, this fascinating ecotype of tall fescue was released in 1943 and farmers happily planted it—the pasture landscape quickly changed on many farms. Now however, if you were to ask a farmer in the fescue belt the question “Do you like Kentucky 31?” you are likely get both positive and negative responses.

Positives

In the early years following the release of Kentucky 31, many farmers and forage industry advisors referred to it as “The Wonder Grass” and “The First Permanent Pasture Grass for the South”. Obviously, there are some positives associated with it, including:

- Well adapted to a wide range of soil types and environmental conditions.
- High nutritive value
- Extensive root system, giving it the ability to withstand drought and high temperature
- Long-lived perennial grass that makes the majority of its growth in the spring and fall but can make notable growth in mild winters and wet summers
- well suited for stockpiling (deferring grazing until a later time) for winter feeding
- can withstand heavy grazing pressure

**Negatives**

With those benefits why would someone want to convert their tall fescue pastures to another ecotype? Well, the *hero* that provides many of the agronomic benefits of Kentucky 31 is also the *villain* that causes annual losses of $600 million annually to beef cattle farmers. So, who is this hero/villain? It is a fungal endophyte, *Epichloë coenophiala*, and it plays both roles very well. It produces ergot alkaloids and other toxins that boost the plant’s defense against insect and nematode pressure, improves drought tolerance and limits overgrazing by herbivores. However, these ergot alkaloids also cause a wide range of health disorders in grazing livestock. Collectively, the issues are termed *fescue toxicosis* and livestock can exhibit:

- Reduced intake and gain during spring and autumn
- Poor reproductive performance
- Inability to shed their winter hair coat resulting in heat stress
- Sloughing of tail switches, hooves and ear tips (extreme cases in the winter)

Now, knowing the many animal health issues related to tall fescue and actually seeing an animal exhibiting fescue toxicosis (Figure 1), the idea of renovating pastures away from Kentucky 31 makes more sense.

**Better Options**

Several new tall fescue varieties are commercially available to farmers that have agronomic characteristics similar to Kentucky 31, but don’t produce the ergot alkaloids associated with fescue toxicosis. These ‘novel’ endophyte tall fescue varieties have long been proven to withstand the harsh environment of the fescue belt and improve animal performance in
comparison to Kentucky 31. Despite these supportive agronomic and livestock data, planted acres of these newer varieties is very small; some estimate less than 1 million acres total.

Feasibility, cost, and lack of replicated field trial data have been mentioned as barriers for those interested in renovation. Therefore, at North Carolina State University we recently conducted a renovation study that examined the whole production system during the renovation of K-31 pastures to Texoma MaxQII. The goal was to show farmers the ‘complete picture’ in order for them to make rational decisions about grazing old, K-31 pastures.

6.2 The Approach

Because we wanted look at the entire system during the renovation, we built a team consisting of a soil scientist, forage agronomist, beef nutritionist, beef physiologist and livestock economist. The replicated field trial took place at the Butner Beef Cattle Field Laboratory in the Piedmont region of North Carolina using well-established, 10-yr old Kentucky 31 pastures. The renovation strategies were set up so that renovation from Kentucky 31 to Texoma MaxQ II occurred in the Fall of 2018 for all renovation strategies. All renovation strategies were compared to a control, which was maintained in Kentucky 31. Renovation strategies included:

- the commonly recommended 1-season (spray-smother-spray-plant) system using a single species of summer annual that began in the spring of 2018.
- a 3-season (spray-smother-spray-smother-spray-smother-spray-plant) system using single species grasses that began a year earlier in 2017.
- a 3-season (spray-smother-spray-smother-spray-smother-spray-plant) system using a complex mixture of grasses, legumes and forbs (Ray’s Crazy Summer Mix and Ray’s Crazy Winter Mix) that began in 2017.
Our motivation to extend the renovation period beyond the common 1-season strategy was multifaceted, but centered around the idea that extending the renovation could potentially reduce Kentucky 31 plants that survive the renovation process (this can be an issue), further improve animal performance, and offset more of the renovation cost. Finally, we felt this extension of time of renovation could allow farmers to become more comfortable using a no-till drill and potentially improve the eventual establishment of novel endophyte tall fescue. Within the two 3-season renovation strategies, we also wanted to know if including legumes and forbs would improve animal performance and reduce renovation costs by eliminating fertilizer N with legumes. In addition, there is a loud ‘buzz’ in the forage industry about these multi-species annual forage mixtures being ‘magical’, improving soil health, crop performance and animal performance, but little university data exists to back up this statement. Therefore, we included this complex mixture to capitalize on the opportunity to examine some key soil health indicators, forage and animal performance, and economics when using it as a smother crop for renovating Kentucky 31.

To initiate the study, soil was sampled to assess soil health using physical, chemical and biological properties as indicators, and hay was cut on the KY-31 pastures in the spring of 2017 during the boot stage. This was because it is crucial to limit tall fescue seed emergence in the spring of the year you decide to renovate. Two weeks later, 3-season renovation pastures were sprayed with glyphosate and the renovation process began. In the spring of 2018, the 1-season renovation pastures were cut for hay and two weeks later sprayed with glyphosate to begin the renovation process for that much shorter process.

All treatments, including the pastures that remained in KY-31, were rotationally grazed with growing steers, and gain per head and gain per acre were determined. “Smother crops”
were grazed in a manner to allow enough canopy before grazing and enough residual forage after grazing to smother K-31 plants that escaped the chemical burn down. Forage was sampled throughout the renovation for all treatments to estimate forage mass, nutritive value, and species composition.

Soil was sampled again following planting of Texoma Max QII in the fall of 2018. In the spring of 2019, newly established pastures were given a pasture stand score and any ‘escape’ Kentucky 31 plants were identified. Finally, all pastures were harvested for hay in May. Input costs for each treatment were accounted, and any potential revenue from cattle weight gains and hay yield was also documented to calculate a net return for each renovation strategy.

6.3 Results

Renovation using 1-season or 3-season approaches led to greater soil bulk density (1.42 g/cc) in the top 4” of soil as compared with Kentucky-31 pasture (1.25 g/cc). Soil bulk density is a measure of compaction, suggesting that a combination of tractor traffic, drilling operations, and decomposition of surface residue during renovation led to greater compaction. However, the level of compaction would not be considered serious enough to limit water infiltration or limit root growth. We plan to further assess soil bulk density into the future on these newly established pastures with different fescue types.

Many routinely analyzed soil chemical properties (i.e. pH, P, K, Ca, and Mg) remained unchanged during the renovation process. Soil pH was 5.8 in the surface 4” depth and was 6.3 in the 4-8” depth under Kentucky-31. The 3-season complex annual forage renovation led to a slight increase in pH at 4-8” depth (6.5). Soil organic matter and soil biological activity were not affected by any of the pasture treatments, suggesting that annual forage renovation treatments had no positive impact on these indicators of soil health. In fact, there was a trend for lower
levels with longer renovation treatments compared with single season and Kentucky-31 pastures. Our data suggest that annual forages (single species or mixtures) were not able to improve the soil health of an existing well-managed perennial forage pasture. We plan to monitor these pastures over the years to see if there is any shift in soil health between Texoma Max QII and Kentucky-31 pastures.

These nutritive values did not take into account the ergot alkaloids produced by K-31, and therefore, animal performance was disconnected from routine measures of nutritive value. For Winter 2018, environmental challenges at planting (low moisture) and below average temperature during the growing season caused both the 3-season single species (1454 lb/ac) and 3-season complex mixture (1690 lb/ac) to produce less forage than the stockpiled Kentucky-31 pasture (2240 lb/ac). For Summer 2018, Mother Nature did not heed our request for perfect planting conditions and we faced challenges. Directly after seeding renovation treatments in May, we received almost 6 inches of rainfall in just 4 days and newly planted seed suffered. For the renovation treatments, the majority of forage present during the grazing period was crabgrass and johnsongrass. Although initially viewed as a misfortune, the forage was productive and had good nutritive value that provided good yield and animal performance. Finally, after planting Texoma MaxQII, we assigned the newly established pastures a stand score (Table A.1) and identified any ‘escape’ plants in the spring of 2019. Stand scores were similar (4.6) across renovation treatments and only 1 escape plant was identified in 1 of the 30 sampling points used for each pasture. These findings show we may not have needed to extend the renovation period to control ‘escape’ plants and all renovation treatments were successful in replacing Kentucky 31 with Texoma MaxQII.
Renovation treatments improved the average daily gain of cattle and the total pounds of beef produced for a pasture in comparison to Kentucky 31 for all grazing periods. In the Summer of 2017, cattle grazing Kentucky 31 actually lost weight (-0.2 lb/d) while cattle on renovations treatments gained roughly 1.8 lb/d. Cattle gains on stockpiled Kentucky 31 in Winter 2018 were 1.0 lb/d and this good performance is why so many farmers like to stockpile this grass. However, the cattle grazing the cool-season forages in the renovation treatments gained nearly 4 pounds a day! It should be noted that our grazing season was only for one month in Winter 2018 because of below average temperature, but total pounds of beef produced per acre was still above 200 lbs for both renovation strategies in that short time period! Finally, in the summer of 2018, gain for cattle grazing renovation treatments was similar at 2.0 lb/d and greater than cattle grazing Kentucky 31 (0.7 lb/d). Again, the gains observed for cattle grazing renovation treatments were predominantly based on native crabgrass and johnsongrass because of planting issues in May of 2018. Although not the preferred scenario for research, this should give producers some comfort in knowing that even if the establishment of annual forages is less than optimal, cattle may perform better on some forages that germinate from the seedbank in the pasture in comparison to Kentucky 31!

Costs for renovation over three seasons were similar between the single species ($604/acre) and complex mixture ($596/acre), and greater than maintaining Kentucky 31 ($172/acre) over three seasons. Our one season renovation cost ($355/acre) was less than the three season strategies but still more than maintaining Kentucky 31. We know that annual seed, herbicide and fertilization application, and Texoma MaxQII seed, all contribute to the cost of renovation and the costs can be large as seen for the three season strategies. However, when we
look at the net returns for these treatments, the added revenue from improved animal performance removes some of the worries that it ‘costs too much’ to renovate.

Total return for Kentucky 31 over three seasons was $307/acre. However, total return for the 3-season single species was $560/acre and return for the 3-season complex mixture was $495/acre. Return for 1-season single species was only $147/acre and was lower than all other treatments because it was only for one season. If you are good at math, you can already see that although returns were good for our renovation strategies, it still cost money to renovate pastures to the point where we ended this part of the experiment. The net cost for our renovation strategies were $208/acre for the 1-season strategy, $44/acre for the 3-season single species, and $108/acre for the 3-season complex mixture. This provides some information about the short-term costs of renovating but we would also like to provide a break-even period for each renovation strategy to truly provide the whole picture to the farmer. Therefore, we plan to continue to track costs and gains for these pastures over the next few years.

### 6.4 Take-Home Message

Some of the soil properties we associate with soil health (e.g. soil bulk density, total organic carbon, and soil-test biological activity) may change for the worse during the renovation of Kentucky 31 tall fescue pastures. Returning land to improved perennial pasture should heal these negative impacts. Monitoring changes with time will still be needed in this study. While the forage smother crops were similar in productivity and lower in nutritive value, cattle still performed well in comparison to those grazing Kentucky 31. Further, the contribution of ‘native’ seed within the seedbank of pastures (mainly crabgrass) may reassure many farmers who worry about issues with annual forage stand establishment. There is a clear and almost shocking difference in cattle performance when cattle graze annual forages and Kentucky 31 side by side.
If farmers start a renovation, and they are able to see this drastic difference and share their experiences, other farmers will likely also want to renovate. Finally, there are still costs associated with renovating Kentucky 31, but they can be reduced by the time of planting a novel-endophyte fescue if the renovation period is extended. We are not finished with this project and hope to continue tracking soil health changes and the payback period of each strategy. When put together as a ‘complete picture’, this information will be useful in explaining to farmers the costs, animal performance, and soil changes expected during a renovation. Truly, a farmer concerned about money, his/her cattle, and the environment should find great interest in the results of this study, and the results will reassure many that converting at least a part of their Kentucky-31 tall fescue pastures to novel endophyte tall fescue can be a successful practice, and that will provide benefits to their farm for many years into the future.
Tables and Figures

**Figure 6.1** Examples of animals from this study during the summer months in NC, including a steer on Kentucky 31 (top) and a steer on annual forage (bottom). Which steer do you want in your pasture?
APPENDIX
**Table A.2** Pasture scale rating (1-5) used for rating newly established novel-endophyte tall fescue.

<table>
<thead>
<tr>
<th>Pasture rating</th>
<th>Photographic Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image1" alt="Photograph 1" /></td>
</tr>
<tr>
<td>2</td>
<td><img src="image2" alt="Photograph 2" /></td>
</tr>
<tr>
<td>3</td>
<td><img src="image3" alt="Photograph 3" /></td>
</tr>
<tr>
<td>4</td>
<td>![Image of grass 1]</td>
</tr>
<tr>
<td>---</td>
<td>-------------------</td>
</tr>
<tr>
<td>5</td>
<td>![Image of grass 2]</td>
</tr>
</tbody>
</table>