

**Increasing Productivity and Biodiversity of Tall Fescue Swards by
Intercropping Cool and Warm-Season Forage Species**

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Degree
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ABSTRACT

Mixed pastures are known to produce greater biomass yields and higher nutritive value than monocultures. Intercropping biologically N fixing legumes, along with the use of intercropping warm-season annual grasses, such as crabgrass [*Digitaria ciliaris* Retz.], provides the potential to aid tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.] productivity. To determine the benefits of intercropping species into tall fescue forage systems in the Southeastern U.S., two studies were developed. The first study consisted of 9 tall fescue paddocks, in which 3 paddocks contained red clover (*Trifolium pratense* L. [TRC]) mixed with tall fescue, 3 paddocks contained sunn hemp (*Crotalaria juncea* L. [TSH]) mixed with tall fescue, and 3 paddocks had only tall fescue with a late summer application of urea (TU). Black Angus steers [*Bos taurus*] were selected to graze the stockpiled paddocks during the grazing period. The study evaluated the botanical composition (BC), herbage mass (HM), nutritive value (NV), steer's average daily gain (ADG), and net return (NR) values. In 2021, the TU treatment showed an overall greater amount of HM at the beginning of the grazing period and greater average CP values compared to the other treatments. The second experiment focused on aiding tall fescue productivity that consisted of tall fescue with no N source (TF-0), tall fescue mixed with red clover (TFR), tall fescue mixed with sunn hemp (TFS), tall fescue plus the application of ammonium nitrate (TFA), tall fescue mixed with crabgrass with no N source (TFC-0), tall fescue mixed with crabgrass and red clover (TFCR), tall fescue mixed with crabgrass and sunn hemp (TFCS), and tall fescue mixed with crabgrass plus the application of ammonium nitrate (TFCA). The study evaluated BC, HM, and NV. The plots containing red clover showed greater HM and crude protein (CP) values along with lesser NDF and NDFD48 values compared to the other treatments in 2020 and 2021. The TFCS plots showed approximately 38% greater herbage

mass compared to TFS in 2020; approximately 32% greater HM in 2021. Suggesting the incorporation of cool and warm-season species with tall fescue can aid in tall fescue productivity.

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LIST OF ABBREVIATIONS AND SYMBOLS

ADF	Acid detergent fiber
ADG	Average daily weight gain
BC	Botanical composition
BW	Body weight
°C	Degrees Celsius
C3	Cool-season
C4	Warm-season
Ca	Calcium
CO ₂	Carbon dioxide
CP	Crude protein
CRD	Completely randomized design
DAP	Di-ammonium phosphate
DM	Dry matter
g	Gram
ha	Hectare
HM	Herbage mass
IVDMD	In-vitro dry matter digestibility
IVTDMD48	In-Vitro Dry Matter Digestibility in 48 hours
K	Potassium
K ₂ O	Potassium oxide
kg	Kilogram
MAX	Maximum
MIN	Minimum
Mg	Magnesium
N	Nitrogen
N ₂	Nitrogen gas
NASS	National Agricultural Statistics Service
NDF	Neutral detergent fiber digestibility
NDFD48	Neutral detergent fiber digestibility in 48 hours
NH ₃	Ammonia
NIRSC	near-infrared spectroscopy
NRCS	National Resources Conservation Service
NV	Nutritive value
O ₂	Oxygen
P	Phosphorous
PREC	Plateau AgResearch and Education Center
RC	Red clover

SAS	Statistical analysis system
SD	Standard deviation
SH	Sunn hemp
T	Tall Fescue
TA	Tall fescue + ammonium nitrate
TC	Tall fescue and crabgrass
TCA	Tall fescue and crabgrass + ammonium nitrate
TCR	Tall fescue and crabgrass + red clover
TCS	Tall fescue and crabgrass + sunn hemp
TN	Tennessee
TR	Tall fescue and crabgrass + red clover
TRC	Tall fescue mixed with red clover
TS	Tall fescue + sunn hemp
TSH	Tall fescue mixed with sunn hemp
TU	Tall fescue fertilized with urea
TWG	Total Weight Gain
U	Urea
U.S.	United States
U.T.	University of Tennessee
USDA	United States Department of Agriculture

INTRODUCTION

There are over 120 million acres of non-federal pastureland in the contiguous 48 U.S. states (NRCS, 2018). The Southeast Region of the United States consists of over 28,000 acres of non-federal pastureland and over 67% of this land is grazed by livestock (NRCS, 2018). These grazed pasturelands of the Southeast Region consist of approximately 67% warm-season grasses, 55% cool-season grasses, and 23% leguminous forbs (NRCS, 2018). Of the cool-season grasses, fescues (*Schedonorus*), such as tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.], are the dominant cool-season grasses (32%) for the Southeast Region (NRCS, 2018). Although tall fescue is a non-native species in this region, it has been incorporated across most of North America and is grown on over 35 million acres across the United States, including pastures, hay crops, and a source for erosion control (Ball, et al., 2007; Cherney et al., 2011). Tall fescue serves as an excellent forage crop due to its persistency, high herbage mass potential, and high nutritive value, especially in the spring and fall; therefore, considered the primary forage base for cow-calf producers in Tennessee. (Kallenbach and Bishop-Hurley, 2004; Ball et al., 2007; Nave et al., 2016). Considering the state of Tennessee has over 2.5 million acres of pastureland with nearly 900,000 head of grazing beef cattle (NASS, 2019; NASS, 2021); tall fescue must be managed properly to ensure optimal forage productivity is achieved. Despite tall fescue's positive forage characteristics, managing tall fescue as a monoculture pasture under conventional forage management methods may be challenging to reach maximum forage productivity while achieving the nutritional demands of grazing beef cattle. It can be especially challenging as limitations of resources, environmental restrictions, and forage establishment and maintenance costs arise. Innovative methods, practices, and strategies must be introduced, researched, evaluated, and compared to conventional methods to increase forage production for primary tall

fescue forage systems in the U.S. Southeast. Forage management strategies that focus on biomass-production systems, i.e., mixtures of multiple forage species, are considered a more sustainable approach compared to managing tall fescue forage as a monoculture (Jordan et al., 2007).

Tall fescue is a cool-season (C3) perennial bunchgrass that is considered deep-rooted with rhizomes growing from 60 to 122 cm that responds well to N fertilization (Ball, et al., 2007). Tall fescue can reach maximum productivity in the spring, but it also produces a considerable amount of forage in the fall (Ball et al., 2007). However, during the summer months when temperatures are higher, tall fescue tends to decline in productivity due to its C3 photosynthetic pathway which enables photorespiration in high temperatures (Furbank and Taylor, 1995).

Proper forage management for tall fescue is essential for reaching maximum forage productivity, such as achieving optimal forage nutritive value and HM. One method of proper forage management is to perform accurate soil testing, so that there are no nutritional limitations, such as nitrogen (N), limiting plant development (Ball et al., 2007). Nitrogen is a limiting nutrient that is essential for increasing forage yield and crude protein (CP) (Ball, et al., 2007). Conventionally, N is applied early in the growing season in synthetic forms, such as ammonium nitrate or urea. However, the application of these synthetic N sources can have negative environmental impacts such as N leaching through the soil, as well as its high volatilization potential in certain weather conditions. (Ball and Keeney, 1983; Alley, 2001). In addition to the environmental concerns associated with synthetic fertilizers, N fertilizer prices continue to increase, which can become very costly to the producer. Local prices of urea in 2020 were

\$331.55 tonnes⁻¹, with a 60% increase in 2021 resulting in \$530.29 tonnes⁻¹, and an additional 52% increase in 2022 resulting in \$805.84 tonnes⁻¹, therefore different sources of N should be explored.

There are different methods for applying or adding N, as well as different sources of N. Incorporating legumes into grass pastures is considered a sustainable and economic method of adding N while also replacing synthetic N fertilizers. Legumes can biologically fix N due to a symbiotic relationship between the Rhizobium bacteria in the soil and the roots of these legume species. The rhizobium strain, which obtains N from soil air, infects the roots (Ball et al., 2007). The N accumulates in the roots, forming nodules that serve as the site of atmospheric nitrogen gas (N₂) fixation (Ledgard and Steele, 1992). Within these nodules is an enzyme called nitrogenase, which is produced by the rhizobium, and is responsible for reducing N₂ to ammonia (NH₃), which is available to the plants. (Ball et al., 2007; Ledgard and Steele, 1992). The biologically fixed N can be transferred by decomposition, exudation of legume roots, or association of arbuscular mycorrhizal fungi (Sanders et al., 2018; Paynel et al., 2001; Thilakarathna et al., 2016). The production status of a legume-grass mixture determines the amount of N transferred from a legume to the companion grass (Ledgard and Steele, 1992). Legumes mixed with grass can retain and provide N at optimum levels in various types of environmental conditions (Schipanski and Drinkwater, 2012). The challenge comes with deciding which legume species are better suited to grow with tall fescue. Therefore, an evaluation method can be carried out by examining and comparing ecosystems with different legume-grass mixtures to determine which legume options are better suited to serve as companions to grass-only swards such as tall fescue pastures (Schipanski and Drinkwater, 2012).

Cool and warm-season legume species and grazing

Integrating cool-season perennial legumes, such as white clover [*Trifolium repens* L.], and/or a biennial/short-lived perennial legume, such as red clover [*Trifolium pratense* L.] into tall fescue is a common and beneficial practice (Ball and Lacefield, 2010). Based on a previous study conducted in Tennessee, tall fescue mixed with red clover produced the greatest values of HM and CP throughout the growing season for two consecutive years compared to other tall fescue-legume mixtures and with the tall fescue fertilized with 67 kg N ha⁻¹ of ammonium nitrate (Corbin et al., 2019). Adding cool-season legumes, such as red clover, to tall fescue can provide greater distribution of forage along with the potential to increase HM (Ball et al., 2007). However, integrating warm-season annual legumes into tall fescue pastures is less known, mainly due to a limited selection of species and the risk of overgrazing resulting in persistency reduction (Hoveland, 2000). Fortunately, Tennessee is in the humid transition zone where cool and warm-season forage species can be mixed in pastures (Hoveland et al., 1997).

Warm-season annual legumes have the potential to benefit cool-season grass pastures during the summer months when cool-season grasses are declining in production due to their C3 photosynthetic pathway enabling photorespiration in high temperatures (Furbank and Taylor, 1995). Therefore, utilizing a warm-season legume forage to incorporate into a tall fescue pasture may serve as a complement and potentially increase forage production in the warmer months (Fribourg et al., 1979). For example, sunn hemp [*Crotalaria juncea* L.] is a warm-season legume that is commonly grown in tropical and subtropical regions, mainly for fiber production (Cook and White, 1996; Mosjidis, 2014). Although sunn hemp is considered a minor crop in the United States, it has been grown and harvested for hay and fresh forage in parts of Southeast Asia (Cook and White, 1996). Sunn hemp has the potential to accumulate substantial amounts of HM along

with the potential to regrow after the initial harvest (Lepcha et al., 2019). Also, sunn hemp is considered a high-quality forage based on its nutritive values recorded in the past (Lepcha et al., 2019). Research suggests sunn hemp grown from mid-July to late September can provide adequate herbage accumulation and nutritive value for supporting livestock production in cool-season-based forage systems (Lepcha et al., 2019). In addition to sunn hemp's herbage accumulation and nutritive values, it also is a C3 drought-tolerant legume crop, that can serve as a beneficial plant that is less likely to become stressed under drought conditions (Parenti et al., 2021).

Incorporating legumes into monoculture grass pastures, such as tall fescue, is a form of intercropping. Intercropping is a forage system that is composed of two or more species grown on the same ground during the same period (Nave & Corbin, 2018). Intercropping has benefits, such as improving land use efficiency, increasing overall forage productivity, and potentially increasing forage nutritional values (Nave & Corbin, 2018; Hauggard-Nielsen et al., 2001; Hardin, 1996; Conteras-Govea et al., 2009). Legumes are not the only forage crops that should be considered as intercropping options to aid in tall fescue productivity. Warm-season (C4) annual grasses such as crabgrass [*Digitaria sanguinalis* L.] have the potential to aid in cool-season (C3) grass grazing systems especially during the warmer months when cool-season grasses, such as tall fescue, are expected to decline in productivity due to the warm temperatures and possible drought conditions (Lomas et al., 2006).

The photosynthetic pathway of C4 plants differs from that of C3 plants. During high temperatures, C3 plants enable photorespiration (Taiz and Zeiger, 2002). Photorespiration leads to the reduction of carbon resulting in less productivity in C3 plants during high temperatures.

This is due to the enzyme called Rubisco which is responsible for the fixation of O₂ and carbon (C), which creates competition and results in the reduction of C (Furbank and Taylor, 1995). However, photorespiration is prevented from occurring in C₄ plants (Taiz and Zeiger, 2002). Based on the C₄ photosynthetic pathway, the CO₂ concentration levels are increased, and reduce the captured levels by converting CO₂ to oxaloacetate, a 4-carbon acid, which is more efficiently used, resulting in a more efficient pathway and a low amount of fixed CO₂ is lost through photorespiration (Furbank and Taylor, 1995). Therefore, warm-season grass, such as crabgrass, will be more productive compared to cool-season grass, such as tall fescue, during higher temperatures.

Although crabgrass is a warm-season annual, its ability to self-reseed allows it to act as a perennial (Teutsch et al., 2005). Crabgrass has the potential to serve as a high-quality forage for grazing due to its favorable nutritional values with an expected CP value of 14% and in-vitro dry matter digestibility (IVDMD) value of 79% at peak vegetative stage (Teutsch et al., 2005; Ball et al., 2007), and potentially provide an abundance of high-quality forage in the transition zone from late spring to late summer (Lomas et al., 2006). Crabgrass forage quality is driven by proper forage management and the addition of N. Dry matter (DM) production of crabgrass is positively impacted by the increase of N fertility (Lomas et al., 2006). Utilizing legumes intercropped with crabgrass and tall fescue has the potential to improve the overall forage nutritive value of the sward, positively impact body weight (BW) gains of grazing animals and reduce the application amount of synthetic N fertilizer (Lomas et al., 2006; Hoveland, 1986). In addition to reducing the amount of synthetic N fertilizer, adding legumes can provide the optimal utilization of crabgrass when intercropped with tall fescue by ensuring the high-quality crabgrass will not be selectively overgrazed throughout the summer (Lomas et al., 2006).

The nutritional and health needs of livestock are better reached when livestock are offered a highly diverse pasture (Provenza et al, 2003). The nutritive value of forage-based diets given to ruminants can be improved by adding high-quality forages, such as legumes (Foster et al., 2009). Livestock feeding on grass-legume mixtures also helps minimize bloat issues compared to livestock feeding on legume-only options (Baylor, 1974). Studies have shown that higher outputs per animal and calf weaning weights are improved by grass-legume mixtures (Blaser et al., 1956; Wedin, 1965; Sinclair, 2019).

Considering tall fescue has a great amount of growth in the fall and N is an essential nutrient that is needed to ensure optimal forage productivity, exploring the incorporation of alternative N sources, such as red clover and sunn-hemp compared to conventional fall application of synthetic N applications under a grazing trial can be beneficial. A grazing trial will result in a more specific evaluation of how each source of N directly impacts overall forage and livestock production.

The economic viability of grass-legume mixed pastures

A consistent supply of high-quality forages is economically viable for the positive production of livestock in grazing systems (Redfearn et al., 2002). Mixed pastures are known to produce greater biomass yields and higher nutritive value than monocultures (Deak et al., 2007; Khatiwada et al., 2020). Mixed pastures also have the potential to reduce the need for weed control. Noxious weeds are considered non-palatable and undesirable among certain grazing livestock and can be expensive to control (Sturlodottir et al., 2014). Legumes mixed with grasses have resulted in fewer weed populations compared to monocultures. (Deak et al., 2007, Picasso et al., 2008, Brink et al., 2015).

Introducing legumes that can biologically fix N to pastures can replenish soil N while reducing the costs associated with synthetic N fertilizer application (Gotsch, 1994; Ledgard et al., 2001). Urea is a form of synthetic N fertilizer that is typically applied in bulk form. In 2005 the use of urea increased to more than 40% of the total N fertilizer used worldwide (Gilbert et al., 2006). Based on the USDA Economic Research, urea is one of the most utilized sources of N, with more than 6 million metric tons in 2015 (USDA, 2019). There was a 153% increase in the yearly average price per metric ton of dry urea from 2016 - \$318.71 tonne⁻¹ to 2022 - \$805.84 tonne⁻¹. High fertilizer prices can result in negative net returns (Huang et al., 2009). The use of legumes to serve as alternative nitrogen sources can reduce the possibility of reaching negative net returns when fertilizer prices are high. The amount of atmospheric N fixed by biological N-fixing legumes in a grass-legume pasture ranges from 100 to 380 kg N ha⁻¹ yr⁻¹ (Ledgard and Steele 1992). Up to 80% of the fixed N can be transferred to the companion crop (Carlsson and Huss-Danell 2003).

Therefore, mixed legume-grass pastures can result in higher outputs and weight gains from grazing livestock by aiding in balancing the desired protein and energy levels of developing ruminants for optimal growth (Khatiwada et al., 2020). These results typically lead to a low-input livestock production system while increasing the biodiversity of pastureland (Khatiwada et al., 2020; Rochon et al., 2004).

Objectives

The objectives of this study were [1] to assess the forage production and grazing potential of tall fescue conventionally managed as a monoculture and tall fescue managed as a polyculture; [2] to evaluate HM and nutritive values affected by red clover or sunn hemp as an

alternative N source mixed with tall fescue as compared with a conventional source of synthetic N (urea) applied to tall fescue; [3] to evaluate the HM effects of incorporating crabgrass to tall fescue alone or tall fescue binary mixtures with red clover or sunn hemp; and [4] to assess the forage and livestock production of stockpiled tall fescue alone with the late summer application of N in the form of urea, as well as tall fescue binary mixtures with red clover or sunn hemp. We hypothesized that [1] the inclusion of crabgrass will increase tall fescue forage productivity during the summer when temperatures are high and tall fescue productivity tends to decline; [2] incorporating legumes, serving as alternative N sources, will produce forage with comparable HM and nutritive value to conventional synthetic N fertilizers in tall fescue production systems; [3] grazing stockpiled forage will be an added economic benefit of the tall fescue binary legume mixture system with additional weight gain or maintenance, and [4] the inclusion of alternative N sources will provide economic advantages to livestock producers in forage HM and profit.

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**CHAPTER I: DOES ADDING COOL OR WARM-SEASON FORAGE
LEGUMES TO TALL FESCUE STOCKPILING SYSTEMS
INCREASE PRODUCTIVITY AND ANIMAL PERFORMANCE?**

Abstract

The rising prices of N fertilizer led to exploring cost-saving efforts, such as intercropping cool and/ or warm season legumes serving as alternative sources of N, for managing fall-stockpiled tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.]. The objective of this study was to evaluate two different legume species, red clover [*Trifolium pratense* L. FSG 401rc] and sunn hemp [*Crotalaria juncea* L. ‘Tropic Sun’], mixed with tall fescue, and determine their ability to serve as alternative sources of N for stockpiling tall fescue in the fall. The experiment was conducted in Crossville, TN in 2020 and 2021, and consisted of tall fescue paddocks mixed with red clover (TRC) or sunn hemp (TSH), and tall fescue fertilized with urea (TU). The experiment was divided into two periods, the pre-grazing period, which included the stockpiling period, and the grazing period. After the stockpiling period, Black Angus beef [*Bos taurus*] steers were used for the grazing period, 69 days in 2020 and 65 days in 2021. The study evaluated the botanical composition (BC), herbage mass, nutritive value, steer average daily gain (ADG), and net returns (NR) which was based on the cost of forage production and ADG. The TRC paddocks had an overall greater proportion of legumes compared to TSH plots in May, October, November, and December of both years. There were no differences among treatments for the total HM and nutritive value in 2020, however, in 2021, the TU treatment showed an overall greater amount of HM at the beginning of the grazing period and greater average CP values compared to the other treatments. In both years, there were no differences among treatments for ADG or NR. It can be concluded that that a producer can still make a profit considering the beef steer price and the cost of conventional and alternative N sources.

Introduction

The transition zone, which is located within the Southeastern Region of the United States, consists of pastureland that involves productive warm and cool season forage species and includes the tall fescue belt that is utilized by 34% of the nation's total livestock. (Sanderson et al., 2012). Nearly 10 million ha of tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.] pastures are located in this region which is primarily managed for beef cattle production (Sanderson et al., 2012). The management of these pasturelands is considered intensive, and the failure to manage these forages properly can reduce production and profit while potentially being harmful to the environment (Sanderson et al., 2012). Although in many instances necessary, inputs such as seeds and fertilizers can drastically increase feeding costs, therefore pressuring producers to find cost-saving alternatives. A cost-saving option for beef producers in the humid transition zone is to stockpile tall fescue in the fall to extend grazing into the winter, which serves as a method for improving grazing management (Freeman et al., 2019).

Stockpiling is the process of allowing forage to accumulate for grazing at a later time (Ball et al., 2007). Cool-season grasses that have been fertilized with N have been widely used as a forage source to stockpile by taking advantage of its forage growth during high-producing periods and stockpiling the growth to be utilized for grazing during periods of low production (Collins & Balasko, 1981). Due to tall fescue's growing season, it typically produces a considerable amount of growth in the fall and is considered an excellent grass for fall stockpiling (Ball et al., 2007). Also, tall fescue forage quality is best when stockpiled in the fall (Ball et al., 2007). Fall growth of tall fescue has been reported to produce greater nutritive values compared to other cool-season perennial grasses such as orchardgrass [*Dactylis glomerata* L.], reed canary

grass [*Phalaris arundinacea* L.], and smooth brome grass [*Bromus inermis* L.] (Archer and Decker, 1977; Wedin et al., 1965). Stockpiling tall fescue in the fall provides the opportunity to extend grazing and reduce hay consumption in the winter (Stricker et al., 1979; Collins & Balasko, 1981). Adequate timing and application rates of N fertilization to tall fescue in the late summer are essential to generate conditions for optimal fall growth before stockpiling. (Kallenbach et al., 2017). Previous studies found that applying 40 to 112 kg N ha⁻¹ in late summer increased tall fescue yield and nutritive value (Collins and Balasko, 1981; Gerrish et al., 1994; Kallenbach et al., 2017). The rising prices of N fertilizer along with the associated input costs of applying N fertilizers led to exploring cost-saving efforts, such as using alternative sources of N, for managing fall-stockpiled tall fescue (Nave et al., 2016).

Intercropping biological N fixing legumes, such as red clover [*Trifolium pratense* L.] and/or sunn hemp [*Crotalaria juncea* L.] to tall fescue pastures can serve as alternative sources of N and aid in the production of stockpiling tall fescue. In addition to legumes generating their own N needs, legumes can increase the overall available N supply that can be transferred to neighboring plant species (Pirhofer-Walzl et al., 2012).

The utilization of red clover mixed with cool-season grasses such as tall fescue is common, mainly due to it being a cool-season short-lived perennial that is known for improving the soil and increasing crude protein (CP) content and herbage mass (HM) (Ball et al., 2007; Ball & Lacefield, 2010). Considering legumes can transfer biologically fixed N to grasses during the growing season (Høgh-Jensen, 2006; Pirhofer-Walzl et al., 2012); it can make red clover an attractive source of N for aiding in the production of stockpiling tall fescue.

Although it is common to interseed cool-season legumes into grass pastures in the Southeast, it is not as common to interseed warm-season legumes into grass pastures. However warm-season legumes have certain characteristics that can potentially benefit cool-season grass pastures. For example, sunn hemp is a warm-season annual legume that is considered fast-growing and can provide optimal nutritive values for beef cattle production (Mansoer et al., 1997; Lepcha et al., 2019). Sunn hemp's growing season and growth characteristics make it an attractive N source alternative worth exploring for stockpiling tall fescue. This is due to sunn hemp's expected timing of decomposition in the early fall when tall fescue is starting to accumulate fall growth to be stockpiled. Decomposition is an important pathway of N transfer from legumes to companion plants resulting in N release from below-ground and above-ground tissues of the decomposing warm-season annual legume to become readily available to the companion plant, such as tall fescue (Vallis, 1977; Mallerino et al., 1990).

Furthermore, the addition of legumes to tall fescue pastures can increase biodiversity in pastures and reduce livestock health-associated problems that can arise when certain livestock graze tall fescue alone. Many producers report animal health problems and symptoms associated with tall fescue toxicosis from their animals' grazing fall stockpiled tall fescue (Kallenbach et al., 2003). These symptoms can be considered troublesome to the animal when the animal is experiencing cold stress (Tor-Agbidye et al., 2001). Therefore, diversifying forage pastures by interseeding legumes into tall fescue is a common strategy to alleviate the effects of fescue toxicosis (Melchior et al., 2018).

The incorporation of legumes to serve as an alternative source of N and aid in stockpiling tall fescue are not as common as applying synthetic N; however, the benefits of increasing

diversity in pastures and potentially reducing the application of synthetic fertilizers are worth exploring. The specific use of sunn hemp as an alternative source of N for stockpiling tall fescue is limited in the Southeastern U.S., and its incorporation could be beneficial in tall fescue stockpiling management.

The objective of this study was to evaluate and assess a cool and a warm-season legume species (red clover and sunn hemp) mixed with tall fescue and determine their ability to provide sufficient N for stockpiling tall fescue, as well as increase productivity and animal performance. It was hypothesized that the addition of these legume species would serve as a more economically viable method for providing N when stockpiling tall fescue, while also increasing overall productivity.

Materials & Methods

Site Description

This study was conducted at the University of Tennessee Plateau AgResearch and Education Center (PREC) in Crossville, TN (35°50'37" N 85°3'22' W, 1830 ft. elevation), on a previously established tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort. 'Kentucky-31'] pasture, subdivided into nine paddocks. The experimental period occurred from April to December 2020 and 2021, and the experimental design was a completely randomized design (CRD) with three treatments and three replications per treatment (n = 9). The treatments were as followed: 1) tall fescue + red clover [*Trifolium pratense* L. 'FSG 401rc'] (TRC); 2) tall fescue + sunn hemp [*Crotalaria juncea* L. 'Tropic Sun'] (TSH); 3) tall fescue + 67 kg ha⁻¹ N, applied in the form of bulk urea [46-0-0] (TU). Individual paddocks measured approximately 1.21 ha⁻¹.

The soil for the experimental site was classified as 21.5% Atkins loam, 5.7% Gilpin loam, 41.3% Lily loam, and 31.5% Whitwell loam (USDA – NRCS, Websoilsurvey). Initial soil samples were collected at 15 cm depth on 28 November 2019 and 24 November 2020 and sent to the University of Tennessee Soil, Plant, and Pest Center laboratory for analysis (Hanlon and Savoy, 2007). The soil characteristics for each paddock that received the same treatment option were grouped and averaged to represent each treatment in 2019 and 2020. In 2019, soil characteristics for TRC were pH: 5.79, phosphorus (P): 23 kg ha⁻¹, potassium (K): 148 kg ha⁻¹, calcium (Ca): 2423 kg ha⁻¹, and magnesium (Mg): 218 kg ha⁻¹; TSH were pH: 5.88, phosphorus (P): 23 kg ha⁻¹, potassium (K): 109 kg ha⁻¹, calcium (Ca): 2824 kg ha⁻¹, and magnesium (Mg): 218 kg ha⁻¹; TU were pH: 6.00, phosphorus (P): 51 kg ha⁻¹, potassium (K): 122 kg ha⁻¹, calcium (Ca): 3222 kg ha⁻¹, and magnesium (Mg): 221 kg ha⁻¹. In 2020, soil characteristics for TRC were pH: 5.95, phosphorus (P): 29 kg ha⁻¹, potassium (K): 109 kg ha⁻¹, calcium (Ca): 2529 kg ha⁻¹, and magnesium (Mg): 284 kg ha⁻¹; TSH were pH: 6.02, phosphorus (P): 23 kg ha⁻¹, potassium (K): 90 kg ha⁻¹, calcium (Ca): 2906 kg ha⁻¹, and magnesium (Mg): 247 kg ha⁻¹; TU were pH: 5.85, phosphorus (P): 32 kg ha⁻¹, potassium (K): 112 kg ha⁻¹, calcium (Ca): 2517 kg ha⁻¹, and magnesium (Mg): 230 kg ha⁻¹. Following soil recommendations, lime was broadcasted to the soil surface at a rate of 4,500 kg ha⁻¹ on 16 July 2019. On 21 March 2019 inoculated red clover was drilled into the 3 desired existent tall fescue paddocks utilizing a Great Plains no-till drill (Great Plains, Salina, Kansas) with 19-cm spacing. The seeding rate for red clover was 8.9 kg ha⁻¹. On 7 April 2020 and 2021, 56 kg ha⁻¹ of potash (K₂O) and 146 kg ha⁻¹ of DAP (18-46-00) were applied to the entire experimental area following recommendations from soil test recommendations.

On 29 April 2020 Shredder® 2,4-D LV4 2,4-Dichlorophenoxyacetic acid, 2-Ethylhexyl ester herbicide was applied to all TU paddocks at a rate of 4.67 L ha⁻¹. On 7 May 2020 2,4-DB 200 4-(2,4-Dichlorophenoxy) butyric acid, dimethylamine salt herbicide was applied to all TRC paddocks at a rate of 7 L ha⁻¹. Both herbicide applications were applied to control broadleaf weeds, such as buckhorn plantain [*Plantago lanceolata*], dandelion [*Taraxacum officinale*], and buttercup [*Ranunculus repens*].

Before planting on 8 June 2020 and 3 June 2021, sunn hemp seeds were inoculated with *bradyrhizobium* peanut inoculant at a rate of 140 g of inoculant per 45 kg of seeds, then no-till drilled into the 3 desired existent tall fescue paddocks at a rate of 33.62 kg ha⁻¹. On 2 September 2020 and 27 August 2021, a single application of bulk urea was applied to the 3 desired paddocks at a rate of 146 kg ha⁻¹ or 67.2 kg of N ha⁻¹ in preparation for stockpiling tall fescue.

The experiment was divided into two periods, the pre-grazing period and the grazing period. The pre-grazing period for 2020 occurred from April 7 to October 6, and for 2021 from April 7 to October 11.

Within the pre-grazing period were the hay harvesting periods and the stockpiling periods. The hay harvesting periods occurred on May 14 and August 3 of 2020, and on May 19, and August 5, 2021. Forage content was harvested for hay from each paddock in May to remove herbage mass in preparation for planting sunn hemp into their desired paddocks in 2020 and 2021, and the forage content was harvested for hay a second time in August to remove herbage mass for initiating the stockpiling period in 2020 and 2021. The stockpiling period occurred from August 4 to October 6, 2020, and from August 6 to October 11, 2021.

The grazing period for 2020 occurred from October 6 to December 14 (69 days), and for 2021 occurred from October 11 to December 15 (65 days). On 6 October 2020, 27 out of 35 black Angus steers [*Bos taurus*] were selected to graze the nine stockpiled paddocks during the 69-day grazing period. From the 35 steers available, the 27 heaviest steers were chosen, and their weights ranged from 273 to 298 kg. On 11 October 2021, 27 out of 33 black Angus beef steers were chosen to graze the stockpiled paddocks during the 65-day grazing period. From the 33 steers available, the 27 heaviest steers were chosen, and their weights ranged from 266 to 292 kg.

Measurements

All paddocks were sampled on May 11, August 3, October 1, November 24, and December 14 of 2020, and on May 18, July 26, October 4, November 15, and December 15 of 2021.

On each sampling date, 10 HM samples, 5 nutritive value (NV) samples, and 5 botanical composition (BC) samples were randomly collected from a 0.1 m² area from each paddock. The HM and NV samples were placed in a drier at 60°C to constant weight (~72 hr.) and the HM sample was weighed for determination of dry matter (DM) HM. Each BC sample was separated into grass, legume, and weed components before being placed in a drier at 60°C to constant weight (~72 hr) and then weighed for analyses of botanical composition.

After drying the NV samples the sampled material was then ground to pass through a 1-mm screen with a Wiley Mill Grinder (Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co., Philadelphia, PA) in preparation for near-infrared spectroscopy (NIRS) analysis. Before analysis, the samples were placed in individual foil tins and dried for an additional 30-min in a forced air oven at 55°C to reach constant moisture content for scanning (McIntosh et al.,

2019). The samples were scanned in small ring cups on NIRS technology (Unity Spectrastar XL-R instrument Unity Scientific, Milford, MA) to predict crude protein (CP), neutral detergent fiber (NDF), *in vitro* true dry matter digestibility 48h (IVTDMD48), and neutral detergent fiber digestibility 48 h (NDFD48). Equations for the forage nutritive analyses were standardized and checked for accuracy with the 2021 Mixed Hay Equation developed, provided, and licensed by the NIRS Forage and Feed Consortium (NIRSC, Berea, KY). The Global H and neighborhood statistical test were analyzed for accuracy across all predictions, in which all forage samples fit the equation with the ($H < 3.0$) and are reported accordingly (Murray and Cowe, 2004). The units of measurement for nutritive value analyses are presented at 100% DM across the entire data set.

On 6 October 2020 and 11 October 2021, the selected steers were individually weighed to determine their initial weights for the beginning of the grazing period, and 3 randomly chosen steers were placed on each of the 9 paddocks to initiate the grazing period of previously stockpiled paddocks. Single-wire electric fences were installed as divider fencing to separate each paddock, just before the grazing period began. Each paddock contained a water source. On 14 December 2020 and 15 December 2021, all steers were removed from their paddocks and individually weighed to determine their final weights for the end of the grazing period. The initial and final weights of each steer were recorded to determine total weight gain (TWG) and divided by the total days of grazing to give the average daily gain (ADG).

Economic Analysis

Annual production budgets for each treatment were developed based on the University of Tennessee Forage Budgets (Bowling et al., 2007). The cost of forage production for interseeding red clover and sunn hemp into tall fescue, and applying urea to tall fescue was determined. Costs included sunn hemp seeds, urea, additional fertilizers, lime, herbicides, utilized machinery, repairs, maintenance, fuel, oil, filter, and operating labor; and these were considered variable expenses. Establishment costs of reseeding tall fescue and/or red clover, machinery depreciation, machinery interests, housing and insurance, fencing depreciation, fencing interests, and management labor were considered fixed expenses.

The values for seeding and machinery for interseeding red clover into existing tall fescue were prorated based on a schedule to reseed red clover every 3 years and reseed tall fescue every 10 years. The values for seeding and machinery for interseeding sunn hemp into existing tall fescue were based on one year of production due to sunn hemp being planted annually.

The budget costs were used to determine the difference between the change in cost per hectare of tall fescue with the use of legumes serving as an alternative N source and tall fescue fertilized with U for the management of stockpiling tall fescue (\$ ha⁻¹). The stocking rate was calculated considering the number of hectares per treatment area then divided by the total number of steers per treatment area and expressed as an animal unit (AU) per hectare. Steer production per treatment (kg ha⁻¹) was determined by averaging the TWG per treatment multiplied by the stocking rate. The total revenue (TR) (\$ ha⁻¹) was determined by multiplying the steer production (kg ha⁻¹) by the steer price (\$ kg⁻¹). The grazing period was determined by dividing 69 grazing days into 365 in 2020 and 65 grazing days into 365 in 2021. The net return

(NR) (\$ ha⁻¹) was determined by multiplying the grazing period by the cost of forage production per ha (\$ ha⁻¹) and then subtracting that value from the TR value.

Statistical Analyses

Differences in least square means by treatments using Fisher's LSD were determined by performing mixed model analyses of variance. Data used to determine HM, and all nutritive value variables of species were evaluated using the PROC MIXED procedures of SAS (SAS for Windows V 9.4, SAS Institute, Cary, NC). For HM and nutritive value analysis, the dependent variable was HM, CP, NDF, IVTDMD48, and NDFD48. Data used to determine botanical composition variables of species were evaluated using the PROC MIXED procedures of SAS (SAS for Windows V 9.4, SAS Institute, Cary, NC). For botanical composition analysis, the dependent variables were grass, legume, and weed. Fixed effects were treatments, applied or implemented to each experimental unit (paddock), and sampling period. Replications were random effects. There was significant year x sampling period x treatment interactions for each species for certain dependent variables. Therefore, the results of the experiment are displayed separately by year for all variables, with repeated measures of sampling periods and displayed separately by sampling period for all variables. All results were evaluated for significance at $P < 0.05$.

Results and Discussion

Weather

The mean air temperature was 5% above the 30-yr average for 2020, and 3% above for 2021 (Fig. 1.1). In 2020, precipitation was 14% above the 30-yr average, and 1% lower in 2021

(Fig. 1.1). In March of 2021 the precipitation was 109% greater than the 30-yr average and 59% greater than the March 2020 average (Fig. 1.1). In July 2020, the precipitation was 12% lower than the 30-year average and 34% lower than in July 2021 (Fig. 1.1). In October 2021 the precipitation was 121% greater than the 30-yr average, and 37% greater than the October 2020 average (Fig. 1.1).

Botanical Composition (BC)

There was a year x treatment interaction along with a sampling period x treatment interaction for certain dependent variables analyzed for the BC analysis (Table 1.1). Therefore, results are reported by year and sampling period.

In summary for 2020 and 2021, BC analysis showed that the proportion of grass averaged 842 g kg⁻¹, with a minimum of 408 g kg⁻¹, and a maximum of 1000 g kg⁻¹ across all treatments (Table 1.2). The proportion of legumes averaged 115 g kg⁻¹, with a minimum of 0 g kg⁻¹, and a maximum of 560 g kg⁻¹ across all treatments that contained legumes; and the proportion of weeds averaged 42 g kg⁻¹, with a minimum of 0 g kg⁻¹, and a maximum of 158 g kg⁻¹ across all treatments.

Average botanical composition during the 2020 and 2021 growing seasons

Among the paddocks with tall fescue mixed with legumes (TRC and TSH), the BC analysis showed that there were no differences among treatments in 2020 and 2021 (Fig. 1.2). This may be due to the greater amount of sunn hemp that was measured during sampling period 2 in 2020 and 2021 (Fig. 1.3).

The BC analysis also showed that there were no differences among treatments for the proportion of weeds in 2020 (Fig. 1.2). However, in 2021 TSH paddocks showed a greater

proportion of weeds than the other treatments (Fig. 1.2). The weeds observed in these paddocks included cool-season weeds such as buckhorn plantain [*Plantago lanceolata* L.] broadleaf plantain [*Plantago major* L.], buttercup [*Ranunculus lappaceus* Sm.], and henbit [*Lamium amplexicaule* L.] and warm-season weeds such as milkweed [*Asclepias syriaca* L.]. This may be due to the greater precipitation that occurred in March, July, and October 2021 compared to 2020 (Fig. 1.1) and suggests that weeds were not competing with a legume species during the cooler months since sunn hemp is a warm-season annual (Ball et al., 2007).

In 2020 and 2021 TU paddocks showed a greater proportion of grass than the other treatments (Fig. 1.2). This is expected considering TRC and TSH contained legumes that served as competitors to the companion grass. However, it is important to mention that in 2020 the difference in the proportion of grass in TU paddocks compared to TRC paddocks was 56 g kg⁻¹ greater than in 2021 (Fig. 1.2). This may be due to the red clover possibly declining in production by the end of 2021, therefore the red clover was not as competitive toward the companion grass in 2021 as it was in 2020. Considering red clover was planted in March of 2019 and red clover is considered a short-lived perennial legume (usually 2 years in this region), that explains its reduced persistence by 2021 (Wiersma et al., 1998; Ball et al., 2007). Meanwhile, in 2020 the difference in the proportion of grass in TU paddocks compared to TSH paddocks was 31 g kg⁻¹ lower than in 2020 (Fig. 1.2), likely due to the greater proportion of weeds in TSH paddocks in 2021 (Fig. 1.2).

Botanical composition for each sampling period during the 2020 and 2021 growing seasons

Botanical composition differences between treatments of tall fescue mixed with legumes (TRC and TSH) showed that paddocks containing red clover had an overall greater proportion of legumes compared to plots containing sunn hemp in May, October, November, and December in

2020 and 2021 (Fig. 1.3). This is due to the different growing seasons and duration of production between the two legume species. Red clover is a cool-season legume that has a seasonal production period from April – October, which is longer than sunn hemp since sunn hemp is a warm-season annual legume that is productive from June through September. It was also shown that the TSH treatment had a greater proportion of legume than TRC in August of both years (Fig. 1.3). The 2nd sampling period occurred during August of both years and sunn hemp is expected to be more productive than red clover when conditions are favorable for the warm-season forage.

The BC analysis showed that the proportion of grass for TU was greater than TRC for each sampling period in 2020 and 2021. However, the proportion of grass for TU was only greater than TSH in August and December 2020, and August 2021. The greater proportion of grass for TU compared to TSH in December 2020 may be due to the greater proportion of weeds measured in TSH, and the greater proportion of legumes measured in TRC that competed with the companion grass compared to the other treatments in December 2020 (Fig. 1.3).

The BC analysis also showed differences among treatments for the proportion of weeds for August and December in 2020; and May and October in 2021 (Fig. 1.3). In August 2020, TU contained a greater proportion of weeds compared to TRC and TSH (Fig. 1.3). This may be because TU did not contain a legume source to possibly serve as a weed suppressor. However, between the tall fescue mixed treatments, TSH showed a greater proportion of weeds compared to TRC during August 2020 (Fig. 1.3). This was unexpected, considering that TSH also showed a greater proportion of legumes during August 2020, indicating that sunn hemp and weeds were outcompeting tall fescue production during this period. In December 2020, similar results were observed with TSH showing a greater proportion of weeds compared to TRC and TU. Even

though TU paddocks did not contain a legume to serve as a weed suppressor, these paddocks were fertilized with urea in September, allowing the tall fescue to outcompete the cool season-weeds later in the season. In 2021, TSH also showed greater weed proportion in May and October (Fig. 1.3). In May 2021, sunn hemp was yet to be established, allowing for greater weed competition. In October 2021, sunn hemp's growing season had come to an end, and cool season weeds growing in TSH paddocks no longer had a legume competitor. Although TU did not have a legume to serve as a weed suppressor at this time, it still showed a lesser proportion of weeds compared to TSH paddocks. This may be because these tall fescue paddocks were fertilized with urea in September which may have aided in tall fescue production and its ability to outcompete present weeds during this period (similarly to what occurred in 2020) (Fig. 1.3).

Hay Herbage Mass

In summary for 2020 and 2021, the total hay harvest period HM averaged 3290 kg ha⁻¹, with a minimum of 2393 kg ha⁻¹, and a maximum of 4617 kg ha⁻¹ across all treatments (Table 1.2).

Total hay herbage mass during the 2020 and 2021 growing seasons

There were no differences among treatments for total hay HM harvested in 2020 and 2021 (Table 1.3). However, it is important to mention that the total hay HM production in 2021 was on average 1398 kg DM ha⁻¹ greater than the total hay HM harvested in 2020. (Table 1.3). This may be due to weather differences between 2020 and 2021. In 2021, there was a greater amount of precipitation (above the 30-yr average) during July and August, which aided in forage production throughout the summer (Fig. 1.1).

Average hay herbage mass for each harvesting period during the 2020 and 2021 growing seasons

The average hay HM of tall fescue and tall fescue-legume mixed sward showed no differences among treatments for the first and second hay harvest periods in 2020 and 2021 (Table 1.4). This may partly be because there was no sunn hemp in the first hay harvest period in 2020 and 2021. However, red clover was present during the first hay harvest period in 2020 and 2021, and yet there were no differences among treatments for HM (Table 1.4). This may be due to the lack of grazing pressure before this first hay harvest period which may have affected the production of red clover. Ball et al. (2007) suggested that it is necessary to graze periodically, especially in the spring for tall fescue, to improve light penetration to stimulate the growth of new leaves of clovers. Undergrazing can result in heavy shading and a reduction in tiller development and forage production especially when clovers are mixed with tall fescue and undergrazed for a long period (Ball et al., 2007). Although sunn hemp was present during our second hay harvest period the paddocks containing sunn hemp did not differ in HM compared to the other treatments (Table 1.4). This may be due to the chosen seeding rate, the climate of the experimental area, the combination of tall fescue mixed with sunn hemp, and the timing of planting and harvesting the tall fescue mixed with sunn hemp. Our results of tall fescue paddocks containing sunn hemp in the second hay harvest period in 2020 and 2021 showed lower HM compared to past research conducted in Georgia and Alabama, which showed herbage accumulation of sunn hemp alone planted at greater seeding rates ranging from 8.9 to 13.0 Mg ha⁻¹ and up to 6.6 Mg ha⁻¹ in Alabama (Schomberg et al., 2007; Balkcom et al., 2011). These two locations favored sunn hemp growth considering both locations provided hot and subtropical climate characteristics during sunn hemp's growing season. Therefore the competition from tall

fescue at our experimental site, along with our lower seeding rate and temperate climate may have restricted sunn hemp's growth and potential to increase HM.

Grazing Period Herbage Mass (HM)

In summary for 2020 and 2021, the total grazing period HM averaged 3754 kg ha⁻¹, with a minimum of 2041 kg ha⁻¹, and a maximum of 6815 kg ha⁻¹ across all treatments (Table 1.2).

The average HM of tall fescue and tall fescue-legume mixed sward for the grazing period showed no differences among treatments in 2020 (Table 1.4). The lack of differences among treatments may be due to the lower-than-30 yr average precipitation for June, July, September, November, and December 2020 (Fig. 1.1). Similarly, Yarber (2008) reported that in Virginia, the lower stockpiled tall fescue yields in response to the N rate in 2007 compared to 2006 is due to low precipitation in 2007 compared to 2006. In relation, Payne (2021) reported that in Kentucky, overall yields of stockpiled tall fescue and response to increasing N rate were less in 2016 due to the lower-than-average precipitation during the fall of 2016. However, TU was greater than TRC and TSH at the beginning of the grazing period in 2021, which occurred in October 2021 (Table 1.4). This may be due to the greater amounts of precipitation before and after the TU treatment was applied in 2021 (Fig. 1.1) and its effect on tall fescue's response to the TU treatment which was applied in September 2021. The fact that the amount of precipitation in July 2021 was 34% greater than in July 2020 and the amount of precipitation in October 2021 was 37% greater than in October 2020 (Fig. 1.1) supports Teutsch et al. (2011) report on how the seasonal precipitation that occurs before and after fertilization can have a greater effect on early-winter DM yields compared to the late-summer fertilization rate. In correspondence to TU producing greater HM compared to TRC and SH; a study that experimented with two sward types: tall fescue and tall

fescue + red clover, with five summer-applied N fertilization rates; reported that stockpiled tall fescue yields were not influenced by the sward type, however, the stockpiled tall fescue yields increased with increased N fertilization rates (Kalenbach et al., 2017). Similarly, Taylor and Templeton (1976) reported that tall fescue swards that received N fertilization had a greater amount of green forage in October through February compared to stockpiled forage that did not receive N fertilization.

Nutritive value

In summary for 2020 and 2021, the total CP values averaged 137 g kg^{-1} , with a minimum of 69 g kg^{-1} , and a maximum of 211 g kg^{-1} across all treatments (Table 1.2). The total NDF values averaged 587 g kg^{-1} , with a minimum of 465 g kg^{-1} , and a maximum of 662 g kg^{-1} (Table 1.2). The total IVTDMD48 values averaged 722 g kg^{-1} , with a minimum of 541 g kg^{-1} , and a maximum of 805 g kg^{-1} across all treatments (Table 1.2). The total NDFD48 values averaged 544 g kg^{-1} , with a minimum of 445 g kg^{-1} , and a maximum of 643 g kg^{-1} across all treatments (Table 1.2).

Average nutritive value during the 2020 and 2021 growing seasons

The average nutritive value (CP, NDF, IVTDMD48, NDFD48) of tall fescue and tall fescue-legume mixed sward sampled across the growing season showed no differences among treatments in 2020 (Table 1.5). However, TU was greater than TRC and TSH in 2021 for average CP concentration (Table 1.5). This may be due to the greater amount of precipitation before and after urea was applied to tall fescue in 2021 (Fig. 1.1) and its effect on tall fescue's response to the applied N fertilizer. There were no differences among treatments for NDF, IVTDMD48, and NDFD48 across the 5 sampling periods in 2020 and 2021 (Table 1.5). The lack

of differences in digestibility values between red clover and sunn hemp is supported by a study completed by Wilson and Minson (1980), which reported little to no differences between the DM digestibility of warm and cool-season legumes. This is due to these species having similar photosynthetic pathways and leaf anatomy (Minson, 1990). Our results differed from a previous study that reported *Trifolium* species can produce greater DM digestibility than temperate grasses when regularly cut (Michell, 1973). This may be because in our study red clover was mixed with tall fescue and it was not regularly cut. And based on the BC analysis for the 2020 and 2021 growing seasons, over 72% of the forage material was grass in the paddocks that contained red clover and sunn hemp (Fig. 1.2)

Nutritive value for each sampling period during the 2020 and 2021 growing seasons

The average CP values for TRC and TSH were greater than TU during the first hay harvest that occurred in May 2020 (Table 1.6). The fact that CP values for TRC were greater than TU was expected since urea had yet to be applied. Also, these results can be supported by a study that showed the CP content in legumes was 55 g kg⁻¹ DM greater than the CP content of temperate grasses (Minson, 1990). During the grazing period, the sampling that occurred in November 2020 showed the average CP values for TSH were greater than TU and TRC, and TU was greater than TRC (Table 1.6). Generally, legumes have greater CP than perennial cool-season grasses (Ball et al., 2007). However, the average CP values for TU were greater than TRC for November and December 2020 (Table 1.6). During this time, steers were constantly grazing these paddocks, and they may have been selectively grazing red clover, removing it from the plots, which can explain the reduced CP content in these paddocks. In addition, tall fescue's response to urea added to its increased CP, while the remaining red clover that was not grazed/removed, was likely mature, therefore decreasing forage quality (Ball et al., 2001). The

fertilization of N to grasses often increases CP levels in the forage (Ball et al., 2001); and the sampling that occurred during the grazing period in November and December was followed by the application of urea. After all, CP can be affected by the amount of available N in the soil, and grasses fertilized with N, such as urea, often increase levels of CP (Minson, 1990; Ball et al., 2001; Corbin et al., 2019). In 2021, the average CP values for TU were greater than TSH for the sampling that occurred in May, November, and December and the average CP values for TU were greater than TRC in December (Table 1.6). Even though CP values for TSH were lower than other treatments for most sampling periods, its CP values were still considered sufficient to support growing beef calves (Rayburn, 2013).

In 2020, there were differences among treatments for NDF in August (2nd hay harvest) and November (second sampling during grazing) (Table 1.6). Results from August 2020 showed the average NDF content of TRC and TU was greater than TSH, which can be related to the BC results showing TSH having a greater proportion of legumes compared to TRC for August 2020 (Fig 1.3). Generally, legumes produce overall lower concentrations of NDF than grasses due to the differences between grass and legume leaves NDF content (Buxton, 1996; Collins et al., 2017). This supports our results from the sampling that occurred in November 2020 which showed the average NDF content of TU was greater than TRC and TSH (Table 1.6). Sampling in November 2020 occurred after urea was applied to TU paddocks which led to an increase in tall fescue production and maturity. Therefore, NDF values are expected to increase with maturity (Buxton, 1996). There were no differences among treatments for NDF content for each sampling period in 2021 (Table 1.6). This may be due to the greater precipitation that occurred in March, July, and October 2021 compared to 2020 (Fig. 1.1), which may have increased the rate of transpiration of these forages compared to the rate of transpiration that occurred in 2020.

Therefore, in 2021, when the rate of transpiration is expected to be higher there is an increase in the larger vascular system to accommodate for the greater amounts of water needed to pass through the plant, which would increase NDF (Minson, 1990). And the proportion of red clover was less in November and December 2021 compared to November and December 2020, suggesting more grass was present at this time and NDF values were similar to grass NDF values due to a higher grass-legume ratio (Fig. 1.3). Also, it is important to mention that even though there were no differences among treatments for NDF content for each sampling period in 2021 (Table 1.6), the NDF values were below the maximum allowance of NDF values of 700-750 g NDF kg⁻¹ for feeding beef cattle, meaning that would not negatively impact beef production and intake (Buxton, 1996).

In 2020, there were differences among treatments for the sampling that occurred in August before the second hay harvest, where TSH showed greater IVTDMD48 values compared to TRC and TU, and TU showed greater IVTDMD48 values compared to TRC (Table 1.6). This may be due to the increase in productivity of sunn hemp during this sampling period. The climate during August is favorable toward sunn hemp, which is a warm-season annual legume. By this time, sunn hemp would have been thriving, and most likely produced a greater amount of growth and production of leaves, compared to the other sampling periods. Although it is known that as fiber increases; the quality of the forage decreases, which can be related to maturity and leaf-to-stem ratio (Ball et al., 2001). The leaf-to-stem ratio most likely increased for sunn hemp at this sampling period and the lower concentration of lignin in leaves compared to the whole plant may further explain why TSH showed a greater IVTDMD48 value for the second sampling period in 2020, compared to the other treatments (Mansoor et al., 1997; Lepcha et al., 2019) (Table 1.6). There were no differences among treatments for IVTDMD48 content for each

sampling period in 2021 (Table 1.6), likely due to the lack of differences in NDF content in 2021 considering NDF is composed of cell wall components that are generally negatively correlated with forage digestibility (Buxton, 1996).

In 2020, there were differences among treatments for NDFD48 from the sampling that occurred before the second hay harvest (August) (Table 1.6), where the average NDFD48 content for TU was greater than TRC and TSH (Table 1.6). Although, TRC showed greater NDF content than TSH for August 2020 the NDFD48 content for TRC was less and comparable to TSH for August 2020 (Table 1.6). This may be due to the warm temperatures that occurred during this sampling period (Fig. 1.1). Wilson and Minson (1983), reported that warm-season conditions, such as an increase in 1°C can decrease digestibility by 3 – 7 g kg⁻¹ in cool-season forages such as red clover and tall fescue. Also, the fiber content in legumes, such as red clover and sunn hemp is generally less digestible, especially as legumes mature (Buxton, 1996). This is due to the decline in legumes leaf to stem ratio as it matures, while lignin content in the cell walls increases for stem and plant reproduction development (Buxton and Russell, 1988; Collins et al, 2017). There were no differences among treatments for NDFD48 content for each sampling period in 2021 (Table 1.6). The lack of differences in NDF and IVTDMD48 content in 2021 can help explain the lack of differences in NDFD48. Also, TRC and TSH plots had a great proportion of grass (greater than 70%) for most sampling periods, except for the second sampling period which occurred in August 2021, when sunn hemp made up nearly 50% of the forage content (Fig. 1.3). Even with this greater proportion of sunn hemp for this sampling period, the NDFD48 content did not differ (Table 1.6). In addition, NDFD48 values for tall fescue paddocks that contained legumes were similar to the tall fescue paddocks without legumes, which can further explain the lack of differences among treatments for NDFD48 values

(Table 1.6). These results are supported by Jensen et al. (2016) that reported tall fescue alone was able to maintain a 590 g kg⁻¹ NDFD during the summer months when tall fescue was expected to decline in forage quality. Lepcha et al. (2019) reported that sunn hemp alone showed NDFD concentrations of 485 g kg⁻¹ DM during the summer months.

Grazing

In summary for 2020 and 2021, the total steer weight gain averaged 38.4 kg, with a minimum of -4 kg, and a maximum of 69 kg across all treatments (Table 1.2). The ADG of steers averaged 0.6 kg, with a minimum of 0 kg, and a maximum of 1 kg across all treatments (Table 1.2).

There were no differences among treatments for the total weight gain of steers or the ADG of steers for 2020 and 2021 (Table 1.7 & Table 1.8). In 2020, total weight gained and ADG were averaged over a 69-day grazing period and a 65-day grazing period in 2021. In 2020, total weight gain ranged from 30 to 34 kg and ADG ranged from 0.4 to 0.5 kg day⁻¹. In 2021, total weight gain ranged from 40 to 51 kg and ADG ranged from 0.6 to 0.8 kg day⁻¹. The lack of differences among treatments for total weight gain and ADG may be related to the lack of differences among treatments for HM and forage digestibility nutritional values during the grazing period in 2020 and 2021 (Table 1.4 & Table 1.5). Even though there were differences among treatments for CP during the grazing period in 2020 and 2021, the differences did not affect total weight gain or ADG. This is supported by Poore et al. (2000), that reported that even though nutritive values of stockpiled tall fescue generally exceed the requirements for dry beef cows, their growth performances are typically less than expected.

Although our ADG analysis showed no differences among treatments the ADG among steers over 69 days of grazing in 2020 was 0.45 kg day^{-1} , and over 65 days of grazing in 2021 was 0.7 kg day^{-1} (Table 1.8) which was similar to previous research showing the average daily gain ranging from $.41 \text{ kg day}^{-1}$ to $.56 \text{ kg day}^{-1}$ for unsupplemented calves grazing stockpiled tall fescue during the late fall and winter (McClure et al., 1977; Poore et al., 2006). This may be due to our HM values at the end of the grazing period in 2020 and 2021 being high (Table 1.4) suggesting our stocking rate did not adequately match the forage availability, resulting in a decrease in DM intake and reducing animal output (Ball et al, 2007). In a previous tall fescue stockpiling study, Caldwell et al. (2009) suggested offering hay when forage mass reaches below $1,120 \text{ kg ha}^{-1}$, which was approximately $2,800 \text{ kg ha}^{-1}$ less than our end HM in 2020 and 1600 kg ha^{-1} less than our end HM in 2021 (Table 1.4).

Economic Analysis

In summary for 2020 and 2021, the net return values showed a minimum of $\$74.11 \text{ ha}^{-1}$, and a maximum of $\$524.76 \text{ ha}^{-1}$ across all treatments (Table 1.2).

In 2020, ADG ranged from 0.4 to 0.5 kg day^{-1} , and the steer production, based on body weight gain, ranged from 91.0 to 100.0 kg ha^{-1} , and the stocking rate from 2.7 AU ha^{-1} to 3.0 AU ha^{-1} . In 2021, ADG ranged from 0.6 to 0.8 kg day^{-1} , steer production ranged from 106.8 to 169.2 kg ha^{-1} , and the stocking rate was the same as in 2020. The cost of forage production ranged from $\$441.32$ to $\$472.63 \text{ ha}^{-1}$ in 2020 and 2021. The cost of forage production was calculated by summing all variable and fixed expenses to calculate a total maintenance expense which represented the cost of forage production ha^{-1} . (Table 1.9). In 2020, the net returns ranged from $\$194.31$ to $\$225.18 \text{ ha}^{-1}$. In 2021, the net returns ranged from $\$248.21$ to $\$443.83 \text{ ha}^{-1}$ (Table

1.10). There were no differences among treatments for the total net returns analysis for the combination of 2020 and 2021 (Table 1.10). The lack of differences among treatments for NR values suggests that even though the annualized cost of forage production for establishing and maintaining TRC and TSH paddocks was slightly greater than the cost of forage production for TU, the method of incorporating legumes such as red clover and sunn hemp to serve as alternative N sources used for producing and managing stockpiled tall fescue systems are comparable to conventional methods of producing and managing stockpiled tall fescue systems. Based on the trend of Urea prices consistently increasing (DTN fertilizer prices 2014-2022), the inclusion of red clover or sunn hemp to tall fescue may serve as a cost-saving effort to aid in tall fescue stockpile production.

Conclusions

Nutritive value and forage digestibility of stockpiled tall fescue during the fall grazing were not affected by the different treatments; however, CP increased following the application of urea. Weather conditions during the stockpiling period (when urea was applied) most likely affected the increase in HM of TU compared to TRC and TSH at the beginning of the fall grazing period in 2021. Sunn hemp performed best during the summer, however future studies involving different sunn hemp seeding rates and dates when mixed with tall fescue should be considered. Also grazing tall fescue mixed with sunn hemp during the summer may help increase beef production during this period and alleviate sunn hemp establishment costs. Even though red clover is considered a cool-season legume, the proportion of red clover did not change during the summer compared to the proportion of red clover in the spring and early fall, implying that grazing tall fescue mixed with red clover during summer may also be beneficial.

Although ADG results did not differ among treatments, NR results from this study show that a producer can still make a profit considering the beef steer price and the cost of conventional and alternative N sources. Therefore, utilizing these results in combination with the costs associated with each source could aid producers in selecting a more cost-effective source of N or method for stockpiling tall fescue.

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Appendix

Tables

Table 1.1. *P* values for all analyzed variables of tall fescue and tall fescue mixed swards during two consecutive growing seasons years (2020 & 2021).

Botanical Composition						
Effect	Weed	Grass	Legume			
<i>P - values</i>						
Treatment (T)	<.0001	<.0001	<.0001			
Sampling Period (SP)	0.69	<.0001	<.0001			
SP x T	0.01	<.0001	<.0001			
Year (Y)	0.00	0.59	0.13			
Y x T	0.02	0.00	0.11			
Y x SP	0.09	0.60	1.00			
Y x SP x T	0.03	0.56	1.00			
Herbage Mass and Nutritional Values						
Effect	HayHM [§]	GrazingHM [§]	CP [§]	NDF [§]	IVTDMD48 [§]	NDFD48 [§]
<i>P - values</i>						
Treatment (T)	0.75	0.03	0.01	0.26	0.22	0.28
Sampling Period (SP)	0.01	0.05	<.0001	0.00	<.0001	<.0001
SP x T	0.18	0.55	0.00	0.01	0.07	0.11
Year (Y)	0.11	0.03	0.23	0.24	0.59	0.00
Y x T	0.31	0.13	0.04	0.63	0.22	0.84
Y x SP	0.14	0.16	<.0001	<.0001	<.0001	<.0001
Y x SP x T	0.51	0.83	0.60	0.06	0.84	0.12
Steer Weight Gain and Net Return Values						
Effect	TWG [§]		ADG [§]		NR [§]	
<i>P - values</i>						
Treatment (T)	0.78		0.78		0.08	
Year (Y)	0.00		0.00		0.05	
Y x T	0.38		0.49		0.25	

[§] HayHM, hay period herbage mass; GrazingHM, grazing period herbage mass; CP, crude protein; NDF, neutral detergent fiber; IVTDMD48, in-vitro true dry matter digestibility in 48 hrs.; NDFD48, neutral detergent fiber digestibility in 48 hrs.; TWG, total weight gained; ADG, average daily weight gain; NR, net return.

Table 1.2. Summary statistics for all analyzed variables of tall fescue and tall fescue mixed swards during two consecutive growing seasons (2020 & 2021).

Variable	<i>n</i>[†]	MIN[†]	MAX[†]	Mean	SD
Hay period herbage mass, <i>kg DM</i>[§] <i>ha</i>⁻¹	36	2393	4617	3290	625
Grazing period herbage mass, <i>kg DM</i>[§] <i>ha</i>⁻¹	36	2041	6815	3754	1356
CP[§], <i>g kg</i>⁻¹	90	69	211	137	24
NDF[§], <i>g kg</i>⁻¹	90	465	662	587	41
IVTDMD48[§], <i>g kg</i>⁻¹	90	541	805	722	36
NDFD48[§], <i>g kg</i>⁻¹	90	445	643	544	39
Grass[§], <i>g kg</i>⁻¹	90	408	1000	842	141
Legume[§], <i>g kg</i>⁻¹	90	0	560	115	149
Weed[§], <i>g kg</i>⁻¹	90	0	158	42	37
Steer total weight[§], <i>kg</i>	53	-4	69	38.4	17.3
Steer ADG[§], <i>kg</i>	53	0	1	0.6	0.3
Net Returns, \$/<i>ha</i>⁻¹	18	74.11	524.76		122.77

[†]*n*, number of observations; MIN, minimum observation; MAX, maximum observation. Each observation was the average of four replicates.

[§]DM, dry mater; CP, crude protein; NDF, neutral detergent fiber; IVTDMD48, in-vitro true dry matter digestibility in 48 hrs.; NDFD48, neutral detergent fiber digestibility in 48 hrs.

Table 1.3. Total herbage mass of tall fescue and tall fescue-legume mixed sward harvested as hay across 2 harvest periods in 2020 and 2021.

Treatment	2020	2021
	Total herbage mass	Total herbage mass
	<i>kg DM^s ha⁻¹</i>	
TRC [†]	6282 [‡]	7188
TSH	5949	7148
TU	5410	7500
<i>P</i>	0.44	0.70

[†] TRC, red clover; TSH, sunn hemp; TU, Urea. ^sDM dry matter.

[‡] Different superscript letter means differences within a column. Means within a column without a common superscript letter differ (P<0.05) using Fisher's LSD test.

Table 1.4. Average herbage mass of tall fescue and tall fescue-legume mixed sward per sampling period for 2020 and 2021.

Year	Treatment	Hay Harvest		Grazing Period	
		Period 1	Period 2	Beginning	End
		May	August	October	December
		<i>kg DM[§] ha⁻¹</i>			
2020	TRC [†]	3408 [‡]	2874	5081	4229
	TSH	3016	2934	4886	3812
	TU	2715	2695	5897	3727
	<i>P</i>	0.34	0.60	0.29	0.86
2021	TRC [†]	4031	3158	2575 ^b	2204
	TSH	4047	3101	2502 ^b	2677
	TU	3804	3697	4036 ^a	3421
	<i>P</i>	0.82	0.32	0.03	0.09

[†] TRC, red clover; TSH, sunn hemp; TU, Urea. [§]DM dry matter.

[‡] Different superscript letter means differences within a column. Means within a column without a common superscript letter differ (P<0.05) using Fisher's LSD test.

Table 1.5. Average nutritive value [crude protein (CP), neutral detergent fiber (NDF), *in vitro* true dry matter digestibility 48h (IVTDMD48), and neutral detergent fiber digestibility 48 h (NDFD48)] of tall fescue and tall fescue-legume mixed swards across 5 sampling dates (hay harvests and grazing period) during the growing season of 2020 and 2021.

Year	Treatment	CP	NDF	IVTDMD48	NDFD48
				<i>g kg⁻¹</i>	
2020	TRC [†]	135 [‡]	586	721	554
	TSH	141	580	725	555
	TU	141	583	725	563
	<i>P</i>	0.71	0.90	0.91	0.60
2021	TRC [†]	128 ^b	596	722	530
	TSH	125 ^b	592	709	523
	TU	150 ^a	587	732	537
	<i>P</i>	0.03	0.74	0.28	0.44

[†] TRC, red clover; TSH, sunn hemp; TU, Urea. [§]DM dry matter.

[‡] Different superscript letter means differences within a column. Means within a column without a common superscript letter differ (P<0.05) using Fisher's LSD test.

Table 1.6. Average nutritive value [crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), neutral detergent fiber 48 h (NDF48), *in vitro* true dry matter digestibility 48h (IVTDMD48), and neutral detergent fiber digestibility 48 h (NDFD48)] of tall fescue and tall fescue-legume mixed swards per sampling date in 2020 and 2021.

		Hay Harvest		Grazing Period		
Year	Treatment	Sampling 1	Sampling 2	Sampling 3	Sampling 4	Sampling 5
		May	August	October	November	December
CP g kg ⁻¹						
2020	TRC [†]	130 ^{a‡}	173	149	116 ^c	105 ^b
	TSH	130 ^a	178	150	132 ^a	113 ^{ab}
	TU	123 ^b	169	164	122 ^b	130 ^a
	P	0.04	0.22	0.29	0.003	0.04
2021	TRC [†]	134 ^{ab}	114	160	126 ^{ab}	107 ^b
	TSH	133 ^b	124	154	118 ^b	96 ^b
	TU	140 ^a	129	191	148 ^a	140 ^a
	P	0.03	0.22	0.13	0.04	0.00
NDF g kg ⁻¹						
2020	TRC [†]	571	527 ^a	597	615 ^a	623
	TSH	572	482 ^b	595	615 ^a	634
	TU	572	552 ^a	584	606 ^b	600
	P	0.95	0.01	0.34	0.04	0.17
2021	TRC [†]	628	642	558	560	593
	TSH	629	634	564	576	557
	TU	627	646	535	550	578
	P	0.95	0.29	0.47	0.23	0.48
IVTDMD48 g kg ⁻¹						
2020	TRC [†]	746	746 ^c	721	701	693
	TSH	749	779 ^a	723	693	682
	TU	739	762 ^b	727	697	702
	P	0.16	0.01	0.33	0.78	0.22
2021	TRC [†]	710	683	746	764	706
	TSH	711	695	738	750	650
	TU	711	682	772	775	722
	P	0.98	0.27	0.27	0.24	0.34
NDFD48 g kg ⁻¹						
2020	TRC [†]	579	510 ^b	550	566	566
	TSH	592	527 ^b	551	550	555
	TU	575	577 ^a	550	555	560
	P	0.47	0.00	0.93	0.74	0.38

Table 1.6. continued

2021	TRC[†]	496	487	592	513	561
	TSH	500	509	585	501	519
	TU	493	493	603	517	578
	<i>P</i>	0.08	0.30	0.66	0.64	0.26

[†] TRC, red clover; TSH, sunn hemp; TU, Urea. [§]DM dry matter.

[‡] Different superscript letter means differences within a column. Means within a column without a common superscript letter differ ($P < 0.05$) using Fisher's LSD test.

Table 1.7. Total weight gain of steers grazing stockpiled tall fescue and stockpiled tall fescue-legume mixed sward in 2020 and 2021.

2020		2021
Treatment	Total weight gain	Total weight gain
		<i>kg ha⁻¹</i>
TRC [†]	34 [‡]	40
TSH	30	46
TU	30	51
<i>P</i>	0.84	0.46

[†] TRC, red clover; TSH, sunn hemp; TU, Urea.

[‡] Different superscript letter means differences within a column. Means within a column without a common superscript letter differ ($P < 0.05$) using Fisher's LSD test.

Table 1.8. Average daily gain of steers grazing stockpiled tall fescue and stockpiled tall fescue mixed sward in 2020 and 2021.

	2020	2021
Treatment	Average daily gain	Average daily gain
	<i>kg ha⁻¹</i>	
TRC [†]	0.5 [‡]	0.6
TSH	0.4	0.7
TU	0.4	0.8
P	0.92	0.53

[†] TRC, red clover; TSH, sunn hemp; TU, Urea.

[‡] Different superscript letter means differences within a column. Means within a column without a common superscript letter differ (P<0.05) using Fisher's LSD test.

Table 1.9. Annual maintenance budget for tall fescue and tall fescue mixed swards production within each assigned treatment.

Treatments:	TU	TRC	TSH
<u>Variable Expenses</u>	Total (\$ ha⁻¹)		
†Sunn Hemp Seed			\$107.49
†No-Till Drill			\$16.89
Fertilizer & Lime	\$204.67	\$96.44	\$96.44
Chemical	\$49.54	\$18.66	\$24.96
Repair & Maintenance	\$2.86	\$2.86	\$6.99
Fuel, Oil & Filter	\$13.29	\$13.29	\$15.03
Fence Repairs	\$16.95	\$16.95	\$16.95
Operating Interests	\$11.49	\$5.93	\$7.09
Total Variable Expenses	\$298.81	\$154.13	\$291.83
<u>Fixed Expenses</u>			
<i>Machinery</i>			
*Establishment Cost of Re-seeding RC		\$78.50	
*Establishment Cost of Re-seeding TF	\$67.75	\$67.75	\$67.75
Depreciation	\$2.96	\$2.96	\$9.38
Interest	\$10.27	\$10.27	\$29.71
Housing and Insurance	\$0.86	\$0.86	\$2.36
<i>Fencing</i>			
Depreciation (Perimeter Fence)	\$17.15	\$17.15	\$17.15
Depreciation (Divider Fence)	\$16.06	\$16.06	\$16.06
Interest (Perimeter Fence)	\$13.74	\$13.74	\$13.74
Interest (Divider Fence)	\$3.21	\$3.21	\$3.21
Total Fixed Expenses	\$132.00	\$210.50	\$159.36
Labor Expenses	\$10.53	\$10.53	\$21.45
Total Maintenance Expenses	\$441.32	\$375.15	\$472.63

† Cost of variable expenses is only displayed in the TSH column due to TSH being planted annually.

* Establishment cost with a 10% risk of re-seeding red clover prorated over 3 years.

* Establishment cost with a 10% risk of re-seeding tall fescue prorated over 10 years.

Table 1.10. Cost of production (\$ ha⁻¹), steer production (kg ha⁻¹), total revenue (TR) (\$ ha⁻¹), and net returns (NR) (\$ ha⁻¹) of steer production from grazing stockpiled tall fescue paddocks fertilized with urea (U) and stockpiled tall fescue paddocks mixed with legumes (RC, red clover; SH, sunn hemp) as alternative N sources in 2020 and 2021.

Year	Treatment	Cost of forage production	Number of grazing days	Steer production	Steer price	TR*	NR*
		<i>\$ ha⁻¹</i>	<i>days</i>	<i>kg ha⁻¹</i>	<i>\$ kg⁻¹</i>	<i>\$ ha⁻¹</i>	<i>\$ ha⁻¹</i>
2020	TRC [†]	\$ 375.15	69	91.0	\$ 3.09	\$280.80	\$209.88
	TSH	\$ 472.63	69	92.6	\$ 3.09	\$285.90	\$196.56
	TU	\$ 441.32	69	100.0	\$ 3.09	\$308.60	\$225.18
	<i>P</i>						0.90
2021	TRC	\$ 457.48	65	106.8	\$ 3.09	\$329.68	\$262.87
	TSH	\$ 472.63	65	141.4	\$ 3.09	\$436.63	\$352.46
	TU	\$ 441.32	65	169.2	\$ 3.09	\$522.42	\$443.83
	<i>P</i>						0.10

[†] TRC, red clover; TSH, sunn hemp; TU, Urea.

[‡] Different superscript letter means differences within a column. Means within a column without a common superscript letter differ (P<0.05) using Fisher's LSD test.

* TR, Total Revenue; TR values are based on multiplying steer price value by steer production value within a treatment row: TR = (Steer production X Steer price).

* NR, Net return; NR values are based on the number of grazing days per year instead of 365 days within a treatment row: NR = (TR - (Cost of forage production X (Number of grazing days/ 365))).

Figures

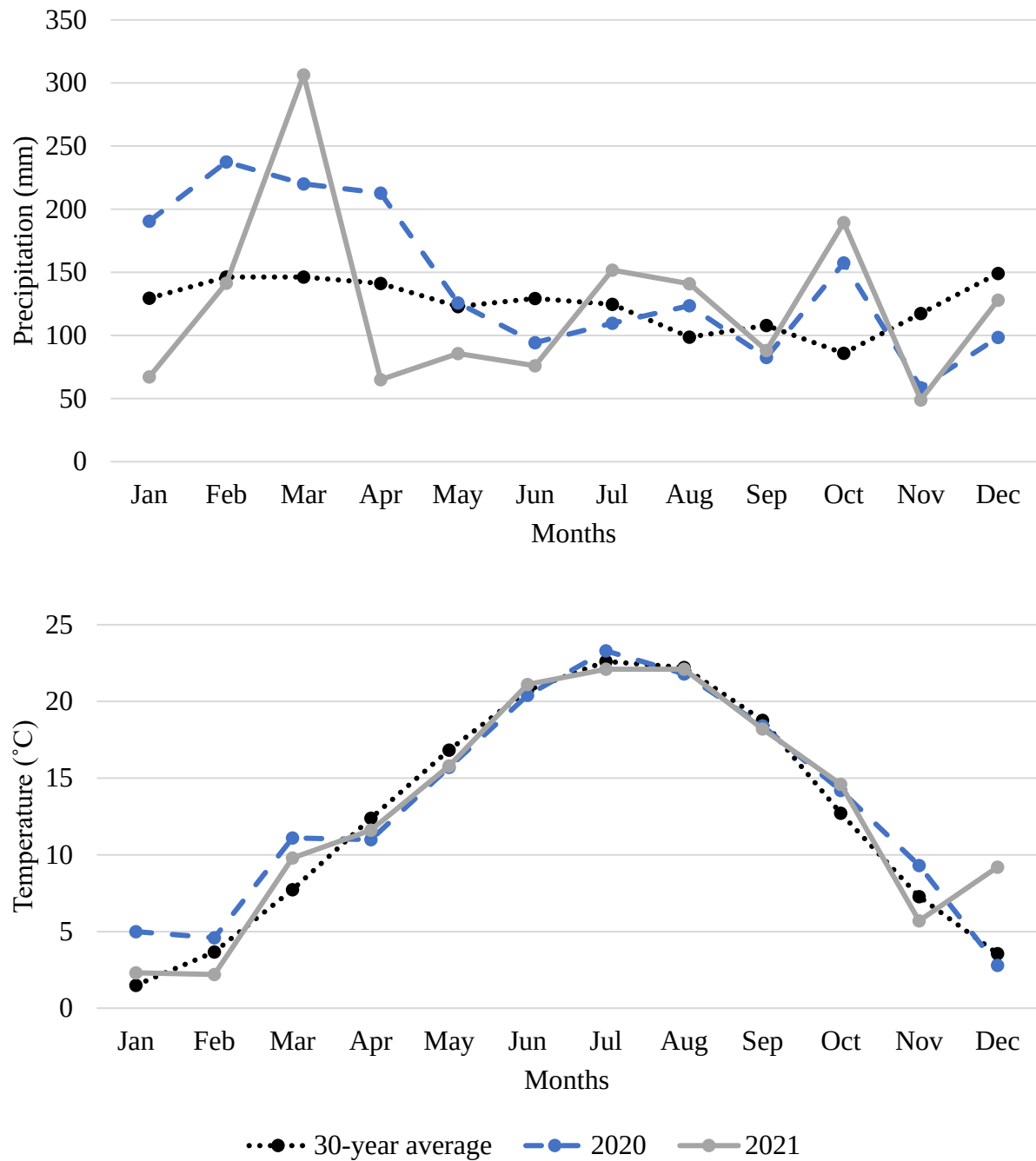


Figure 1.1. Weather for Crossville, TN, including 30-yr average for the growing season of 2020 & 2021.

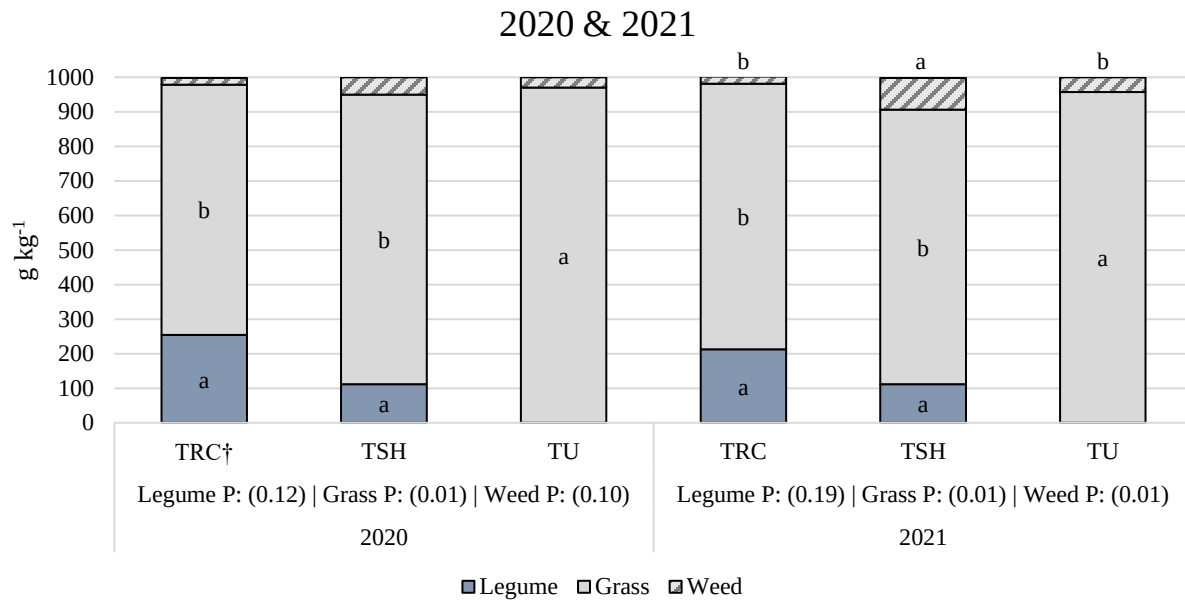


Figure 1.2. Average botanical composition (legumes, grass, and weeds) of tall fescue and tall fescue mixed swards across 5 sampling periods (hay harvest and grazing period) during the 2020 & 2021 growing seasons. † TRC, red clover; TSH, sunn hemp; TU, Urea.

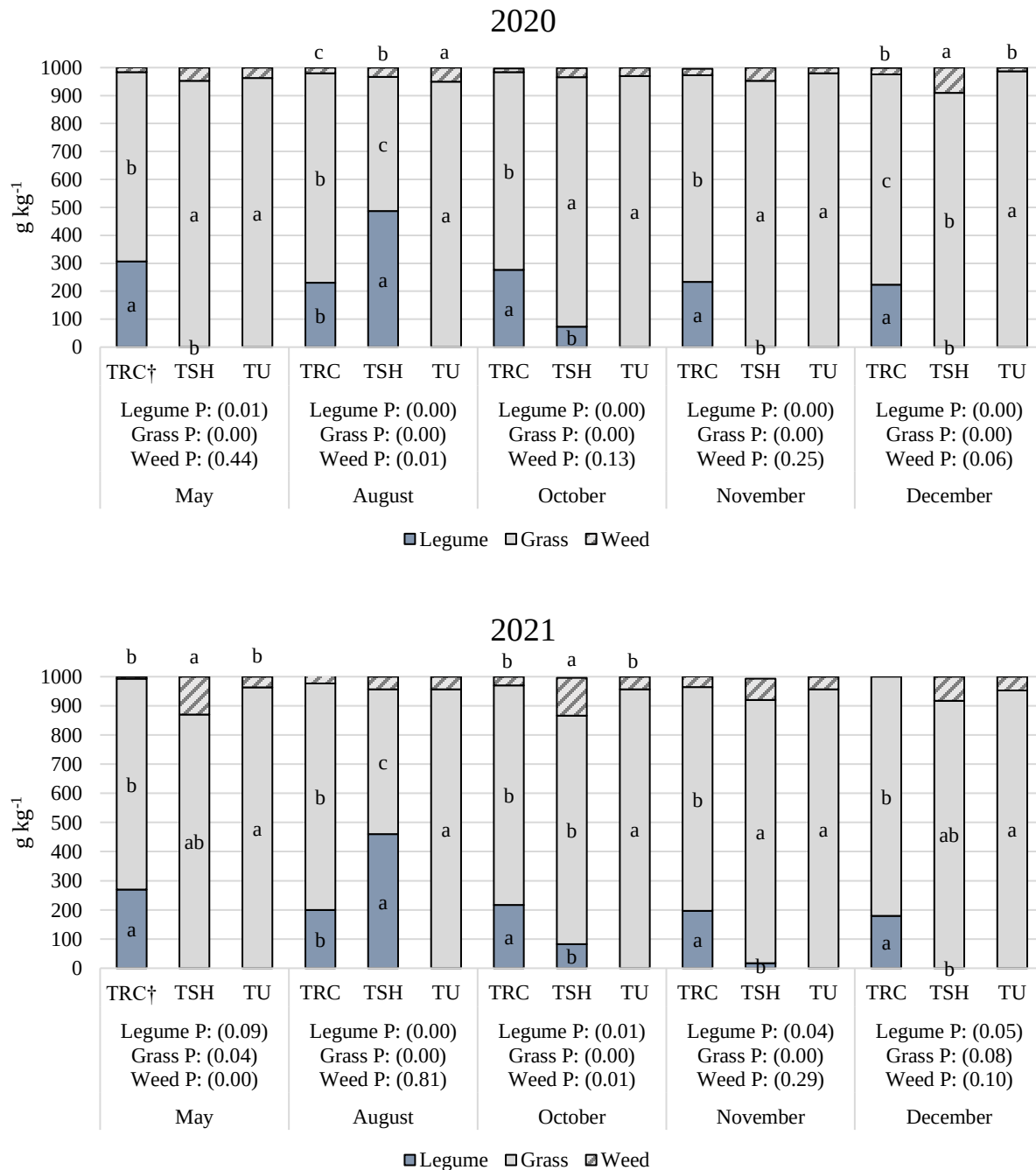


Figure 1.3. Average botanical composition (legumes, grass, and weeds) of tall fescue and tall fescue mixed swards per sampling period during the 2020 and 2021 growing seasons. † TRC, red clover; TSH, sunn hemp; TU, Urea.

**CHAPTER II: ADDING COOL AND WARM-SEASON SPECIES TO
TALL FESCUE SWARDS FOR INCREASED PRODUCTIVITY AND
SUSTAINABILITY**

Abstract

Developing a forage system that includes the incorporation of cool- and warm-season forage species has the potential to enhance tall fescues' [*Schedonorus arundinaceus* (Schreb.) Dumort.] forage productivity during its growing season, including summer. The objectives of this study were to incorporate crabgrass [*Digitaria ciliaris* Retz.] into tall fescue swards and compare the production of monoculture tall fescue to a binary mixture of crabgrass and tall fescue as well as its effect with different sources of nitrogen (N). The experiment was conducted in Crossville, TN in 2020 and 2021, and consisted of two main plots, tall fescue (TF) or tall fescue mixed with crabgrass (TFC), as well as four treatments added to the main plots. The treatments were as followed: 1) tall fescue only + 0 N (TF-0), 2) tall fescue + red clover cultivar FSG 401rc (TFR), 3) tall fescue + sunn hemp cultivar Tropic Sun (TFS), 4) tall fescue + ammonium nitrate (TFA), 5) tall fescue and crabgrass + 0 N (TFC-0), 6) tall fescue and crabgrass + red clover cultivar FSG 401rc (TFRCR), 7) tall fescue and crabgrass + sunn hemp cultivar Tropic Sun (TFCS), 8) tall fescue and crabgrass + ammonium nitrate (TFCA). The plots containing red clover showed greater HM and crude protein (CP) values along with lesser NDF and NDFD48 values compared to the other treatments in 2020 and 2021. The plots containing red clover also showed a greater proportion of legumes compared to the plots containing sunn hemp in the 2020 and 2021 growing seasons. The TFCS plots showed approximately 38% greater herbage mass compared to TFS (5221 kg ha⁻¹ vs. 3766 kg ha⁻¹) in 2020; approximately 32% greater HM (4661 kg ha⁻¹ vs. 3527 kg ha⁻¹) in 2021. Tall fescue swards that were mixed with crabgrass and a source of N (addition of legumes or N fertilizer) showed greater HM during the warm season.

Introduction

Tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort.] is a cool-season forage grass that is predominant in the transition zone of the Southeastern Region (Collins et al., 2017). Due to tall fescue's physiology (C3 photosynthesis), its growth and productivity tend to decline during the summer when heat and drought conditions are frequent in the transition zone (Moore et al., 2004; Volenec et al., 2007; Tracey et al., 2010). During this period of low productivity, forage management can become challenging. Fortunately, the climate in the transition zone allows warm – and cool–season species to overlap (Collins, et al., 2017). Therefore, warm-season grasses, such as crabgrass [*Digitaria ciliaris* Retz.], can be integrated into cool-season forage systems to enhance summer production when cool-season grasses, such as tall fescue, are less productive (Taiz & Zeiger, 2002; Collins et al., 2017; Sosinski et al., 2022). Warm-season grasses such as crabgrass have a different physiology (C4 photosynthesis), that allows them to be productive during the summer and usually more tolerant to drought conditions compared to cool-season grasses (Tracey et al., 2010).

In the Southeastern Region, annual warm-season grasses, such as crabgrass, are normally used for generating high-quality emergency forage (Collins et al., 2017). This is due to its ability to establish quickly, and its superior nutritive value compared to perennial warm-season grasses (Ball et al., 2007; Collins et al., 2017). Crabgrass at the vegetative stage can have crude protein (CP) concentration averaging 14% and *in-vitro* dry matter (DM) digestibility (IVDMD) of approximately 79% (Ball et. al, 2007). Although crabgrass is an annual warm-season grass, its ability to self-reseed when managed properly allows it to perennate, which is a more economically viable option compared to selecting other annual warm-season grasses to

incorporate into tall fescue, which requires the extra cost of re-establishing each year (Tracey et al., 2010; Collins et al., 2017).

Endophyte-infected tall fescue varieties dominate other cool-season grasses in the transition zone (Collins et al., 2017). This is due to the endophytic fungus living in various plant components, generating a symbiotic relationship that enables the plant to tolerate grazing pressure, increase its persistence, resist insect damage, and survive the warm summers and moderate winters (Collins et al., 2017). Even though endophyte-infected tall fescue is more persistent than endophyte-free tall fescue varieties, the endophyte can be toxic to livestock, causing severe health problems in some instances. A method to dilute the toxicity of endophyte-infected tall fescue is to increase diversity in the field, mixing other forage species such as crabgrass or forage legumes (Ball et al., 2007).

The incorporation of crabgrass may serve as a beneficial companion to tall fescue, especially during the active growing season of crabgrass. However, for both types of grass to reach optimal production levels, nitrogen (N) fertilization should be conducted (Ball et al., 2007). Conventionally, N is applied in synthetic forms, typically as urea. However, with increasing urea prices and environmental concerns associated with fertilizer application, it is important to explore alternative sources of N for managing these forage systems, such as incorporating legumes that biologically fix N to tall fescue mixed with crabgrass. Adding legumes, such as red clover [*Trifolium pratense* L.] or sunn hemp [*Crotalaria juncea* L.] can serve as an alternative source of N and can increase the HM and forage quality of these multi-species forage systems (Collins et al., 2017).

Developing a forage system that includes the incorporation of cool- and warm-season forage species provides the potential to enhance forage productivity over the entire grazing season by increasing HM and reducing costs related to supplemental feeding during the summer season (Weinert-Nelson et al., 2021). Therefore, it is worth further exploration methods to incorporate crabgrass with tall fescue to improve summer forage production while utilizing legumes to increase N availability and biodiversity.

The objectives of this study were to incorporate crabgrass into tall fescue swards and compare the production of monoculture tall fescue to a binary mixture of crabgrass and tall fescue as well as its effect with different sources of N. It was hypothesized that interseeding crabgrass and legume species into cool-season tall fescue will improve tall fescue productivity during summer when the productivity of cool-season grasses is generally low.

Materials & Methods

Site Description

This study was conducted at the University of Tennessee Plateau Research and Education Center (PREC) in Crossville, TN (GPS Coordinates, elevation). The experiment involved 32 already established tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort. ‘Kentucky-31’) plots. The experimental period occurred from April to September 2020 and 2021. The experimental design was a split plot in a randomized complete block design with two main plots, four treatments per main plot, and four replications per treatment (n=32). The main plots were either tall fescue (TF) or tall fescue mixed with crabgrass [*Digitaria ciliaris* Retz. ‘Red River’] (TFC). The treatments were as followed: 1) tall fescue only + 0 N (TF-0), 2) tall fescue + red clover cultivar FSG 401rc (TFR), 3) tall fescue + sunn hemp cultivar Tropic Sun (TFS) , 4) tall

fescue + ammonium nitrate (TFA), 5) tall fescue and crabgrass + 0 N (TFC-0), 6) tall fescue and crabgrass + red clover cultivar FSG 401rc (TFCR), 7) tall fescue and crabgrass + sunn hemp cultivar Tropic Sun (TFCS), 8) tall fescue and crabgrass + ammonium nitrate (TFCA). Individual plots measured 3 x 6 m to accommodate the size of the no-till drill (Great Plains, Salina, Kansas).

The soil type in this experiment was 85% Lily, 5% Gilpin, 5% Lonewood, and 5% Ramsey. Initial soil samples were collected at 15 cm depth on 28 November 2019 and 24 November 2020 and sent to the University of Tennessee Soil, Plant, and Pest Center laboratory for analysis (Hanlon and Savoy, 2007). The first application of ammonium nitrate (34-0-0) (A) which served as the synthetic N treatment was applied to the desired paddocks at a rate of 88 kg ha⁻¹ in the first week of April 2020 and 2021, and the second application was applied at the same rate in the second week of June of 2020 and 2021.

Soil characteristics for 2019 were pH: 6.0, phosphorus (P): 30 kg ha⁻¹, potassium (K): 118 kg ha⁻¹, calcium (Ca): 2918 kg ha⁻¹, and magnesium (Mg): 91 kg ha⁻¹. Soil characteristics for 2020 were pH: 6.1, P: 22 kg ha⁻¹, K: 73 kg ha⁻¹, Ca: 2442 kg ha⁻¹, and Mg: 54 kg ha⁻¹.

On 22 March 2019, inoculated red clover (R) seed was drilled into existent tall fescue plots that were randomly chosen as TFR or TFCR plots utilizing a Great Plains no-till drill (Great Plains, Salina, Kansas) with 19-cm spacing. The seeding rate for R was 8.9 kg ha⁻¹. On 2 April 2020 and 5 April 2021 75 kg ha⁻¹ of K (0-0-60) and 112 kg ha⁻¹ of P (0-45-0) were applied to the entire experimental area following recommendations from soil test analysis. On 2 April 2020 and 5 April 2021, the first application of ammonium nitrate (34-0-0) (A) which served as the synthetic N treatment was applied to the existing tall fescue plots that were randomly chosen

as TFA or TFCA plots at a rate of 88 kg ha⁻¹ and the second application of A was applied at the same rate to the same plots on 14 June 2020 and 18 June 2021. On 16 April 2020 Shredder® 2,4-D LV4 2,4-Dichlorophenoxyacetic acid, 2-Ethylhexyl ester herbicide was applied to paddocks that did not include legume mixtures at a rate of 4.67 L ha⁻¹. The herbicide was applied to control broadleaf weeds, such as buckhorn plantain [*Plantago lanceolata*], dandelion [*Taraxacum officinale*], and buttercup [*Ranunculus repens*]. On 4 June 2020 and 17 June 2021, sunn hemp (S) seeds were inoculated with *bradyrhizobium* peanut inoculant at a rate of 140 g of inoculant per 45 kg of seeds, then drilled into existent tall fescue plots that were randomly chosen as TFS and TFCS plots utilizing a Great Plains no-till drill (Great Plains, Salina, Kansas) with 19-cm spacing. The seeding rate for S was 33.62 kg ha⁻¹. On 4 June 2020 and 17 June 2021, crabgrass (C) seeds were drilled into existent tall fescue plots that were randomly chosen as TFC-0, TFCR, TFCS, and TFCA plots utilizing a Great Plains no-till drill (Great Plains, Salina, Kansas) with 19-cm spacing. The seeding rate for C was 3.36 kg ha⁻¹.

Measurements

All plots were harvested and sampled on May 2, June 2, July 10, September 10, and October 29 of 2020, and on May 18, June 14, August 3, September 23, and October 27 of 2021. On each sampling date, botanical composition BC samples were randomly collected from a 0.1 m² area from each plot just before harvesting occurred. Each BC sample was separated into tall fescue, crabgrass, legume, and weeds before being placed in a drier at 60°C to constant weight (~72 hr) and then weighed for analyses of BC. On each harvest date, a center strip of all plots was harvested utilizing a 0.91 m wide carter forage harvester (Carter, Brookston, Indiana) at a 15 cm height for data collection. The border material of each plot was cleaned off after each harvest.

A sample from the harvested material from each plot was collected, weighed, dried at 60°C up to constant weight (~ 72 h), and weighed again for determination of dry matter (DM) and herbage mass. After drying the NV samples were then ground to pass through a 1-mm screen with a Wiley Mill Grinder (Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co., Philadelphia, PA) in preparation for near-infrared spectroscopy (NIRS) analysis. Before analysis, the samples were placed in individual foil tins and dried for an additional 30-min in a forced air oven at 55°C to reach constant moisture content for scanning (McIntosh et al., 2019). The samples were scanned in small ring cups on NIRS technology (Unity Spectrastar XL-R instrument Unity Scientific, Milford, MA) to predict the nutritional values of crude protein (CP), neutral detergent fiber (NDF), *in vitro* true dry matter digestibility 48h (IVTDMD48), and neutral detergent fiber digestibility 48 h (NDFD48). Equations for the forage nutritive analyses were standardized and checked for accuracy with the 2021 Mixed Hay Equation developed, provided, and licensed by the NIRS Forage and Feed Consortium (NIRSC, Berea, KY). The Global H and neighborhood statistical test were analyzed for accuracy across all predictions, in which all forage samples fit the equation with the ($H < 3.0$) and are reported accordingly (Murray and Cowe, 2004). The units of measurement for nutritive analyses are presented at 100% dry matter (DM) across the entire data set.

Statistical analysis

Differences in least square means by treatments using Fisher's LSD were determined by performing mixed model analyses of variance. Data used to determine HM, and all nutritive value variables of species were evaluated using the PROC MIXED procedures of SAS (SAS for Windows V 9.4, SAS Institute, Cary, NC). For HM and nutritive value analysis, the dependent

variables were HM, CP, NDF, IVTDMD48, and NDFD48. For BC analysis, the dependent variables were crabgrass, tall fescue, legume, and weed. Fixed effects were treatments and crabgrass applied or implemented to each experimental unit and harvest period. Replications were random effects. There were significant year x harvest period x treatment interactions for each species for certain dependent variables. Therefore, the results of the experiment are displayed separately by year for all variables, with repeated measures of harvest periods and displayed separately by harvest period for all variables. All results were evaluated for significance at $P < 0.05$.

Results & Discussion

Weather

The mean air temperature was 5% above the 30-yr average for 2020, and 3% above for 2021 (Fig. 2.1). In 2020, precipitation was 14% above the 30-yr average, and 1% lower in 2021 (Fig. 2.1). In March 2021, the precipitation was 109% greater than the 30-yr average, and 59% greater than the March 2020 average. In July 2020, the precipitation was 12% lower than the 30-yr average and 34% lower than in July 2021 (Fig. 2.1).

Botanical composition (BC)

There was a year x main plot x treatment interaction along with a harvest period x treatment interaction; therefore, results are reported by year and harvest period (Table 2.1).

In summary for 2020 and 2021, the BC analysis showed that the amount of tall fescue averaged 841 g kg⁻¹, with a minimum of 304 g kg⁻¹, and a maximum of 1000 g kg⁻¹ across all treatments; the amounts of legumes averaged 172 g kg⁻¹, with a minimum of 0 g kg⁻¹, and a

maximum of 696 g kg⁻¹ across all treatments that contained legumes; the amounts of crabgrass averaged 73 g kg⁻¹, with a minimum of 0 g kg⁻¹, and a maximum of 597 g kg⁻¹ across all treatments that contained crabgrass; the amounts of weeds averaged 37 g kg⁻¹, with a minimum of 0 g kg⁻¹, and a maximum of 256 g kg⁻¹ across all treatments (Table 2.3).

Average botanical composition (BC) during the 2020 and 2021 growing seasons

Among plots mixed with legumes (TFR, TFS, TFCR, and TFCS), the BC analysis showed that plots containing red clover had an overall greater proportion of legume compared to plots containing sunn hemp (Fig. 2.2). This is due to red clover being productive for a longer period during the growing season (April-October), compared to sunn hemp, which is productive only from late May to early September under the climatic conditions experienced at this experimental site (Ball et al., 2007).

Among the TFC plots, there were differences among treatments for the proportion of crabgrass. In 2020, TFC-0 showed a lower proportion of crabgrass compared to TFCA and TFCS (Fig. 2.2). In 2021, TFCR showed a lower proportion of crabgrass compared to TFCA and TFC-0 (Fig. 2.2). This may be because red clover served as a competitor to crabgrass production.

In 2020, there were differences among the main plots and their treatments for the proportion of weeds. Main plots containing ammonium nitrate and sunn hemp as treatments showed TFC with greater proportions of weeds compared to TF (Fig. 2.2). And plots containing no nitrogen treatment showed TF with greater proportions of weeds compared to TFC (Fig. 2.2). There were no differences among the main plots for the proportions of weeds in 2021.

Among the TF main plots, TF-0 showed a greater proportion of weeds compared to TFA and TFS. And among the TFC main plots, TFCR showed a greater proportion of weeds compared to the other treatments (Fig. 2.2). This may be due to the lower precipitation that

occurred in June, July, and September 2020, than the 30-year average for these specific months, which were during the experimental period (Fig. 2.1). Weeds or invasive species tend to benefit or adapt better under variable precipitations (Ren et al., 2022). In 2021, among the TF main plots, TFR showed a considerably lower proportion of weeds compared to the other treatments (Fig. 2.2). And among the TFC plots, TFCR showed a lower proportion of weeds compared to TFCS (Fig. 2.2). Red clover combined with tall fescue (both cool season species) may have better outcompeted cool season weeds, as compared to other treatments. Most weeds observed in the study included cool-season weeds such as buckhorn plantain [*Plantago lanceolata* L.], broadleaf plantain [*Plantago major* L.], and dandelion [*Taraxacum officinale* L.]; and warm-season weeds such as non-desired volunteer crabgrass [*Digitaria sanguinalis*] which was observed in plots that did not contain the C treatments (TF-0, TFA, TFR, and TFS).

Botanical composition (BC) for each harvesting period during the 2020 and 2021 growing seasons

Among the tall fescue mixed plots containing legumes, the BC analysis showed that there were differences among the main plots in the proportion of red clover. In harvest period 3, in 2020, TFCR showed greater proportions of red clover compared to TFR (Fig. 2.3). It is important to mention that the plots containing crabgrass and sunn hemp were not established until after the second harvest period (June) of 2020 and 2021, and their growing season was coming to an end by the last harvest period of 2020 and 2021, which can better explain the results shown in figures 2.3 and 2.4. There were no differences among the main plots in the proportion of red clover or sunn hemp in 2021 (Fig. 2.4).

Among the TF main plots containing legumes, TFR showed a greater proportion of legumes compared to TFS for harvest period 4 in 2020, and 2021 (Fig. 2.3 & 2.4). And among

the TFC main plots containing legumes, TFCR showed a greater proportion of legumes compared to TFCS for harvest periods 3 and 4 in 2020, and 2021 (Fig. 2.3 and Fig. 2.4). There were no differences among treatments for legume measured in harvest period 3, 2021 which occurred in August (Fig. 2.4). Sunn hemp's growing season and its increased productivity during this harvest period (August and September) may be responsible for the lack of differences.

There were differences among the main plots for the proportion of weeds for harvest periods 1, 2, and 4 in 2020 (Fig. 2.3), and harvest period 4 in 2021 (Fig. 2.4). In harvest periods 1 and 4, in 2020, plots containing sunn hemp showed TFCS with a greater proportion of weeds compared to TS; in harvest period 2, in 2020 and harvest period 4, in 2021, plots containing no nitrogen treatment showed TF-0 with a greater proportion of weeds compared to TCF-0; and in harvest period 4, in 2020, plots containing ammonium nitrate as a treatment showed TFCA with a greater proportion of weeds compared to TFA (Fig. 2.3 & 2.4).

Among the TF main plots, TF-0 showed a greater proportion of weeds compared to TFS in harvest period 2 in 2020 (Fig. 2.3). And TF-0 showed a greater proportion of weeds compared to TFA and TFR in harvest period 4 in 2020 (Fig. 2.3). In 2021, TFR showed a greater proportion of weeds compared to TFA in harvest period 3 (Fig. 2.4). And in harvest period 4 in 2021, TFS showed a greater proportion of weeds compared to TFA (Fig. 2.4).

Among the TFC main plots, TFCS showed a greater proportion of weeds compared to TFCR in harvest period 1 in 2020 (Fig. 2.3). And TFCA and TFCS showed a greater proportion of weeds compared to TFC-0 and TFCR in harvest period 4 in 2020 (Fig. 2.3). In 2021, TFCS showed a greater proportion of weeds compared to the other treatments in harvest period 4 (Fig. 2.4).

Among the TFC plots, the BC analysis for the proportion of crabgrass, TFCS showed a greater proportion of crabgrass compared to TFC-0 in harvest period 4 in 2020 (Fig. 2.3). And in harvest period 3 in 2021, TFCA showed a greater proportion of crabgrass compared to the other treatments (Fig. 2.4). This may be because even though crabgrass is considered an annual, it has the potential to reseed itself, therefore the reseeding that occurred in 2021 combined with the plants from 2020 that may have re-seeded itself, contributed to the increased proportion. In addition, crabgrass responds well to the N provided by ammonium nitrate which is highly soluble and readily available to the grasses (Collins et al., 2017). Also, the mixed legume species, although a source of N, may have added to the competition of the sward, reflecting on the reduced BC of crabgrass in the TFCR and TFCS treatments in harvest periods 3 and 4 in 2021 (Fig. 2.4). Red clover is a biannual cool-season legume that generally produces greater biomass during its second year of growth (Wiersma et al., 1998). Therefore, the larger amount of red clover that was produced during the production year 2021, increased the competition for crabgrass to be productive in this species' biodiverse environment.

Herbage mass

There was a year x treatment interaction along with a harvest period x treatment interaction therefore, results are reported by year and harvest period (Table 2.1). In summary for 2020 and 2021, HM averaged 977 kg DM ha⁻¹, with a minimum of 156 kg DM ha⁻¹, and a maximum of 3639 kg DM ha⁻¹ across all treatments (Table 2.2).

Average HM during the 2020 and 2021 growing seasons

Among the main plots containing sunn hemp as a treatment, TFC produced greater HM values compared to TF in 2020 and 2021 (Table 2.3). In 2021, main plots containing red clover produced greater HM values compared to all other treatments (Table 2.3). In 2021, plots

containing red clover showed an increase of approximately 21% (7920 kg ha⁻¹ vs. 6536 kg ha⁻¹ in 2020) for TFCR and approximately 32% (7121 kg ha⁻¹ vs. 5393 kg ha⁻¹ in 2020) for TFR in total HM (Table 2.3). This may be due to red clover being a short-lived perennial legume, usually, 2 yr in the south, having greater productivity during its second year following establishment (Wiersma et al., 1998; Ball et al., 2007). These results are also supported by past research that showed a greater amount of annual uptake of transferred N from red clover to tall fescue in the second year following red clover's establishment (Mallarino et al., 1990).

Interestingly, TFCS showed approximately 38% greater HM compared to TFS (5221 kg ha⁻¹ vs. 3766 kg ha⁻¹) in 2020; and approximately 32% greater HM (4661 kg ha⁻¹ vs. 3527 kg ha⁻¹) in 2021 (Table 2.3). Even though there were no differences among the remaining treatments (TFC vs. TF and TFCA vs. TFA), TFC showed approximately 6% greater HM compared to TF (4635 kg ha⁻¹ vs. 4378) in 2020; and approximately 29% greater HM (3990 kg ha⁻¹ vs. 3088) in 2021 (Table 2.3). Similarly, TFCA showed approximately 25% greater HM compared to TFA (5119 kg ha⁻¹ vs. 4090 kg ha⁻¹) in 2020; and approximately 15% greater HM (4614 kg ha⁻¹ vs. 3991 kg ha⁻¹) in 2021 (Table 2.3). Suggesting the incorporation of crabgrass to TF with or without sources of N served as a method to increase HM.

Herbage mass for each harvesting period during the 2020 and 2021 growing seasons

Among the main plots containing sunn hemp as a treatment, TFC produced greater HM values compared to TF for harvest period 3 in 2020 (Table 2.4). In 2021 there were differences among treatments for the first three harvest periods, which occurred in May, June, and August (Table 2.4). Among the TF and TFC plots, the plots containing red clover showed greater HM compared to the other treatments for harvest periods 1, 2, & 3 in 2021 (Table 2.4). The greater HM shown in plots containing red clover may be due to the climatic conditions of the

experimental site that were favorable for red clover's second year of production during the experimental period of 2021. Red clover production is expected to be optimal from April - October, if conditions are favorable (Ball et al., 2007). Our results agree with past research conducted in Tennessee that showed red clover when mixed with tall fescue generated greater HM, compared to tall fescue fertilized with ammonium nitrate and tall fescue fertilized with broiler litter (Corbin et al., 2019). This also supports past research conducted by Dobsen et al., 1976, that showed varieties of red clover mixed with tall fescue more than doubled tall fescue's HM when compared to a tall fescue monoculture over a 3-yr period.

however, interestingly, in harvest period 4 in 2020, TFCR produced 883 kg ha⁻¹ or 50% more average HM than TFR but resulted in no significant differences between main plots in HM, however in harvest period 4 in 2021, TFCR produced 437 kg ha⁻¹ or 36% more than TFR in 2021 and was significantly greater in HM (Table 2.4). This may be due to the addition of crabgrass and the production of red clover during its second year, which is generally greater in the second year of production (Mallarino et al., 1990; Wiersma et al., 1998). The available crabgrass in the TFCR plots may have taken advantage of the supplied N provided by the red clover. Also, considering harvest period 4, which was in September, occurred during the later part of the summer it possibly favored crabgrass growth since crabgrass seasonal production is from May to September in this region (Ball et al., 2007). This can be further supported by our results in harvest period 4 in 2021, which showed differences among main plots that contained no nitrogen treatment; TFC-0 showed greater HM values compared to TF-0 (Table 2.4).

Similarly, harvest period 4 in 2021 reflected TFCS 's greatest HM productivity. During this period, TFCS produced 468 kg ha⁻¹ or nearly 50% more HM compared to TFS (Table 2.4). This may also be explained by the addition of crabgrass that took advantage of the added N

provided by the sunn hemp, especially during the summer when both these warm-season species are highly productive (Ball et al., 2007). All plots containing crabgrass had greater HM than TF, suggesting that crabgrass incorporated into tall fescue and tall fescue mixed with a source of N served as an opportunity to increase HM during the warm season when tall fescue is not as productive.

Nutritive value

There was a year x treatment interaction along with a harvest period x treatment interaction, therefore results are reported by year and harvest period (Table 2.1). In summary for 2020 and 2021, the total CP values averaged 151 g kg⁻¹, with a minimum of 100 g kg⁻¹, and a maximum of 216 g kg⁻¹ across all treatments (Table 2.2). The total NDF values averaged 537 g kg⁻¹, with a minimum of 409 g kg⁻¹, and a maximum of 662 g kg⁻¹ (Table 2.2). The total IVTDMD48 values averaged 764 g kg⁻¹, with a minimum of 679 g kg⁻¹, and a maximum of 859 g kg⁻¹ across all treatments (Table 2.2). The total NDFD48 values averaged 587 g kg⁻¹, with a minimum of 395 g kg⁻¹, and a maximum of 764 g kg⁻¹ across all treatments (Table 2.2).

Average nutritive value during the 2020 and 2021 growing seasons

Among the main plots containing ammonium nitrate as a treatment, TFCA showed greater CP values compared to TFA in 2020 (Table 2.5). Also in 2020, there were differences among treatments for both main plots. Among the TF main plots, TFR showed greater CP values compared to TF-0 and TFS (Table 2.5). Among the TFC main plots, TFCR showed greater CP values compared to the other treatments (Table 2.5). In 2021, plots containing red clover were greater than the CP values for all other treatments for both main plots (Table 2.5).

Legumes typically have greater CP concentrations compared to grasses (Buxton, 1996; Ball et al., 2001). Even though sunn hemp is a legume, plots containing sunn hemp still produced lower CP concentrations compared to plots that contained red clover. This may be due to their differences in growing seasons, structure, and morphology. Red clover is a cool-season short-lived perennial, that grows much closer to the ground with a maximum height of 80 cm (Den Hollander et al., 2007). In contrast, sunn hemp, which is a warm-season annual, tends to have a more vertical growth pattern that requires more stem elongation and structure to support. Red clover plants can produce as many as 5-8 leaf blades per petiole which results in a greater leaf-to-stem ratio compared to sunn hemp (Collins et al., 2017). Therefore, when comparing these legumes during their mid to late vegetative stage of maturity, legumes, such as red clover, with a greater leaf-to-stem ratio typically produce greater CP concentrations than warm-season legumes such as sunn hemp (Collins et al., 2017). Our results are similar to Lepcha et al. (2019) who reported sunn hemp CP concentrations ranging from (96 – 178 g kg⁻¹ DM). In addition, both these results showed lower CP concentrations than the values reported by Mansoer et al. (1997) (ranging from 209-360 g kg⁻¹). The values derived from Mansoer et al. (1997) were taken from only the sunn hemp leaves, whereas our study was made up of material collected above-ground from the whole plant of sunn hemp mixed with tall fescue or sunn hemp mixed with tall fescue and crabgrass. Typically leaves of legumes have greater N concentrations than stems (Muller et al., 1988). Although plots containing sunn hemp showed overall lower CP concentrations compared to plots containing red clover, it was not significantly lower than TFA plots (Table 2.5). Additionally, the CP concentration found in TFS and TFCS plots were within the parameters of CP requirements to support most mature beef cattle (70 g kg⁻¹) to highly

productive dairy cattle (190 g kg^{-1}) (Buxton, 1996). These results suggest that sunn hemp can be considered an alternative source of N in tall fescue or tall fescue and crabgrass mixed plots.

In 2020 and 2021, NDF concentrations for TFCR and TFR plots were significantly lower than all other treatments (Table 2.5). This may be due to the addition of red clover, which is a cool-season short-lived legume (Ball et al., 2007). Generally, legumes produce overall lesser NDF concentrations than grasses due to the differences in the NDF content of leaves between grass and legume species (Buxton, 1996; Collins et al., 2017). However, in 2020 and 2021, plots containing sunn hemp, which is also a legume, showed greater NDF values compared to plots containing red clover, which is similar to a study that showed mixtures that included more erect legumes, such as sunn hemp had higher NDF values compared to low-growing legumes such as red clover (Kleen et al., 2011). Neutral detergent fiber analysis estimates the total cell wall constituents that include hemicellulose, and its values are normally used to estimate forage intake (Ball et al., 2001). As fiber increases, the quality of the forage decreases, and this can be related to maturity and leaf-to-stem ratio (Ball et al., 2001). Sunn hemp has an increased amount of stem elongation and growth that comes with maturity, therefore its NDF levels are expected to increase with maturity (Buxton, 1996).

There were no differences among treatments IVTDMD48 in 2020 and 2021 (Table 2.5). For NDFD48, in 2020 and 2021, plots containing red clover showed lower NDFD48 values compared to the other treatments (Table 2.5). This is most likely due to the similar explanations for red clover's lower NDF results. Also in 2021, TFCA showed greater NDFD48 values compared to TFA (Table 2.5), suggesting the incorporation of crabgrass utilizing ammonium nitrate, as an N source, most likely increased the leaf-to-stem ratio which lead to an increased NDFD48 value.

Nutritive value for each harvesting period during the 2020 and 2021 growing season

Among the plots containing ammonium nitrate as a treatment, TFA showed greater CP values compared to TFCA in harvest periods 1 and 2 in 2020 (Table 2.6). It is important to mention the plots containing crabgrass and sunn hemp were not established until after the second harvest period (June) of 2020 and 2021, which can better explain their lower CP values compared to other treatments for harvest periods 1 and 2 in 2020 and 2021 (Table 2.6). This is expected considering TF, TFC, TFCS, and TFS plots contained no source of added N. After all, CP can be affected by the amount of available N in the soil, and grasses fertilized with N often show increased levels of CP (Minson, 1990; Ball et al., 2001; Corbin et al., 2019). However, as the season progressed in 2020 and for the majority of harvest periods in 2021, plots containing red clover had greater CP values than all other treatments (Table 2.6). As previously mentioned, this may be due to the increased amount of red clover production which is expected in red clover's second year of growth (Wiersma et al., 1998). Legumes typically produce greater CP values compared to grasses which is in agreement with a study that showed mean concentrations of CP in legumes averaging 55 g kg⁻¹ DM higher than in temperate grasses (Minson, 1990). And in this study, plots containing red clover as an alternative N source produced greater CP values than grasses with and without synthetic N application in 2021 (Table 2.6).

The same trend in values was also observed for NDF, IVTDMD48, and NDFD48, with a higher NDF combined with lower IVTDMD48 for plots containing crabgrass and sunn hemp, due to their later establishment during the growing season (Table 2.6).

For NDF, among the TF main plots, TFR showed lower NDF values compared to TF-0 and TFS for the first harvest period in 2020. And in harvest period 2 in 2020, among the main

plots that contained ammonium nitrate as a treatment, TFCA showed greater NDF values compared to TFA (Table 2.6). As the season progressed and the warm-season species were actively present, differences among treatments occurred. In harvest period 3 in 2020 plots containing red clover showed lower NDF values compared to the other treatments, and plots containing sunn hemp showed lower NDF values compared to plots containing ammonium nitrate (Table 2.6). Among the TF main plots, TFR showed lower NDF values compared to TF-0 and TFA in harvest period 4 in 2020; and TFR showed lower NDF values compared to the other treatments in harvest period 5 in 2020 (Table 2.6). Among the TFC main plots, TFCR showed lower NDF values compared to all other treatments in harvest periods 4 and 5 in 2020.

In 2021, among the main plots containing sunn hemp as a treatment, TFC showed greater NDF values compared to TF in harvest periods 2 and 3 (Table 2.6). And among the main plots containing red clover as a treatment, TFC showed greater NDF values compared to TF in harvest period 3 in 2021. Also in 2021, among the TF main plots, TFR usually showed lower NDF values for all harvest periods (Table 2.6). Interestingly, in harvest period 5 in 2021, TFA showed greater NDF values compared to TFR and TFS (Table 2.6), suggesting that adding legumes to tall fescue swards lowered NDF at the end of the growing season. Harvest period 5 occurred in October 2021 and this was the last harvest period for this experiment. By this time red clover and tall fescue were most likely benefiting from the cooler fall temperatures and in response produced new immature leaves that resulted in lower NDF values. Also, at this time the 2021 BC analysis for harvest period 5 resulted in little to no S legume measured (Fig. 2.4), considering the warm season had come to an end by October and the primary forage content consisted of cool-season tall fescue.

In harvest period 5 in 2020, plots containing sunn hemp produced lower IVTDMD48 values compared to all other plots (Table 2.6). Actively growing sunn hemp was not present or measured during harvest period 5 (Fig. 2.3), because sunn hemp short growing season was coming to an end at this time as temperatures began to cool, and the crabgrass that was present in TFCS plots was also reaching the end of their growing season. Forage digestibility and intake are expected to decline as maturity increases and the leaf-to-stem ratio decreases, due to a potential increase in lignin content in the cell walls for stem and plant reproduction development (Buxton and Russell, 1988; Collins et al., 2017). Therefore, the maturity levels and decline in production of sunn hemp could explain the low IVTDMD48 values during harvest period 5 in 2020. Meanwhile, in 2021, there were differences among the main plots and treatments. Among the main plots containing sunn hemp as a treatment, TFC showed greater IVTDMD48 values compared to TF (Table 2.6). In harvest period 1 in 2021, among TF main plots, TFS showed lower IVTDMD48 values compared to TFR (Table 2.6). In harvest period 3 in 2021, among the TF main plots, TFR showed lower IVTDMD48 values compared to TFA, and among the TFC main plots, TFCR showed lower IVTDMD48 values compared to TFCS and TFCA (Table 2.6). At this time warm-season species were actively present which can explain the differences.

In 2020, among the TF main plots, TFA showed greater NDFD48 values compared to TF-0 and TFR in harvest period 1 (Table 2.6). In harvest period 5 in 2020, TFCA showed greater NDFD48 values compared to plots containing legumes (Table 2.6). And the plots containing red clover produced significantly lower NDFD48 values for harvest periods 3 and 4 in 2020, and harvest periods 1, 2, and 3 in 2021 for both main plots (Table 2.6). Considering red clover is a cool-season legume, it is expected for their NDFD48 values to decrease during harvest periods 3 and 4, which occurred in July and September 2020 when the warm-season conditions are

expected to negatively affect its fiber digestibility as it is increasing in HM and maturity and stem production. Wilson and Minson (1983), reported that the digestibility of cool-season forages can decrease by 3 – 7 g kg⁻¹ when temperatures increase by 1°C. This is supported by Collins et al. (2017), who that stated forage production is lower when growth occurs during warmer temperatures as opposed to cooler temperatures. Also, the fact that digestibility is expected to decline when forages advance in maturity (Collins et al., 2017), supports our results that show plots containing red clover produced lower NDFD48 values compared to the other treatments in harvest periods 1, 2, and 3 of 2021 (Table 2.6). Again, in 2021, red clover was advancing in maturity and increasing production in 2021 compared to 2020. This is due to the fiber content in legumes being generally less digestible as legumes mature, compared to grasses (Buxton, 1996). In harvest period 5 in 2020, and as the season progressed in 2021, sunn hemp productivity and maturity increased resulting in similar NDFD48 values to plots containing red clover for harvest period 4 (Table 2.6).

Conclusion

Tall fescue and tall fescue plus crabgrass mixed with red clover produced greater proportions of legume content in 2020 and 2021; HM in 2021; and CP in 2020 and 2021 values than all other treatments, favored by the climatic conditions of the experimental site and red clover's growth characteristics. Based on these findings, the incorporation of red clover into tall fescue swards can greatly increase forage productivity and sustainability. Tall fescue swards that were mixed with crabgrass showed greater HM during the warm season in 2021. Although crabgrass is considered an annual, it has the potential to reseed itself, which suggests the incorporation of crabgrass to tall fescue swards with the addition of an N source may serve as an

opportunity to increase HM during the warm season when tall fescue is not as productive. Sunn hemp performed best during the mid-summer and our CP results showed that plots containing sunn hemp produced CP values within the adequate requirements to support most mature beef cattle. Future grazing studies including tall fescue and crabgrass mixed with legumes, especially during the warm season, are warranted to evaluate animal performance and the economic viability of the system.

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Appendix

Tables

Table 2.1. *P* values for all analyzed variables of a tall fescue and tall fescue mixed sward during two consecutive growing seasons (2020 & 2021).

Botanical Composition					
Effect	Weed	Crabgrass	Tall fescue	Legume	
P - values					
Main Plot (MP)	0.94	.	<.0001	0.81	
Treatment (T)	0.01	0.00	<.0001	<.0001	
MP x T	0.01	.	0.09	0.24	
Harvest Period (HP)	0.17	<.0001	<.0001	<.0001	
HP x MP	0.19	.	<.0001	1.00	
HP x T	0.94	0.07	<.0001	0.00	
HP x MP x T	0.68	.	0.12	0.78	
Year (Y)	0.09	0.83	0.00	1	
Y x MP	0.25	.	0.90	0.76	
Y x T	0.24	0.01	0.16	0.01	
Y x MP x T	0.00	.	0.18	0.55	
Y x HP	0.54	<.0001	<.0001	0.03	
Y x HP x MP	0.31	.	0.00	0.59	
Y x HP x T	0.82	0.06	0.00	0.01	
Y x HP x MP x T	0.59	.	0.01	0.26	
Herbage Mass and Nutritional Values					
Effect	Yield	CP	NDF	IVTDMD48	NDFD48
P - values					
Main Plot (MP)	<.0001	0.74	0.52	0.04	0.15
Treatment (T)	<.0001	<.0001	<.0001	0.27	<.0001
MP x T	0.63	0.61	0.50	0.89	0.77
Harvest Period (HP)	<.0001	<.0001	<.0001	<.0001	<.0001
HP x MP	0.01	0.02	0.32	0.48	0.10
HP x T	<.0001	<.0001	<.0001	<.0001	<.0001
HP x MP x T	0.27	0.63	0.52	0.62	0.82
Year (Y)	0.97	<.0001	<.0001	0.0401	<.0001
Y x MP	0.87	0.13	0.12	0.21	0.72
Y x T	0.00	0.00	0.58	0.52	0.17
Y x MP x T	0.81	0.52	0.75	0.58	0.63
Y x HP	<.0001	<.0001	<.0001	<.0001	<.0001
Y x HP x MP	0.33	0.34	0.03	0.42	0.35
Y x HP x T	0.00	<.0001	<.0001	<.0001	<.0001
Y x HP x MP x T	0.92	0.65	0.39	0.71	0.47

Table 2.2. Summary statistics for all analyzed variables of tall fescue and tall fescue-legume mixed sward during two consecutive growing seasons (2020 & 2021).

Variable	†<i>n</i>	†MIN	†MAX	†Mean	SD
Herbage Mass, <i>kg DM</i>[§] <i>ha</i>⁻¹	320	156	3639	977	609
CP[§], <i>g kg</i>⁻¹	318	100	216	151	22
NDF[§], <i>g kg</i>⁻¹	318	409	662	537	53
IVTDMD48[§], <i>g kg</i>⁻¹	318	679	859	764	37
NDFD48[§], <i>g kg</i>⁻¹	318	395	764	587	68
Legume[§], <i>g kg</i>⁻¹	160	0	696	172	157
Tall Fescue[§], <i>g kg</i>⁻¹	320	304	1000	841	163
Crabgrass[§], <i>g kg</i>⁻¹	160	0	597	73	110
Weed[§], <i>g kg</i>⁻¹	320	0	256	50	50

†*n*, number of observations; †MIN, minimum observation; †MAX, maximum observation; †Mean, average observation. Each observation was the average of four replicates.

§ DM, dry mater; CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber; NDF48, neutral detergent fiber in 48hrs.; IVTDMD48, in-vitro true dry matter digestibility in 48 hrs.; NDFD48, neutral detergent fiber digestibility in 48 hrs.

Table 2.3. Total herbage mass of tall fescue and tall fescue mixed swards across 5 harvesting dates in 2020 and 2021.

Year	Main Plot	†0	†A	†R	†S	P
Total herbage mass $kg\ DM^{\S}\ ha^{-1}$						
2020	‡TF	4378 ^{a*,A‡}	4090 ^{a,A}	5393 ^{a,A}	3766 ^{b,A}	0.13
	‡TFC	4635 ^{a,A}	5119 ^{a,A}	6536 ^{a,A}	5221 ^{a,A}	0.06
	P	0.71	0.15	0.11	0.04	
2021	TF	3088 ^{a,B}	3991 ^{a,B}	7121 ^{a,A}	3527 ^{b,B}	<.0001
	TFC	3990 ^{a,B}	4614 ^{a,B}	7920 ^{a,A}	4796 ^{a,B}	<.0001
	P	0.11	0.26	0.15	0.03	

‡TF, Tall fescue; ‡TFC, Tall fescue + Crabgrass; †0, Control (no N source added); †A, Ammonium nitrate; †R, Red clover; †S, Sunn hemp. [§]DM, dry matter.

*Means within a column for each year without a common lowercase superscript letter differ in species effect ($P < 0.05$) using Fisher's LSD test. ‡Means within a row for each year without a common uppercase superscript letter differ in treatment effect ($P < 0.05$) using Fisher's LSD test.

Table 2.4. Average herbage mass of tall fescue and tall fescue mixed swards per harvesting period for 2020 and 2021.

Year	Harvest Period	Main Plot	†0	†A	†R	†S	P
Average herbage mass kg DM^s ha⁻¹							
2020	1	‡TF	509 ^{a*,A‡}	680 ^{a,A}	654 ^{a,A}	649 ^{a,A}	0.47
		‡TFC	452 ^{a,A}	519 ^{a,A}	611 ^{a,A}	555 ^{a,A}	0.60
		P	0.64	0.18	0.72	0.43	
	2	TF	496 ^{a,A}	520 ^{a,A}	716 ^{a,A}	439 ^{a,A}	0.24
		TFC	416 ^{a,A}	665 ^{a,A}	716 ^{a,A}	555 ^{a,A}	0.17
		P	0.57	0.31	1	0.41	
	3	TF	862 ^{a,A}	729 ^{a,A}	1416 ^{a,A}	430 ^{b,A}	0.12
		TFC	561 ^{a,A}	1065 ^{a,A}	1302 ^{a,A}	1308 ^{a,A}	0.22
		P	0.45	0.4	0.77	0.04	
	4	TF	1501 ^{a,A}	1438 ^{a,A}	1773 ^{a,A}	1668 ^{a,A}	0.75
		TFC	2178 ^{a,A}	1065 ^{a,A}	2656 ^{a,A}	1962 ^{a,A}	0.12
		P	0.15	0.37	0.07	0.51	
	5	TF	1011 ^{a,A}	723 ^{a,A}	833 ^{a,A}	581 ^{a,A}	0.34
		TFC	1027 ^{a,A}	1026 ^{a,A}	1250 ^{a,A}	842 ^{a,A}	0.41
		P	0.95	0.21	0.09	0.28	
2021	1	TF	455 ^{a,C}	785 ^{a,B}	1376 ^{a,A}	986 ^{a,B}	<.0001
		TFC	772 ^{a,B}	1072 ^{a,B}	1518 ^{a,A}	914 ^{a,B}	0.00
		P	0.06	0.08	0.38	0.65	
	2	TF	784 ^{a,B}	856 ^{a,B}	2301 ^{a,A}	811 ^{a,B}	<.0001
		TFC	888 ^{a,B}	956 ^{a,B}	2399 ^{a,A}	995 ^{a,B}	0.00
		P	0.74	0.75	0.76	0.56	
	3	TF	469 ^{a,B}	685 ^{a,B}	1758 ^{a,A}	435 ^{b,B}	<.0001
		TFC	576 ^{a,B}	694 ^{a,B}	1859 ^{a,A}	994 ^{a,B}	<.0001
		P	0.62	0.96	0.64	0.02	
	4	TF	971 ^{b,A}	1138 ^{a,A}	1191 ^{b,A}	933 ^{b,A}	0.21
		TFC	1306 ^{a,A}	694 ^{a,A}	1628 ^{a,A}	1401 ^{a,A}	0.13
		P	0.03	0.14	0.01	0.00	
	5	TF	410 ^{a,A}	527 ^{a,A}	494 ^{a,A}	362 ^{a,A}	0.12
		TFC	449 ^{a,A}	538 ^{a,A}	515 ^{a,A}	491 ^{a,A}	0.66
		P	0.6	0.88	0.77	0.09	

‡TF, Tall fescue, ‡TFC, Tall fescue + Crabgrass; †0, Control (no N source added); †A, Ammonium nitrate; †R, Red clover; †S, Sunn hemp. ^sDM, dry matter.

*Means within a column for each year without a common lowercase superscript letter differ in species effect (P < 0.05) using Fisher's LSD test. ‡Means within a row for each year without a common uppercase superscript letter differ in treatment effect (P < 0.05) using Fisher's LSD test.

Table 2.5. Average nutritive value [crude protein (CP), neutral detergent fiber (NDF), *in vitro* true dry matter digestibility 48h (IVTDMD48), and neutral detergent fiber digestibility 48h (NDFD48)] of tall fescue and tall fescue mixed swards across 5 harvesting periods during the growing seasons of 2020 and 2021.

Year	Main Plot	[†] 0	[†] A	[†] R	[†] S	P
CP g kg⁻¹						
2020	[‡] TF	139 ^{a*,B*}	148 ^{a,AB}	156 ^{a,A}	139 ^{a,B}	0.00
	[‡] TFC	133 ^{a,B}	138 ^{b,B}	153 ^{a,A}	136 ^{a,B}	0.00
	P	0.21	0.04	0.59	0.5	
2021	TF	486 ^{a,B}	469 ^{a,B}	559 ^{a,A}	472 ^{a,B}	0.00
	TFC	474 ^{a,B}	491 ^{a,B}	544 ^{a,A}	489 ^{a,B}	0.01
	P	0.56	0.27	0.46	0.41	
NDF g kg⁻¹						
2020	TF	565 ^{a,A}	549 ^{a,A}	504 ^{a,B}	556 ^{a,A}	<.0001
	TFC	558 ^{a,A}	558 ^{a,A}	508 ^{a,B}	563 ^{a,A}	0.00
	P	0.55	0.42	0.71	0.52	
2021	TF	554 ^{a,A}	541 ^{a,A}	496 ^{a,B}	545 ^{a,A}	<.0001
	TFC	542 ^{a,A}	544 ^{a,A}	488 ^{a,B}	525 ^{a,A}	<.0001
	P	0.28	0.77	0.45	0.08	
IVTDMD48 g kg⁻¹						
2020	TF	757 ^{a,A}	764 ^{a,A}	761 ^{a,A}	757 ^{a,A}	0.43
	TFC	764 ^{a,A}	763 ^{a,A}	765 ^{a,A}	755 ^{a,A}	0.30
	P	0.2	0.82	0.47	0.84	
2021	TF	763 ^{a,A}	766 ^{a,A}	767 ^{a,A}	763 ^{a,A}	0.86
	TFC	767 ^{a,A}	772 ^{a,A}	773 ^{a,A}	774 ^{a,A}	0.70
	P	0.46	0.3	0.34	0.07	
NDFD48 g kg⁻¹						
2020	TF	583 ^{a,A}	582 ^{a,A}	523 ^{a,B}	567 ^{a,A}	0.00
	TFC	589 ^{a,A}	588 ^{a,A}	532 ^{a,B}	572 ^{a,A}	0.00
	P	0.71	0.69	0.51	0.71	
2021	TF	624 ^{a,A}	618 ^{b,A}	551 ^{a,B}	621 ^{a,A}	<.0001
	TFC	631 ^{a,AB}	640 ^{a,A}	557 ^{a,C}	617 ^{a,B}	<.0001
	P	0.49	0.03	0.56	0.6396	

[‡]TF, Tall fescue, [‡]TFC, Tall fescue + Crabgrass; [†]0, Control (no N source added); [†]A, Ammonium nitrate; [†]R, Red clover; [†]S, Sunn hemp. [§]DM, dry matter.

*Means within a column for each year without a common lowercase superscript letter differ in species effect (P < 0.05) using Fisher's LSD test. *Means within a row for each year without a common uppercase superscript letter differ in treatment effect (P < 0.05) using Fisher's LSD test.

Table 2.6. Average nutritive value [crude protein (CP), neutral detergent fiber (NDF), *in vitro* total dry matter digestible 48h (IVTDMD48), and neutral detergent fiber digestible 48h (NDFD48)] of tall fescue and tall fescue mixed swards per harvesting period in 2020 and 2021.

Year	Harvest Period	Main Plot	†0	†A	†R	†S	P
CP g kg ⁻¹							
2020	1	‡TF	128 ^{a*,A*}	150 ^{a,A}	133 ^{a,A}	132 ^{a,A}	0.06
		‡TFC	129 ^{a,A}	133 ^{b,A}	139 ^{a,A}	136 ^{a,A}	0.56
		P	0.95	0.04	0.43	0.57	
	2	TF	141 ^{a,A}	166 ^{a,A}	148 ^{a,A}	135 ^{a,A}	0.05
		TFC	124 ^{a,A}	127 ^{b,A}	136 ^{a,A}	128 ^{a,A}	0.72
		P	0.16	0	0.33	0.55	
	3	TF	154 ^{a,B}	151 ^{a,B}	184 ^{a,A}	155 ^{a,B}	0.00
		TFC	147 ^{a,B}	152 ^{a,B}	174 ^{a,A}	151 ^{a,B}	0.00
		P	0.34	0.96	0.18	0.58	
	4	TF	136 ^{a,A}	137 ^{a,A}	158 ^{a,A}	144 ^{a,A}	0.10
		TFC	124 ^{a,A}	152 ^{a,A}	151 ^{a,A}	133 ^{a,A}	0.07
		P	0.21	0.95	0.44	0.25	
	5	TF	136 ^{a,B}	139 ^{a,B}	157 ^{a,A}	130 ^{a,B}	0.01
		TFC	140 ^{a,B}	142 ^{a,B}	168 ^{a,A}	132 ^{a,B}	0.00
		P	0.51	0.58	0.15	0.76	
2021	1	TF	124 ^{a,B}	146 ^{a,B}	180 ^{a,A}	125 ^{a,B}	0.00
		TFC	121 ^{a,B}	140 ^{a,B}	174 ^{a,A}	123 ^{a,B}	0.00
		P	0.78	0.6	0.67	0.93	
	2	TF	146 ^{a,B}	135 ^{a,B}	178 ^{a,A}	136 ^{a,B}	<.0001
		TFC	138 ^{a,B}	143 ^{a,B}	172 ^{a,A}	149 ^{a,B}	0.00
		P	0.23	0.24	0.33	0.06	
	3	TF	160 ^{a,B}	160 ^{a,B}	178 ^{a,A}	157 ^{a,B}	0.01
		TFC	164 ^{a,AB}	160 ^{a,B}	175 ^{a,A}	167 ^{a,AB}	0.11
		P	0.51	0.96	0.71	0.14	
	4	TF	158 ^{a,B}	150 ^{a,B}	174 ^{a,A}	148 ^{a,B}	0.00
		TFC	150 ^{a,B}	160 ^{a,B}	170 ^{a,A}	148 ^{a,B}	0.01
		P	0.2	0.43	0.53	0.9568	
	5	TF	184 ^{a,AB}	175 ^{a,B}	197 ^{a,A}	179 ^{a,B}	0.02
		TFC	180 ^{a,B}	186 ^{a,B}	203 ^{a,A}	186 ^{a,B}	0.02
		P	0.54	0.14	0.42	0.37	
NDF g kg ⁻¹							
2020	1	‡TF	550 ^{a,A}	538 ^{a,AB}	503 ^{a,B}	550 ^{a,A}	0.03
		‡TFC	537 ^{a,A}	515 ^{a,A}	513 ^{a,A}	537 ^{a,A}	0.32
		P	0.46	0.22	0.54	0.47	
	2	TF	572 ^{a,A}	515 ^{b,A}	536 ^{a,A}	561 ^{a,A}	0.05

Table 2.6. continued.

2021	3	TFC	568 ^{a,A}	575 ^{a,A}	535 ^{a,A}	575 ^{a,A}	0.19
		P	0.88	0.01	0.99	0.55	
		TF	589 ^{a,A}	579 ^{a,A}	489 ^{a,C}	538 ^{a,B}	<.0001
	4	TFC	570 ^{a,AB}	578 ^{a,A}	491 ^{a,C}	547 ^{a,B}	<.0001
		P	0.3	0.92	0.91	0.62	
		TF	623 ^{a,A}	613 ^{a,A}	550 ^{a,B}	589 ^{a,AB}	0.02
	5	TFC	630 ^{a,A}	578 ^{a,A}	549 ^{a,B}	612 ^{a,A}	0.00
		P	0.75	0.52	0.95	0.31	
		TF	491 ^{a,B}	495 ^{a,B}	442 ^{a,C}	543 ^{a,A}	<.0001
	1	TFC	485 ^{a,B}	494 ^{a,B}	452 ^{a,C}	547 ^{a,A}	<.0001
		P	0.7	0.95	0.51	0.81	
		TF	588 ^{a,A}	534 ^{a,B}	470 ^{a,C}	587 ^{a,A}	0.00
	2	TFC	572 ^{a,A}	564 ^{a,A}	497 ^{a,B}	588 ^{a,A}	0.01
		P	0.5	0.23	0.32	0.96	
		TF	588 ^{a,A}	591 ^{a,A}	537 ^{a,B}	594 ^{a,A}	0.00
	3	TFC	585 ^{a,A}	586 ^{a,A}	521 ^{a,B}	554 ^{b,A}	0.00
		P	0.87	0.76	0.31	0.02	
		TF	553 ^{a,A}	532 ^{a,A}	504 ^{a,A}	530 ^{a,A}	0.07
4	TFC	537 ^{a,A}	532 ^{a,A}	482 ^{a,B}	470 ^{b,B}	0.00	
	P	0.37	0.99	0.2	0		
	TF	571 ^{a,A}	565 ^{a,A}	519 ^{a,B}	560 ^{a,A}	0.00	
5	TFC	557 ^{a,A}	532 ^{a,A}	514 ^{a,B}	558 ^{a,A}	0.00	
	P	0.19	0.73	0.66	0.8709		
	TF	468 ^{a,AB}	481 ^{a,A}	439 ^{a,C}	453 ^{a,BC}	0.02	
2020	1	TFC	458 ^{a,A}	476 ^{a,A}	424 ^{a,B}	456 ^{a,A}	0.01
		P	0.45	0.71	0.29	0.83	
		IVTDMD48 g kg ⁻¹					
	2	‡TF	791 ^{a,A}	802 ^{a,A}	807 ^{a,A}	793 ^{a,A}	0.15
		‡TFC	800 ^{a,A}	807 ^{a,A}	804 ^{a,A}	799 ^{a,A}	0.67
		P	0.24	0.54	0.75	0.44	
	3	TF	755 ^{a,A}	759 ^{a,A}	751 ^{a,A}	746 ^{a,A}	0.4
		TFC	758 ^{a,A}	753 ^{a,A}	757 ^{a,A}	753 ^{a,A}	0.86
		P	0.69	0.47	0.43	0.39	
	4	TF	735 ^{a,A}	749 ^{a,A}	734 ^{a,A}	759 ^{a,A}	0.11
		TFC	749 ^{a,A}	743 ^{a,A}	742 ^{a,A}	753 ^{a,A}	0.76
		P	0.24	0.64	0.51	0.62	
	5	TF	712 ^{a,A}	722 ^{a,A}	715 ^{a,A}	734 ^{a,A}	0.53
		TFC	701 ^{a,A}	743 ^{a,A}	720 ^{a,A}	714 ^{a,A}	0.71

Table 2.6. continued.

		<i>P</i>	0.52	0.44	0.75	0.23	
	5	TF	792 ^{a,A}	799 ^{a,A}	800 ^{a,A}	752 ^{a,B}	0.01
		TFC	812 ^{a,A}	803 ^{a,A}	803 ^{a,A}	759 ^{a,B}	0.01
		<i>P</i>	0.18	0.8	0.81	0.63	
2021	1	TF	740 ^{a,BC}	756 ^{a,AB}	760 ^{a,A}	737 ^{a,C}	0.04
		TFC	747 ^{a,A}	758 ^{a,A}	754 ^{a,A}	738 ^{a,A}	0.12
		<i>P</i>	0.35	0.82	0.57	0.88	
	2	TF	728 ^{a,A}	726 ^{a,A}	736 ^{a,A}	723 ^{b,A}	0.58
		TFC	731 ^{a,A}	733 ^{a,A}	746 ^{a,A}	747 ^{a,A}	0.20
		<i>P</i>	0.77	0.45	0.27	0.01	
	3	TF	758 ^{a,BC}	778 ^{a,A}	744 ^{a,C}	762 ^{b,AB}	0.00
		TFC	761 ^{a,BC}	776 ^{a,B}	747 ^{a,C}	798 ^{a,A}	<.0001
		<i>P</i>	0.7	0.8	0.67	<.0001	
	4	TF	755 ^{a,A}	750 ^{a,A}	761 ^{a,A}	750 ^{a,A}	0.61
		TFC	756 ^{a,A}	776 ^{a,A}	769 ^{a,A}	752 ^{a,A}	0.28
		<i>P</i>	0.86	0.14	0.4	0.7975	
	5	TF	833 ^{a,A}	818 ^{a,A}	832 ^{a,A}	841 ^{a,A}	0.28
		TFC	840 ^{a,A}	829 ^{a,A}	847 ^{a,A}	834 ^{a,A}	0.46
		<i>P</i>	0.5	0.34	0.22	0.57	
NDFD48 g kg ⁻¹							
2020	1	‡TF	619 ^{a,B}	650 ^{a,A}	606 ^{a,B}	626 ^{a,AB}	0.04
		‡TFC	636 ^{a,A}	622 ^{a,A}	622 ^{a,A}	632 ^{a,A}	0.60
		<i>P</i>	0.19	0.06	0.21	0.64	
	2	TF	588 ^{a,A}	533 ^{a,A}	535 ^{a,A}	545 ^{a,A}	0.21
		TFC	577 ^{a,A}	579 ^{a,A}	539 ^{a,A}	581 ^{a,A}	0.40
		<i>P</i>	0.72	0.12	0.89	0.2	
	3	TF	565 ^{a,A}	583 ^{a,A}	437 ^{a,B}	562 ^{a,A}	<.0001
		TFC	574 ^{a,A}	578 ^{a,A}	452 ^{a,B}	554 ^{a,A}	<.0001
		<i>P</i>	0.71	0.82	0.53	0.76	
	4	TF	529 ^{a,A}	535 ^{a,A}	461 ^{a,B}	542 ^{a,A}	0.00
		TFC	519 ^{a,A}	578 ^{a,A}	463 ^{a,B}	524 ^{a,A}	0.01
		<i>P</i>	0.6	0.69	0.93	0.37	
	5	TF	616 ^{a,AB}	626 ^{a,A}	576 ^{a,BC}	560 ^{a,C}	0.02
		TFC	637 ^{a,A}	633 ^{a,A}	585 ^{a,B}	568 ^{a,B}	0.01
		<i>P</i>	0.35	0.74	0.67	0.72	
2021	1	TF	570 ^{a,A}	546 ^{a,A}	466 ^{a,B}	571 ^{a,A}	0.00
		TFC	577 ^{a,A}	584 ^{a,A}	497 ^{a,B}	574 ^{a,A}	0.00

Table 2.6. continued.

2	TF	588 ^{a,A}	583 ^{a,A}	502 ^{a,B}	587 ^{a,A}	<.0001
	TFC	594 ^{a,A}	599 ^{a,A}	521 ^{a,B}	582 ^{a,A}	<.0001
	<i>P</i>	0.71	0.31	0.2	0.71	
3	TF	617 ^{a,B}	646 ^{a,A}	488 ^{a,C}	608 ^{a,B}	<.0001
	TFC	624 ^{a,A}	639 ^{a,A}	462 ^{a,C}	596 ^{a,B}	<.0001
	<i>P</i>	0.61	0.65	0.08	0.42	
4	TF	638 ^{a,A}	627 ^{a,A}	593 ^{a,B}	620 ^{a,A}	0.01
	TFC	634 ^{a,AB}	639 ^{a,A}	605 ^{a,C}	615 ^{a,BC}	0.01
	<i>P</i>	0.74	0.16	0.35	0.6862	
5	TF	707 ^{a,A}	687 ^{b,A}	675 ^{a,A}	722 ^{a,A}	0.06
	TFC	725 ^{a,A}	732 ^{a,A}	698 ^{a,A}	718 ^{a,A}	0.25
	<i>P</i>	0.29	0.02	0.21	0.82	

‡TF, Tall fescue; ‡TFC, Tall fescue + Crabgrass; †0, Control (no N source added); †A, Ammonium nitrate; †R, Red clover; †S, Sunn hemp. §DM, dry matter.

*Means within a column for each year without a common lowercase superscript letter differ in species effect ($P < 0.05$) using Fisher's LSD test. *Means within a row for each year without a common uppercase superscript letter differ in treatment effect ($P < 0.05$) using Fisher's LSD test.

Figures

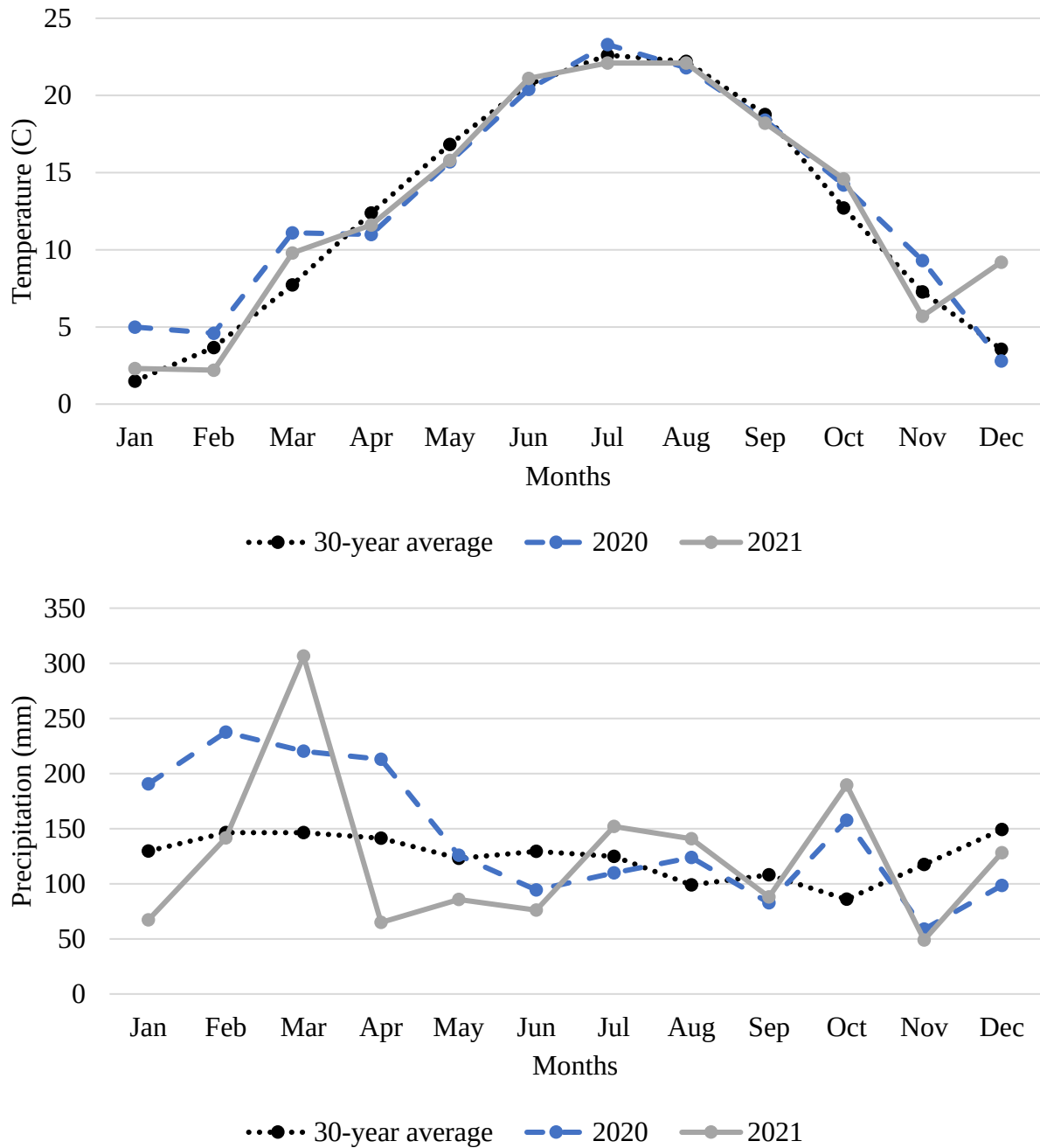


Figure 2.1. Weather for Crossville, TN, including 30-yr average for the growing season of 2020 & 2021.

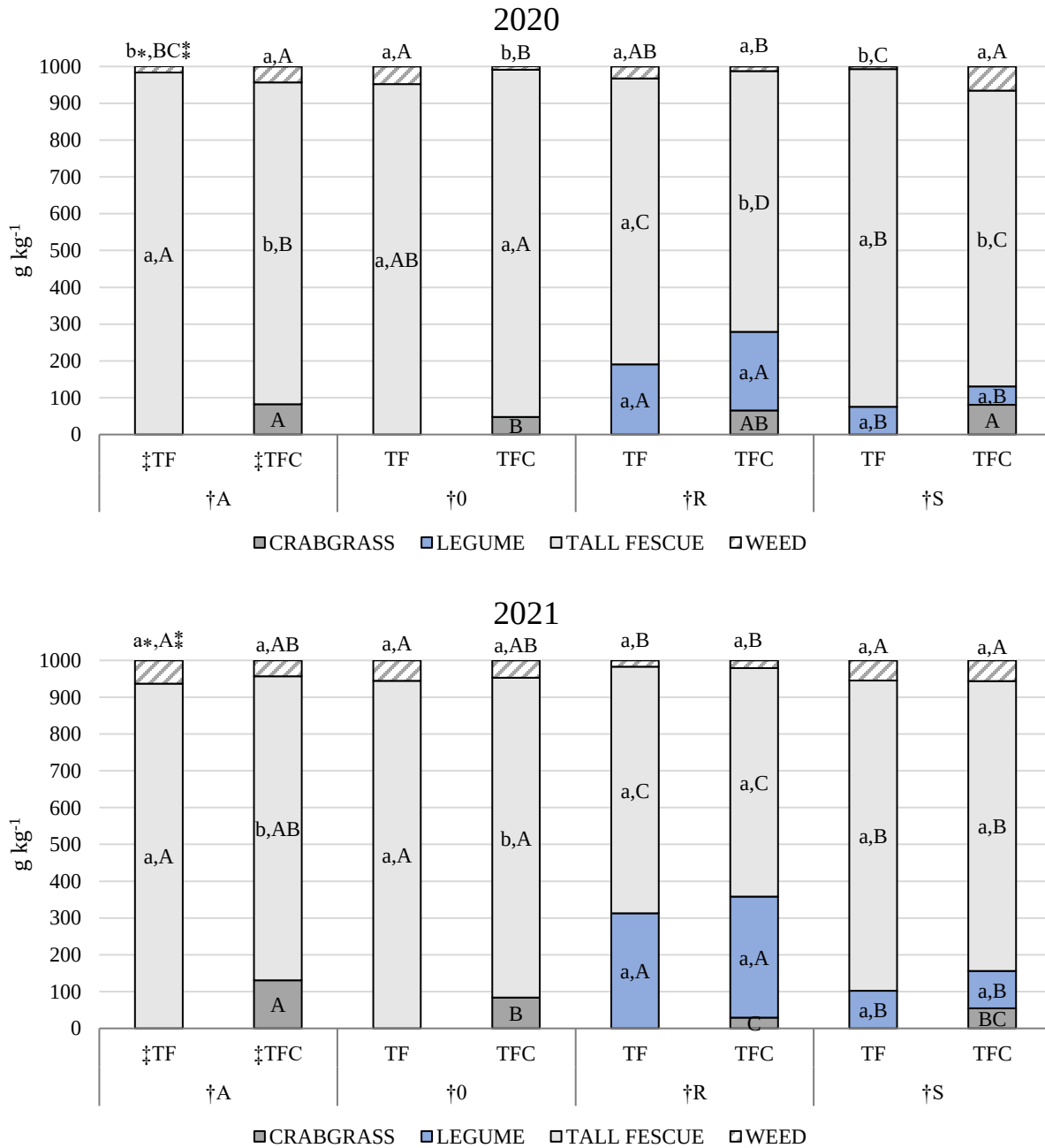


Figure 2.2. Botanical composition of tall fescue and tall fescue mixed swards in Crossville, TN, during two consecutive growing seasons in 2020 & 2021. *Means for each year without a common lowercase superscript letter differ in species effect ($P < 0.05$) using Fisher's LSD test. *Means for each year without a common uppercase superscript letter differ in treatment effect ($P < 0.05$) using Fisher's LSD test. ‡TF, Tall fescue; ‡TFC, Tall fescue + Crabgrass; †0, Control (no N source added); †A, Ammonium nitrate; †R, Red clover; †S, Sunn hemp.

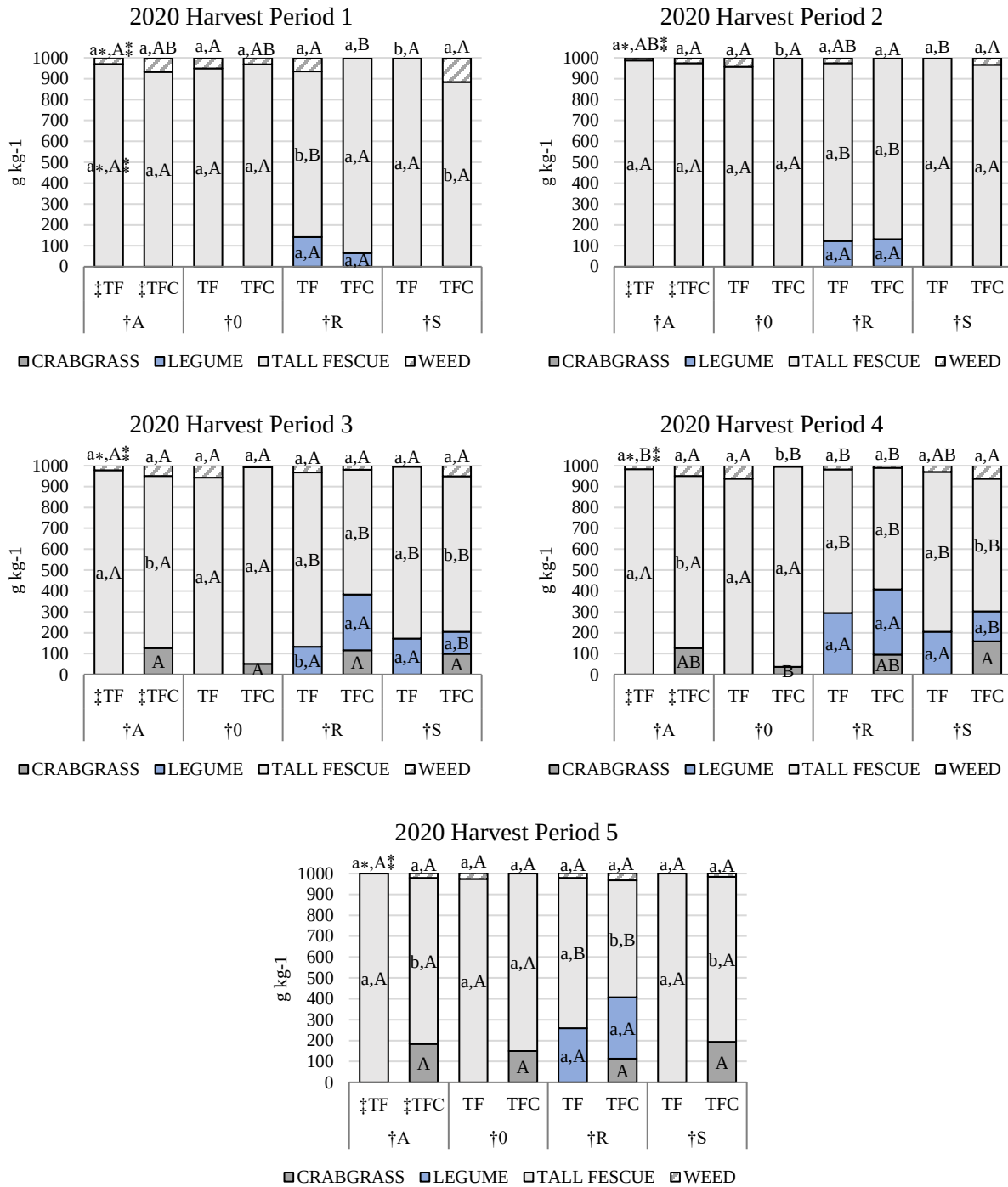


Figure 2.3. Botanical composition of tall fescue and tall fescue mixed swards in Crossville, TN, per harvesting period during the growing season in 2020. *Means for harvest period without a common lowercase superscript letter differ in species effect ($P < 0.05$) using Fisher's LSD test. *Means for each harvest period without a common uppercase superscript letter differ in treatment effect ($P < 0.05$) using Fisher's LSD test. †TF, Tall fescue; †TFC, Tall fescue + Crabgrass; †0, Control (no N source added); †A, Ammonium nitrate; †R, Red clover; †S, Sunn hemp.

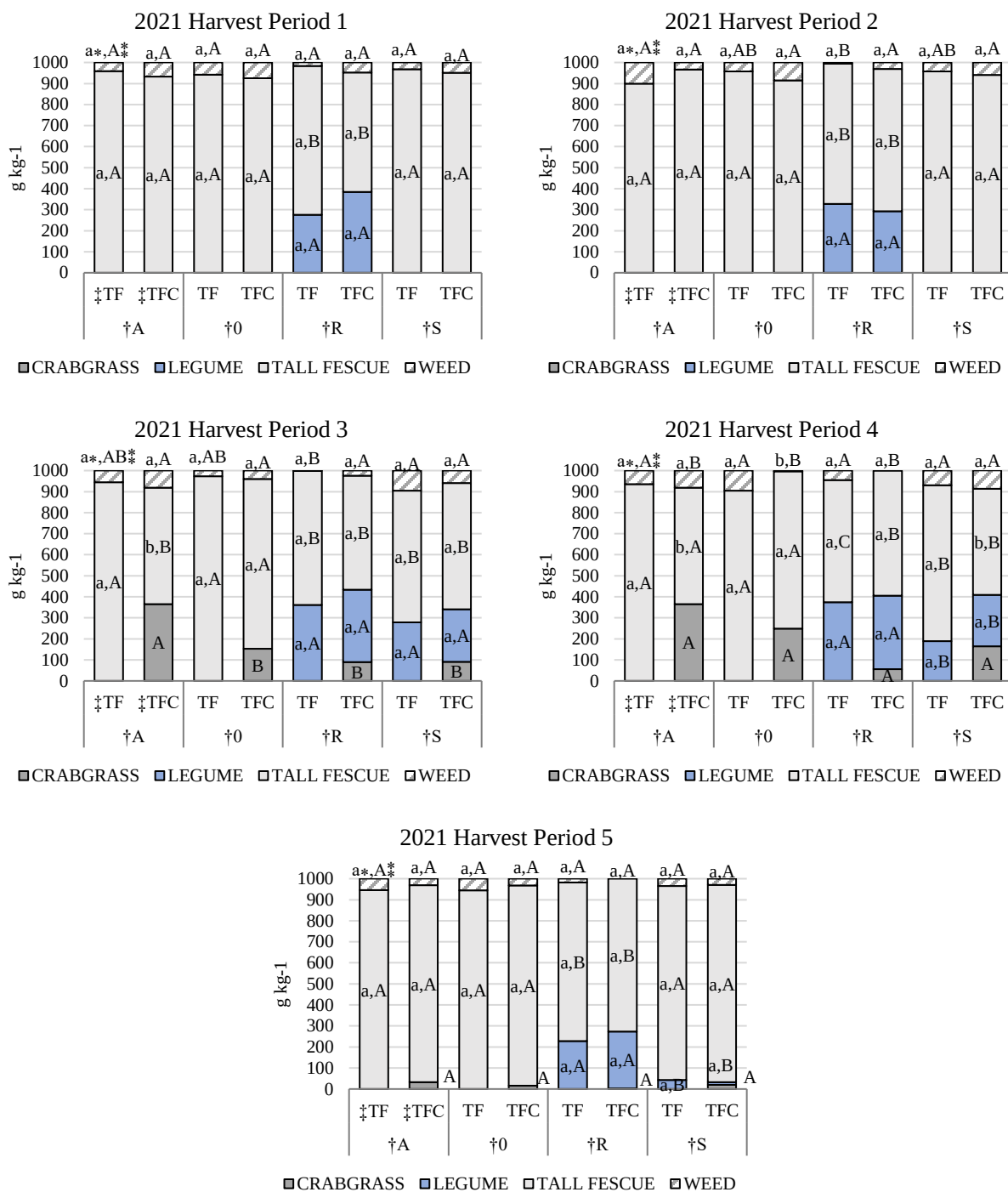


Figure 2.4. Botanical composition of tall fescue and tall fescue mixed swards in Crossville, TN, per harvesting period during the growing season in 2021. *Means for harvest period without a common lowercase superscript letter differ in species effect ($P < 0.05$) using Fisher's LSD test. *Means for each harvest period without a common uppercase superscript letter differ in treatment effect ($P < 0.05$) using Fisher's LSD test. ‡TF, Tall fescue; ‡TFC, Tall fescue + Crabgrass; †0, Control (no N source added); †A, Ammonium nitrate; †R, Red clover; †S, Sunn hemp.

CONCLUSIONS & FUTURE DIRECTIONS

The study of intercropping cool and warm season biologically N fixing legumes to tall fescue forage systems is a method of using alternative N sources that can aid in the productivity of stockpiling tall fescue. Even though the CP values for TU were greater than the other treatments in 2021 and the HM values for TU were greater than TRC and TSH at the beginning of the grazing period of 2021, the ADG and NR values showed no difference among treatments in 2020 and 2021.

The study of intercropping cool and warm season biologically N fixing legumes to tall fescue and tall fescue intercropped with warm-season crabgrass are methods that have the potential to aid in tall fescue productivity. The results showed that the incorporation of red clover produced greater, legume content, HM, and CP values than all other treatments. And the inclusion of crabgrass with an N source serves as an opportunity to increase HM and nutritional value, especially during the warm season.

Therefore, based on our results the utilization of different incorporated species such as red clover with tall fescue and sunn hemp with tall fescue along with the option of incorporating crabgrass with tall fescue mixed swards provides the opportunity for producers to choose alternative methods for aiding in tall fescue production systems.

Future studies should focus on extending the grazing period and increasing the grazing pressure on stockpiled tall fescue systems. Along with adding grazing pressure before the stockpiling period to evaluate the cattle and forage performance when sunn hemp is the intended warm-season legume to be intercropped with tall fescue. Also, different seeding rates and planting dates of intercropping crabgrass with tall fescue should be further evaluated.

VITA

M. Dereck Corbin was born in Crossville, TN. From 2008 to 2011, he attended Tennessee Technological University and graduated with a Bachelor of Science degree in Agriculture. In, 2017 he completed his Master's degree in crop sciences from The University of Tennessee with the mentoring of Dr. Renata Oakes. In 2018, he started his doctoral program at The University of Tennessee under Dr. Renata Oakes. Upon getting his degrees, Dereck has co-authored 6 peer-reviewed manuscripts and achieved primary author on one peer-reviewed manuscript, and was a member of the Gamma Sigma Delta from 2019 to 2022.