MANAGEMENT STRATEGIES OF ALFALFA-BERMUDAGRASS MIXTURES IN THE SOUTHEASTERN US

by

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(Under the Direction of Jennifer J. Tucker)

ABSTRACT

Improvements to the nutritional and harvest management of Southern pasture systems may benefit beef cattle producers in the Southeastern US. Potentially, this can be achieved by interseeding alfalfa (*Medicago sativa*) into bermudagrass (*Cynodon* spp.) which can improve the nutritive value of the forage base, improve overall animal performance, and extend the grazing season. The objectives of this research were to: 1) evaluate the concurrent production of alfalfa-bermudagrass (BGA) mixtures with bermudagrass monoculture pastures supplemented with (BGN) or without (BG) synthetic nitrogen, and determine the economic input these systems have on forage and animal productivity when grazed by stocker cattle, 2) to compare 'Bulldog 805' alfalfa interseeded into 'Russell' or 'Tifton 85' bermudagrass bases and the effect on forage and animal productivity when managed under three varied harvest management strategies of Cut only (CT), graze only (GR), or Cut and Graze (CG), and to determine the optimal harvest management strategy for alfalfa-bermudagrass mixtures in the Southeastern US; and 3) compare the predictive accuracy of three nondestructive sampling procedures in predicting herbage mass in alfalfa-bermudagrass mixed pastures when harvested to two stubble heights. BGA treatments resulted in a higher nutritive value for crude protein and total digestible nutrients, while also observing a greater average daily gain (ADG) and liveweight gain ha (LWG) for grazing stocker cattle compared to BG and BGN treatments. When alfalfa was interseeding into either Russell or Tifton 85 bermudagrass, it was observed that bermudagrass did not impact animal or forage responses. However, the harvest method strategy did influence the measured animal and forage responses, in that the CG treatment optimized the utilization of alfalfa-bermudagrass mixtures. Additionally, of the three nondestructive estimation techniques evaluated, rising plate meter, pasture ruler, or digital imaging analysis, none were able to reliably predict herbage mass in alfalfa-bermudagrass mixtures. As a result of these evaluations, the strategic management of alfalfa-bermudagrass mixtures is an essential practice for producers utilizing this mixture in their pasture systems.

INDEX WORDS: Alfalfa, Bermudagrass, alfalfa-bermudagrass mixtures, harvest management, nondestructive forage estimation

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DEDICATION

This work is dedicated in memory of Mimi and Pa and in honor of Mama, Daddy, Caroline, and Orry, for always believing in me and helping me to achieve my goals.

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CHAPTER 1

INTRODUCTION

Livestock production in the Southern United States is unique as it has many challenges and opportunities that are exclusive to the region. The temperate environment is conducive for excellent forage production, with long growing seasons; however, other deleterious factors such as, humidity, pest, and disease pressure can limit the forage species that can thrive in the region. With rising costs associated with livestock production, many producers are seeking alternative ways to increase productivity while also reducing the input costs, specifically those associated with feeding their livestock. While these input costs are present with most livestock production nationwide, the Southern United States has an advantage, in that forages grow and can be utilized nearly year round with little to no other feed supplementation being required when the forage is managed appropriately. Livestock producers in the Coastal Plains region utilize perennial warm-season forages in combination with supplemental feedstuff to meet their livestock production needs. Pastures in this region are dominated by warm-season perennial grasses, with bermudagrass (*Cynodon dactylon*) being one of the most common. While common throughout the region bermudagrass has high N fertility requirements for optimum performance and a nutritive value that is moderate at best, often requiring other forms of supplementation to meet the individual animal production needs (Johnson et al, 2001; Ball et al., 2015; BCNRM, 2016).

Additionally, the increased cost of N fertilizer sources has resulted in producers seeking alternatives for traditional N fertilizer sources or electing not to apply N fertilizer to their bermudagrass pastures at all (Doxon et al., 2011; Biermacher et al., 2012; USDA, 2019; Quinn, 2022). A potential way to decrease the reliance on synthetic N fertilizer sources is with the incorporation of a legume into the forage base. Many of the forage legumes available for use in the Southeast are cool-season annual species, making them suitable for incorporation with winter annual grasses. While there are few warm-season legume options to use in a bermudagrass system, specifically ones that are warm-season perennial legumes, the incorporation of a cool-season perennial legume, such as alfalfa (*Meticago sativa*) is a potential option.

Alfalfa is grown on approximately 9.6 million hectares in the United States for the production of stored forage (NASS, 2020). Alfalfa is also the fourth most valuable crop in the US, behind corn, soybeans, and wheat, with an estimated value of $10 billion annually (NASS, 2020). In the United States, alfalfa production is predominantly in Northern and Western states, as the cooler and dryer climates improve conditions for stored forage production (Lacefield et al., 2009; Melton et al., 1988). Although alfalfa was once the dominant perennial forage legume species in the Southeast, the poor soil fertility, low soil pH, high temperatures, and elevated insect pressure, eliminated many of the productive alfalfa stands by the 1950's (Haby and Leonard, 2005; Terrill et al., 1996; Lacefield et al., 2009). In recent years the development of alfalfa cultivars that are adapted to the environmental conditions of the South have provided an opportunity for alfalfa production to increase again in the southern United States (Bouton et al.,2007; Bouton and Gates, 2003; Brown et al., 1990; Haby and Leonard, 2005; Thinguldstad et al., 2020). Other alfalfa varieties, such as glyphosate-resistant cultivars, like 'Alfagraze 600 RR', have been bred to aid in weed control options (Bouton et al., 2006). Southern breeding efforts in alfalfa have also resulted in semi- to non-dormant varieties in addition to the development of grazing tolerant dual-use alfalfa varieties, meaning that they can be utilized for stored forage or grazing production.

Typically, throughout the US alfalfa is grown in a monoculture. However, in the Southern US, alfalfa is an excellent complementary forage for bermudagrass. The incorporation of alfalfa into a bermudagrass-based system has been shown to improve the overall nutritive value of the forage base while also reducing the need for additional N fertilization (Brown and Byrd, 1990; Haby et al., 1999; Cassida et al., 2006; Beck et al., 2017a,b,c; Beck et al., 2017d; Stringer et al., 1994, 1996; Hendricks et al., 2020, Groce, 2020; Mason, 2020; Rushing et al., 2022). While alfalfa-bermudagrass mixtures (ABG), have been evaluated in baleage systems (Hendricks et al., 2020) and in other rotational grazing beef cattle systems in Arkansas and Mississippi (Beck et al, 2017a,b,c; Beck et al., 2017d; Rushing et al., 2022), they have not been fully evaluated in Georgia as a grazable forage option for stocker cattle.

Previous work with ABG mixtures have also been evaluated for the performance of alfalfa interseeded into various hybrid bermudagrass varieties (Haby et al., 1999; Biermacher et al., 2012; Stringer et al., 1994, 1996; Cassida et al., 2006; Groce, 2020. Mason, 2020, Hendricks et al., 2020; Rushing et al., 2022), however, these evaluations utilized only one bermudagrass variety at a time. No data currently exists on ABG mixtures within multiple bermudagrass varieties simultaneously.

Research associated with the grazing of ABG mixtures have grazed this mixture no further than September (Cassida et al., 2006; Beck et al., 2017d, Rushing et al., 2022). However, Hendricks et al., (2020) produced baleage in October and November, suggesting that ABG mixtures are productive into the fall of the year. While Cassida et al., (2006) reports that grazing ABG mixtures can extend the grazing season; data is limited on how long the grazing season can be extended under various grazing management strategies of ABG mixtures. Grazing can be extended by using different forage management practices, including grazing stockpiled forage (Matches and Burns, 1985). Stockpiling forage for grazing is a common practice in many forage grass species and has been successful with stockpiled bermudagrass for grazing, (Lalman et al., 2000; Scarbrough et al., 2001, 2006; Bievens et al., 2017; Holland et al., 2018). While these stockpiled forages have an increased herbage mass and a lower nutritive value (Riesterer et al., 2000), they have been observed to maintain cattle production with little to no supplementation being required (Bivens et al., 2017; Holland et al., 2018). Legumes are more fragile than cool- and warm-season grasses and lose a large portion of their leaves after the first killing frost, thus limited data exists on legumes and legume-grass mixtures being stockpiled for grazing (Rohweder and Albrecht, 1995; Hitz and Russell, 1998). No data currently exist specifically to the utilization of ABG mixtures as a stockpiled forage grazing option for stocker cattle.

The combination of stored forage production and grazing production together in the same pastures have focused on grass based monoculture systems (D'Souza et al., 1990). Previous ABG work has focused on the singular use of this mixture in baleage production systems (Hendricks et al., 2020) or for rotationally grazing beef cattle (Beck et al., 2017a,b,c; Beck et al., 2017d; Rushing et al., 2022). However, no data exists on the ability to utilize stored forage production and grazing management strategies in conjunction with one another on the same pastures as a harvest management strategy for ABG mixtures.

The ability to accurately estimate forage accumulation, in real time, is an essential tool for livestock producers making stocking density decisions. This estimation of forage accumulation is an invaluable part of any harvest management strategy of forages in the Southeast. Various forage estimation tools currently exist, ranging from using a pasture ruler to utilizing a rising plate meter (RPM) or digital technologies (Michalk and Herbert, 1977; Fricke and Wachendorf, 2023; Ferro et al., 2012; Baxter et al., 2017). Primarily, these forage estimation tools are utilized in monoculture or cool season polyculture pastures, but data are limited on the extent of their application and accuracy in ABG mixtures.

Therefore, the objectives of this research are to:

1) evaluate the concurrent production of ABG mixtures with bermudagrass monoculture pastures supplemented with or without synthetic nitrogen, and the economic input these systems have on forage and animal productivity when utilized by stocker cattle in a Southern bermudagrass grazing system
2) evaluate alfalfa interseeded into two different bermudagrass bases when grazed by stocker cattle or harvested for baleage and the impact on forage productivity, animal performance, and total system performance under three varied harvest management strategies, to aid in determining the best management practices for ABG mixtures in the Southeast
3) compare the predictive accuracy of three nondestructive sampling techniques in predicting herbage accumulation in ABG mixed pastures

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CHAPTER 2

LITERATURE REVIEW

Introduction to Forage-Based Livestock Systems in the Southeast

Beef Cattle Production in the Southeast

Many of the cattle operations in the Southeast are comprised of cow/calf operations, where a herd of cows are kept, producing offspring that can be sold at weaning or retained in the herd. In Georgia alone beef cows comprise 33.6% of the state's livestock production (Kane, 2021). A common production method in the cow/calf operation is for the calves to be born in the spring and weaned and sold in the fall or vice versa. These beef producers greatly benefit from the ability to have year-round grazing, as compared to other regions of the United States, if managed correctly. The most common market for the weaned calves is the Midwestern United States where they are fed until they reach the desired body weight and frame size of the subsequent feedlot (Simms, 2013).

In addition to cow/calf operations, there is an opportunity for producers in this region for "stocker" cattle (Hoveland, 1986). Stocker cattle production, or backgrounding cattle, typically consist of taking calves at weaning, around 227 kg., and adding 90 to 181 kgs. of weight over a 3 to 8-month time frame before being placed in the feedlot for finishing (Peel, 2003). The goal of this production method is to increase the cattle weights instead of the fattening the animal as would be done in a feedlot. This can be done by economically utilizing standing (fresh) or stored forage sources instead of an expensive concentrate feed (Peel, 2003; Gaylean et al., 2011).

Typically, stocker cattle are grown on winter forages, such as wheat (*Triticum aestivum*), which is commonly grown in Kansas, Oklahoma, and in the Texas Panhandle region (Simms, 2013). However, the climatic conditions of the Southeastern United States allow for essentially year-round growing of various grazeable forage species, thus providing producers a more economical feed source for livestock production in the region. As with many livestock species, forages have a major contribution to the total diet dry matter (DM) in ruminant production systems, and their nutritive value is more variable than that of concentrate feeds (Allen and Mertens, 1987; Krizsan et al., 2012a). This is in part to the ruminant's unique ability to convert the fiber fractions of a forage into energy for production, making them an economical feed source for ruminant species (Krizsan and Huhtanen, 2013; Ball et al, 2015).

The majority of cattle nutrient requirements can be met with little to no supplementation with the utilization of forages alone, but only if the forage species is utilized and managed appropriately. While the nutrient requirements of mature cows range from 70 to 120 g kg^{-1} crude protein (CP) and 500 to 600 g kg^{-1} total digestible nutrients (TDN), stocker cattle often have a greater nutritional requirement (Ball et al., 2015; BCNRM, 2016). Typically, weaned calves enter the stocker phase at approximately 200 kg and enter the next phase at around 362 kg. Nutrient requirements for stocker cattle range from 100 to 120 g kg^{-1} CP and 650 to 680 g kg^{-1} TDN for a growing beef steer or heifer depending on stage of growth (Ball et al., 2015; BCNRM, 2016).

Forages of the Southeast

Forages are defined by their functional groups which include combinations of warm-season or cool-season forages that are annual or perennial and may be grasses, legumes, or forbs. Warm-season perennial grasses, such as bermudagrass (*Cynodon dactylon* L. Pers.) and bahiagrass (*Paspalum notatum* Flüggé), are the primary forages found in many cow/calf systems in the Deep South. These two forages grow on an estimated 24 million hectares across the region, and account for almost 75 percent of pasturelands in the Southern US (Ball et al., 2015). These perennial forages have moderate forage quality, are moderate to high-yielding, moderate nutritive value, and are relatively inexpensive to maintain. They require nitrogen fertilization to maintain adequate forage production but often cannot meet the nutrient requirements (CP, TDN) of lactating cows or stocker animals, even under ideal management. Another issue is that these forages only grow during the warmer (summer) months, forcing producers to supplement with stored forages and higher energy or protein supplements during the winter months. The inclusion of a cool-season perennial legume, such as alfalfa into bermudagrass, has the potential to improve the overall total forage accumulation and extend the grazing season, thus reducing the reliance on sources of supplementation, while also reducing the need for additional N fertilization.

Bermudagrass

Bermudagrass, is native to Southeastern Africa and is thought to have been introduced in the southern U.S. during the 1600's (Ball et al., 2015) and to Georgia in 1751 (Hancock et al., 2013). Bermudagrass is grown on a range of approximately 6-8.1 million hectares in the in the Southern United States (Hancock et al., 2017; Redfearn and Nelson, 2003) and has become one of the most common warm-season perennial forages grown for pasture or hay in the region (Taliaferro et al., 2004). This forage has a prostrate growth habit, extensive root system, and ability to spread via rhizomes and/or stolons depending on the variety (Barnes et al., 2003). Bermudagrass forage accumulation and nutritive value is highly dependent on temperature, light, and availability of moisture (Jolliff et al., 1979; Henderson and Robinson, 1982). Dependent on the region of the South, in relation to latitude, bermudagrass can produce harvestable forage between May to October (Taliaferro et al., 2004; Ball et al., 2015).

Bermudagrass was once considered to be a weed species, but selective breeding has transformed it into a high producing forage crop. Taliaferro et al., (2004) mentions that ‘Tift’ bermudagrass was discovered in a cotton patch in 1929 in Tifton, GA USA, which provided the genetic material for Dr. Glen Burton to develop improved bermudagrass varieties (Burton 1947, 1954). The first improved bermudagrass variety, ‘Coastal,’ was released in 1943, by the USDA ARS and the University of Georgia Coastal Plain Experiment Station (Burton et al., 1943). Coastal produces both rhizomes and stolons, has larger stems, and grows taller than common ecotypes of bermudagrass. Coastal also showed improved vigor, drought tolerance, and produced more forage. Since the release of Coastal, over twelve different varieties of hybrid bermudagrass have been released (Anderson et al., 2009; Hancock et al., 2013; Grossman et al., 2021). Hybrid bermudagrasses typically produce little to no viable seed, so they must be established vegetatively from rhizomes and stolons. These hybrid varieties are high-yielding (producing 9 to 13 Mg ha^{-1} annually, when provided with adequate fertility) and long-lived compared with seeded bermudagrass varieties, making them a preferred choice for forage and livestock producers throughout much of Georgia (Hancock et al., 2015). Two hybrid bermudagrasses varieties that are found in Georgia are ‘Russell’ and ‘Tifton-85’.

Russell bermudagrass was found in the 1970’s by a county agent in Russell County, Alabama. Russell is either a mutation of ‘Callie’ bermudagrass or a natural hybrid between Callie and common bermudagrasses. The Alabama Agricultural Experiment Station and the Louisiana Agricultural Experiment Station jointly released Russell bermudagrass in 1994 (Ball et al., 1996). Compared to Coastal, Russell has higher yields, more vigor, and improved winter hardiness, along with an earlier spring green-up (Ball et al., 1996). Ball et al. (1996) reported that while forage nutritive value appeared to be similar to Coastal, Russell bermudagrass is quite dense thus allowing for higher yields even though forage height at normal cutting stage is typically lower than other improved bermudagrass hybrids. It establishes rapidly via sprigging and the thick sod holds up well under grazing and can help prevent erosion (Ball et al., 1996).

Dr. Glenn Burton released Tifton-85 bermudagrass, a hybrid resulting from a cross between 'Tifton-68' and stargrass (*Cynodon nlemfuensis* Vanderyst) from South Africa (Burton et al., 1993). Tifton-85 has a robust growth habit, rapid establishment, and it is a sterile pentaploid ($2n = 5x = 45$) (Burton et al., 1993). It is darker green in color, taller, has large stems and wider leaves than Coastal. Tifton-85 has higher dry matter and fiber digestibility than Coastal, resulting in higher gains and utilization by cattle (Hill et al., 1993; Mandebvu et al., 1999; Hill et al., 2001b). Tifton-85 also has lower concentrations of ether-linked ferulic acid than Coastal, and decreased ether bonding in lignin in Tifton-85, which results in higher ruminal microbial digestion of this forage (Mandebvu et al., 1999; Hill et al., 2001a, 2001b).

Alfalfa

Alfalfa (*Medicago sativa L.*) is a cool-season perennial legume that can improve forage–livestock systems with biological N_2 fixation, improve forage nutritive values, and increase animal gains (Thinguldstad et al., 2020). Alfalfa is thought to have originated in Iran or Turkey (Hanson 1972; Ball et al., 2015) and was introduced to Georgia in the 1800's. The first alfalfa was introduced to the United States in California from Chile, and then it spread east and north from there (Hanson and Davis, 1972).

Today, there are approximately 9.6 million hectares of alfalfa grown in the United States for stored forage production with an estimated value of $10 billion annually, making it the third most valuable crop behind corn and soybeans (first and second, respectively; NASS, 2020). Most of the alfalfa grown in the U.S. can be found in Northern and Western states, as the cooler and dryer climates improve conditions for hay production (Lacefield et al., 2009; Melton et al., 1988). Although alfalfa was once the dominant perennial legume species in the Southeast, the poor soil fertility, low soil pH, high temperatures, and elevated insect pressure, eliminated many of the productive alfalfa stands were eliminated (Haby and Leonard, 2005; Terrill et al., 1996; Lacefield et al., 2009). The development of cultivars that are adapted to conditions of the South in recent years, have provided an opportunity for alfalfa production to increase again in the Southern United States (Brown et al., 1990; Bouton and Gates. 2003; Haby and Leonard, 2005; Thinguldstad et al., 2020). Other alfalfa varieties, such as glyphosate-resistant varieties like 'Alfagraze 600 RR', have been bred to aid in weed control options (Bouton et al., 2006).

Alfalfa breeding efforts made by Dr. Joe Bouton at the University of Georgia in the late 1980's led to the release of dual-use alfalfa varieties like 'Alfagraze' and later 'Bulldog 505' and 'Bulldog 805' (Bouton and Gates, 2003). 'Bulldog 805' was released by the Georgia Agricultural Experiment Stations in 1996 (Bouton et al., 1997). This variety of alfalfa is considered non-dormant since it has a dormancy rating of 8, and is recommended for grazing, hay, and silage production (Bouton et al., 1997). Bulldog 805 alfalfa is highly resistant to Fusarium wilt (caused by *Fusarium oxysporum* f. sp. *Medicaginis*), southern root-knot nematode (*Meloidogyne incognita*), phytophthora root rot (caused by *Phytophthora megasperma* f. sp. *Medicaginis*), spotted alfalfa aphid (*Therioaphis maculate*); and moderately resistant to anthracnose (*Colletotrichum trifolii*), bacterial wilt (caused by *Clavibacter* (*Corynebacterium*) *michiganense* subsp. *Insidiosum*, subsp.), verticillium wilt (*Verticillium albo*-*atrum*) and stem nematode (*Ditylenchus dipsaci*) (Bouton et al., 1997). Bulldog 805 alfalfa is susceptible to insect damage throughout the growing season and should be scouted frequently for alfalfa weevil [(*Hypera postica* (Gyllenhal) (Coleoptera: Curculionidae)]; cowpea aphid [(*Aphis craccoivora)* (Koch) (Hemiptera: Aphidoidea]; potato leafhopper [*Empoasca fabae* (Harris) (Hemiptera: Cicadellidae)]; three-cornered alfalfa leaf hopper [*Spissistilus festinus* (Say) (Hemiptera: Membracidae)]; and fall armyworm [*Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae).

While improved varieties of alfalfa have been developed to better endure the environmental conditions of the Southeastern United States, the hot and humid climate can negatively impact alfalfa production. Alfalfa typically goes through a "summer slump" in warmer climates during July and August where the high humidity can impair alfalfa by reducing root carbohydrate concentration because of increased plant photorespiration (Feltner and Massengale, 1965; Robison and Massengale, 1968; Ottman and Mostafa, 2013; White et al., 2012). Similarly, Ottman and Mostafa (2013) describe alfalfa harvested during the "summer slump" as low quality and suited only for dry cows.

Forage Fertilization

Bermudagrass Fertilization

Bermudagrass, like most warm-season perennial grasses, is highly responsive to nitrogen fertilization. Burton et al. (1963) found that increasing N fertilizer rates up to 1008 kg ha^{-1} could increase dry matter production from 'Coastal' bermudagrass up to 15.82 Mg ha^{-1}. Power (1980) observed a positive correlation between applied N fertilizer and forage yields up to 224 kg N ha^{-1}. Bermudagrass yields increased linearly with N fertilization up to 448 kg N ha^{-1} (Stringer et al., 1994). Osborne et al. (1999) found that even in rain-fed systems, bermudagrass yields could be doubled at high rates of N (>672 kg N ha^{-1}).

Nitrogen recovery from applied fertilizer in warm-season grasses can be variable and highly dependent on the environment as well as the N fertilizer rate. Bermudagrass can have a recovery of up to 88% at high rates (>100 kg N ha^{-1}) of N before reaching its maximum efficiency (Ashley et al., 1965). Overman and Everts, (1992) found that during high rainfall periods bermudagrass N recovery can be as great as 97%, during periods of minimal rainfall.

Several studies have focused on the nutrient uptake of bermudagrass under various N–P_2O_5–K_2O (N-P-K) fertilization ratios and defoliation management strategies (grazing or stored forage production). Burton (1954), recommended that the fertilizer ratio for N-P-K in Coastal, should be a 4:1:2 for hay production if N was 448 kg ha^{-1} yr^{-1}. Robinson (1996) reported that Coastal bermudagrass needed 440, 48, and 300 kg ha^{-1} of N, P, and K respectively to reach 90% of maximum yield, resulting in an approximate ratio of 9:1:6. Anderson et al., (2016) conducted a study on the N-P-K ratios for Tifton-85 in two different soils in the Coastal Plains. It was determined that in the actual nutrient uptake, the ratio that proved to be most beneficial to forage yield was 4:1:5. Nitrogen should be applied at 330 to 448 kg ha^{-1}, to achieve the maximum economic yield (Anderson et al., 2016).

Growing forage legumes in mixtures with grasses is considered a viable alternative to synthetic N fertilizer application to grass monocultures, as these mixtures produce greater seasonal yields and greater economic returns than legume monocultures or N-fertilized grass alone (Sanderson et al., 2013; Sturludóttir et al., 2014; Humphreys et al., 2012; Adjesiwor et al., 2017; Beck et al., 2017a,b,c; Beck et al., 2017d). Grasses have a greater growth rate when mineral N is high as mineral N uptake and use is more efficient for grasses than by legumes (Thornley et al., 1995). However, grass-legume mixtures are unique in that competition between the grass and legume species does not hinder the yield. In fact, the yield of the grass component of the mixture can often exceed its yield if it had been grown in a monoculture (Whitehead, 1995).

Alfalfa Fertilization

Proper fertilization is essential to the establishment and maintenance of successful alfalfa stands. Nitrogen fertilization is not required since alfalfa can biologically fix nitrogen (Vance et al., 1979). However, P and K are two essential macronutrients for alfalfa establishment as they aid in the development of the alfalfa taproot which allows for improved winter survival (Hancock et al., 2015). Fertilizing with P and K can improve alfalfa herbage accumulation and alfalfa stand persistence. Sanderson and Jones (1993) report that after two years, stands declined from 495 to 98 plants m^{-2} when 59 kg P ha^{-1} was applied compared to unfertilized stands which sustained 134 plants m^{-2}. Berg et al. (2007) observed that fertilizing with P and K will increase alfalfa herbage accumulation each year and help in sustaining alfalfa stand persistence.

It is well known that potassium fertilization and harvest timing both influence the productivity and longevity of an alfalfa stands (Berg et al., 2009; Gasser et al., 1969; Undersander et al., 2011), but soil type has a major role in the plant absorption of potassium, in that sandy soils have a high potential for nutrient leaching of potassium (Undersander et al., 2011; Lacefield et al., 2009). Deficiencies of potassium are associated with increased disease, decreased photosynthetic ability, and reduced carbohydrate availability, all of which can negatively influence yield potential in alfalfa through winter kill or stand thinning (Amtmann, Troufflard, and Armengaud, 2008; Cooper, Blaser, and Brown, 1967; Peoples and Koch, 1979). Since alfalfa is a luxury consumer of potassium, splitting potassium applications across the season is recommended to better distribute nutrient uptake through the growing season to improve potassium utilization (Thinguldstad et al., 2020).

Soils in the southern Coastal Plains are low in the available potassium to plants because of the low cation exchange capacity (Sonon, Kissel, and Saha, 2014). It is recommended in theses soils to provide *at least* an additional 280 kg K_2O ha^{-1} annually to maintain established alfalfa in these soils. In a recent study by Thinguldstad et al., (2020) the objective was to determine the impact of reduced rates of potassium fertilization on the alfalfa cultivar Bulldog 805, managed under different harvest strategies on forage yield, stand persistence, and nutritive value when grown in the southern Coastal Plains. They applied reduced rates of potassium (applied three times across the season at total rates of 0, 67, 101, 134, and168 kg K_2O ha^{-1}), that were all below current University of Georgia recommended levels of potash applications for alfalfa management and harvested the alfalfa at various growing stages of bud, 10%, 30%, and 50% bloom. The researchers determined that the levels of potassium fertilization had no effect on alfalfa yield, mass $shoot^{-1}$, leaf/stem, shoots m^{-2}, percent alfalfa ground cover, or stand density via crown and stem counts. Additionally, they observed that potassium treatment had no effect on common nutritive value parameters of CP, *in-vitro* digestible dry matter (IVTDMD), or TDN, as well as no effect on potassium content of alfalfa tissue samples.

Nitrogen Fixation

Alfalfa's ability to produce upwards of 112 kg N ha^{-1} indicates that the utilization of alfalfa in a forage or crop rotation could be a viable option for producers in the Southeast (Lacefield et al., 2009). The key benefit of incorporating a legume species is that they can convert atmospheric N into an organic N-source that is available for plant uptake. Nitrogen is the element that most frequently limits the growth of grasses (Burton, 1976). Unlike grasses, legumes obtain much of their N from the symbiotic relationship with the N-fixing rhizobia bacteria found in the legume nodules (Burton 1976). The N_2 fixation process is highly sensitive to water with decreases occurring under both drought or water logging than those utilizing N_2

(Minchin and Pate, 1975), along with temperatures between 20 – 35 °C produce maximum N_2 fixation rates for most temperate legumes (Burton, 1976).

Several studies have focused on the production of N in alfalfa. Ta and Farris (1987) first reported that alfalfa, via biological N fixation, can produce 50 to 168 kg N ha^{-1} yr^{-1}. This is also supported by both Hardarson et al., (1988) and Ledgard and Steele (1992) who reported 112-280 kg N ha^{-1} yr^{-1} and 112 to 224 kg N ha^{-1} yr^{-1}, respectively. Huang et al. (1996) found that N recovery was similar between nodulating alfalfa and non-nodulating alfalfa, suggesting that low N recovery was the action of suppressed recovery by alfalfa during limited growth.

Importance of Nitrogen Fixation in Alfalfa-Bermudagrass Mixtures

The continued increase of N fertilizer costs has led producers to consider reincorporating legumes into pasture-based systems (Rouquette and Smith, 2010; Quinn, 2022). The inclusion of legumes into a grass swards increase dry matter yields, crude protein content of the herbage, and livestock gain (Whyte et al., 1953), while also aiding in extending the production season (Burton, 1976, Hendricks et al., 2020). Yields of herbage from a grass-legume mixture usually have been as large as or larger than those of either of the components grown in pure stand (Carter and Scholl, 1962; Sprague and Garber, 1950; Washko and Pennington, 1956).

Haby et al. (2006) observed the N fixation capacity of alfalfa and its potential to transfer and provide N when interseeded with bermudagrass. They found that atmospheric N fixation of alfalfa contributed 42 to 91% of the total plant N in the alfalfa-bermudagrass mixture. Atmospheric N fixation was affected by alfalfa row spacing; the 23-cm row space consistently fixed the least atmospheric N and is thought to be from competition between the rhizobia bacteria when plants are in close proximity. The fixed N yield of the alfalfa in the alfalfa-bermudagrass stand ranged from 80 to 222 kg N ha^{-1} yr^{-1}; however, the transferred N yield was only 2 to 17 kg N ha^{-1} yr^{-1} (Haby et al., 2006). Haby et al. (2006), study suggests that very little of the N fixed by alfalfa was transferred to the bermudagrass although sandy soil conditions and early spring regrowth of alfalfa may have limited the soil N availability and reduced bermudagrass N needs from lower distribution of bermudagrass in the sward.

Conversely, Beck et al. (2017a) observed that both the alfalfa-bermudagrass and clover-bermudagrass mixtures led to similar carryover N, herbage mass, and pasture carrying capacity as pastures fertilized with either 56 or 112 kg N ha^{-1} during the growing season. The study from Beck et al., (2017a) supports other studies from Knight (1990) and Morris et al. (1990) that N transfer from legumes to grasses occurs during the early stages of the following growing season, rather than during the same season. Louarn et al. (2015) found that alfalfa was twice as effective as white clover (*Trifolium repens*) at productivity and biological N fixation during years 2 and 3, although clover root residues provided more N to other species upon senescence and induction of dormancy.

In contrast to other cool-season legumes, alfalfa is productive through the summer with the exception of July and August (White et al., 2012; Ottman and Mostafa, 2020), which are the “summer slump” months. While active growth is slowed during this time of the year, alfalfa provides high nutritional value during the summer months, a time which most available forage species lack nutritive value (Hoveland, 1986). Interseeding alfalfa into hybrid bermudagrass swards has the potential to increase overall herbage accumulation, nutritive value, and extend the grazing season for livestock production (Brown and Byrd, 1990; Stringer et al., 1994, Beck et al., 2017a-d). When incorporated into bermudagrass, it will offset alfalfa’s herbage accumulation potential in the summer months, allowing the mixture to exhibit an ebb and flow relationship across the growing season (Ball et al., 2015; Hendricks et al., 2020).

Beck et al. (2017*b*) also observed that interseeding legumes into bermudagrass swards increased herbage accumulation and pasture carrying capacity as compared to bermudagrass treatments fertilized with rates of 0-112 kg N ha^{-1} in the early season. However, Beck et al (2017*b*) did observed that at the end of the growing season, herbage accumulation declined but was still comparable to bermudagrass swards fertilized with 56 kg N ha^{-1}.

Establishment of Alfalfa-Bermudagrass Mixtures

Establishment

In the Southeastern U.S., alfalfa should be established in the fall when temperatures begin to cool, slowing down bermudagrass production, typically mid-October (Hancock et al., 2015; Tucker et al., 2021). The bermudagrass sod should be mowed to 5-cm prior to planting alfalfa. Glyphosate may be needed prior to planting to suppress bermudagrass (Jennings et al., 2016). If glyphosate is applied, a withdrawal period may be required before planting, dependent on the alfalfa variety used (Jennings et al., 2016). It is highly recommended that alfalfa be interseeded using a no-till drill, for optimum planting depth and row spacing to be achieved.

Jennings et al. (2016) evaluated the use of a no-till drill to plant alfalfa at 11, 22, 33 and 44 kg ha^{-1} into a suppressed bermudagrass stand. Alfalfa plant counts were initially lower at the 11 kg ha^{-1} rate compared to the 33 and 44 kg ha^{-1} seeding rates, and after one year alfalfa stand persistence declined significantly at the 11 kg ha^{-1} rate. Alfalfa persistence was greatest using the 44 kg ha^{-1} rate but the 22 and 33 kg rates were not different (Jennings et al., 2016). Jung et al. (1991) evaluated alfalfa and perennial ryegrass mixtures and their sward characteristics. Various alfalfa seeding rates (7, 14, 17, 21, 28 kg ha^{-1}) were used in the experiment. Jung et al., (1991) found that as alfalfa seeding rates increased, alfalfa total herbage accumulation increased but the ryegrass yields were reduced.

Row Spacing of Alfalfa-Bermudagrass Mixtures

Optimal row spacing is essential for the establishment of alfalfa into existing bermudagrass sod, as the row spacing in legume-grass mixtures influences total herbage accumulation, botanical composition, and N transfer. In an alfalfa-bermudagrass mixture, row spacing should not be too narrow as the alfalfa has the potential to shade out the bermudagrass and it should not be planted too wide which would allow for bermudagrass to potentially outcompete the alfalfa causing the alfalfa stand to become thin or non-existent. Since the overall goal of interseeding the alfalfa into the bermudagrass sward is to reduce the need for other sources of N, the rows should be wide enough to prevent shading and narrow enough that efficient N transfer can occur (Haby et al., 1999; Stringer et al., 1994).

Row spacing and its effect on stand composition, yield, and quality was evaluated in a series of studies conducted by Stringer et al. (1994; 1996). Stringer et al. (1994) evaluated the yield and botanical composition of a ‘Tifton-44’ bermudagrass stand at increasing rates of N fertilization with and without alfalfa interseeded at increasing row spacing. They found that alfalfa interseeded at 20-, 40-, and 60-cm row spacing, resulted in herbage accumulation being greater than or equal to bermudagrass monoculture receiving 224 kg N ha^{-1} yr^{-1} and there was no difference in the average stand yield between the three row spacings. Stringer et al. (1994) observed that by increasing row spacing, there was an increase in the contribution of bermudagrass as it reduces the potential of shading from competing forages.

Stringer et al., (1996) conducted a study to examine the effects of alfalfa row spacing and N fertilization on concentration and yield and nutritive value of components of bermudagrass and interseeded alfalfa. They found that increasing row spacing of alfalfa reduced grass crude protein by 9 to 23 g kg^{-1} and had no effect on alfalfa crude protein. However, they did observe that bermudagrass interseeded with alfalfa had yields that exceeded those of bermudagrass monoculture at the 448 kg ha^{-1} N rate. They concluded that even at a wide row spacing, it appeared to produce enough biological N to replace 448 kg fertilizer N ha^{-1} or more in the production of herbage protein in bermudagrass.

Brown and Byrd (1990) evaluated herbage accumulation and botanical composition of alfalfa-bermudagrass mixtures compared to species monocultures. In one of the two experiments, 'Apollo' alfalfa was interseeded into Coastal bermudagrass using a 15-cm and 30-cm row spacing. It was observed that regardless of row spacing, alfalfa dominated the mixture in the spring harvests as bermudagrass had not fully broken dormancy and there were no differences in total herbage accumulation by row spacing, however the mixtures yielded higher than bermudagrass monocultures that were fertilized with 100 kg N ha^{-1}. Hendricks et al., (2020) observed this fluctuation in botanical composition, in which alfalfa was greatest early in the growing season and bermudagrass greater later in the growing season.

Baleage in the Southeast

Overview of Baleage Production

The climate of the Coastal Plains Region, including the extended time needed for curing to produce hay creates many challenges but also has provided producers an opportunity to still produce a high-quality stored forage via baleage technology. Ball et al. (2015) describes baleage as a high moisture forage which has been cut (not chopped), wilted, and then baled. Baleage has a larger particle size than silage and is baled at a higher moisture content than dry hay (40-65% moisture vs. 15-18 %; McCormick, 2013; Ball et al., 2015; Tucker et al., 2020). Baleage bales are then wrapped in plastic to exclude O_2 and create an anerobic environment for fermentation, by either with an individual bale wrapper or in a row using an in-line wrapper (Ball et al., 2015).

Forages that have a higher nutritive value and sugar content tend to do better in baleage production. Warm- and cool-season annual forages are best suited for baleage, but legumes and legume-grass mixtures can work as well (Tucker et al., 2020). Although perennial grasses can be harvested as baleage, they do not ferment as quickly or easily as forages previously mentioned.

After the forage is baled and wrapped in plastic, anaerobic fermentation occurs where available plant sugars are converted into lactic acids, acetic acid, butyric acid, propionic acid, carbon dioxide, and heat (Tucker et al., 2020). The fermentation process of baleage occurs in four stages: Aerobic phase, lag phase, fermentation phase, and stable phase (Tucker et al., 2020). During the aerobic phase carbon dioxide and heat are produced with the lag phase that follows resulting in the fermentation of plant sugars and carbohydrates into volatile fatty acids (VFAs) (Collins and Owens, 2003; Tucker et al., 2020). During the fermentation phase lactic and acetic acid is produced with a terminal pH of 4.2-5.2, in which the stable phase begins which typically occurs 21-28 days post-harvest (Collins and Owens, 2003; Tucker et al., 2020).

The current University of Georgia recommendation is to feed baleage within 9 months of production (Tucker et al., 2020). However, Burt et al., (2021) reported that the nutritive value of baleage stored longer than the 9-month recommended period did not change up to 1-year post-harvest and storage. When baleage is stored for an extend period of time, bale integrity becomes the main issue. If stored for longer than 9 to 12 months extra layers of plastic may be required to help preserve the bale integrity (Tucker et al., 2020; Burt et al., 2021).

Advantages and Disadvantages of Baleage

Since weather has a critical role in the production of baleage timely harvest management strategies are crucial to maintaining high quality nutritive value. Baleage provides the ability to cut, rake, bale, and wrap within a 48 hr. window, therefore mitigating many environmental factors that should be considered when producing a dry hay product (Tucker et al., 2020). Producing baleage over a dry hay product also allows for the forage to be baled at a high moisture level, which also aids in the reduction of nutritive value losses that can occur while waiting on hay to cure. McGechan (1989) reported that when rainfall occurs on cut forage that is in the wilting stage there will be a 4-16% nutrient loss. Rain damage, in general, during stored forage production can be excluded in baleage production versus hay production in part to the differences in dry matter at baling (Hancock and Collins, 2006). The cut forage moisture should also be considered, with baleage moisture in the target range of 45-60% moisture, resulting in proper fermentation of the forage with the assumption that oxygen is excluded from the wrapped bale (Tucker et al., 2020). Conversely, dry hay that is baled at higher than 15% moisture has the potential for spontaneous heating, thus converting plant sugars to carbon dioxide, water, and heat (Martinson, 2011). Bale density should also be consideration for baleage as when produced at a higher density, less oxygen remains in the bale, further promoting fermentation (Han et al., 2014).

Disadvantages of baleage production are: bales can be bulky and hard to handle, requires baleage specific equipment for baling and storage, maintaining bale integrity when in storage, not as marketable if it is not utilized on the farm where it was harvested, once removed from the plastic it must be fed immediately, and the disposal of the excess plastic from storage (Ball et al., 2015). In hay production the greatest issue is the time required to cure the forage to the appropriate moisture content, in baleage production the greatest challenge is during the wrapping phase. It is recommended that bales be wrapped within 4 hours after baling to maintain bale shape, improve wrapping, and ensure proper ensiling (Tucker et al., 2020). Another disadvantage is the need for plastic for wrapping depending on if wrapping, difficulty handling wrapped bales, and disposal of plastic after feeding (Tucker et al., 2020). Unlike hay which can essentially be fed immediately it is not recommended to feed until to 4-6 weeks post-harvest to ensure proper ensiling (Tucker et al., 2020).

Animal Performance on Baleage

Baleage not only can provide a high nutritive value store forage, but it also can improve palatability and animal performance when compared to dry hay. Han et al. (2004) observed that baleage has a lower neutral-detergent fiber (NDF), acid-detergent fiber (ADF), and acid-detergent lignin (ADL) compared with dry hay which led to increased forage digestibility and palatability for the animals. Hancock and Collins (2006) observed that cows consumed a larger proportion of the dry matter provided to them when it was in the form of baled silage rather than dry hay. Bernard et al. (2010) found that bermudagrass baleage could be included up to a rate of 15% of the DM of the ration with corn silage before any deleterious effects on milk yield were observed. McCormick et al. (2011) observed greater dry matter intake (DMI), improved feed efficiency, but no negative effects on milk production or body weight when cattle were offered baleage, opposed to hay that had been stored both inside and outside of a barn.

Alfalfa-Bermudagrass harvested as Baleage

Traditionally, alfalfa mixtures have been harvested and stored as dry hay, but this can be challenging in the humid climate with frequent, unpredictable rainfall in the Southeastern United States (Hendricks et al., 2020). When alfalfa is harvested for baleage rather than dry hay, alfalfa’s leaf shatter potential is reduced, in part to the forage being baled at a higher moisture level than that of dry hay (Hendricks et al., 2020; Tucker et al., 2020). While it has be previously mentioned that the addition of alfalfa into a bermudagrass sward improves the overall forage nutritive value (Stringer et al., 1996; Haby et al., 1999; Cassida et al., 2006; Beck et al., 2017a,b,c), research is limited on the nutritive valur of alfalfa interseeded into bermudagrass and harvested as baleage.

Hendricks et al. (2020) reported that alfalfa-bermudagrass baleage had increased herbage accumulation and nutritive value when compared with bermudagrass fertilized with N alone and harvested as baleage. They found that alfalfa-bermudagrass mixtures had a higher CP and TDN when compared to bermudagrass baleage only for all harvest for years 2 (18-23% CP; 69-71.5% TDN versus 9.5-15%CP; 64.5-65.5%TDN) and 3 (18-23% CP; 65.6-72.6% TDN versus 9.5-15%CP; 62.6-67.3%TDN).

Grazing Systems of the Southeast

Overview of Grazing Systems

Grazing systems of the Southeast are defined by the way they are stocked with livestock 'continuous' or 'rotational' grazing systems, and each of these systems have their own advantages and disadvantages. Allen et al., (2011) defines continuous stocking as a method of grazing livestock on a specific unit of land where animals have unrestricted and uninterrupted access throughout the time when grazing is allowed. The advantage to this method is there is a reduction in the labor required to maintain the grazing animals (Allen et al., 2011). However, the disadvantage of this method is that there is an increased risk of the pastures becoming overgrazed, resulting in the deterioration of the forage stand (Allen et al., 2011; Simms, 2013). While not as common as the continuous stocking method, rotational stocking is another common grazing method applied to southern pastures systems. Allen et al., (2011) defines rotational stocking as a grazing method that utilizes recurring periods of grazing and rest among three or more paddocks in a grazing management unit throughout the time when grazing is allowed. The advantage to this method is that there is a reduction in risks associated with the overgrazing of the pasture, however, this method is more labor intensive (Allen et al., 2011; Simms, 2013).

Grazing bermudagrass

Bermudagrass is adapted to tolerate sustained close grazing from livestock, making it an ideal forage to utilize in pasture systems (Taliaferro, et al., 2004). Several studies have evaluated the continuous and rotational stocking of bermudagrass under various stocking conditions (Hart et al., 1976; Conrad et al., 1981; Pedreira et al., 1999; Hill et al., 1993; Hill et al., 2001a,b; Roth et al., 1990).

Hart et al., (1976) evaluated stocker steer performance under continuous, weekly rotation, strip grazing daily, green-chop dehydrated hay, and pelleted Coastal bermudagrass. They observed a difference among the grazing methods for average daily gain (ADG), which they attributed to the grazing pressure differences of each method (Hart et al., 1976). A study by Conrad et al., (1981), compared four stocking rates for stocker steers that were continuously or rotationally grazing of Coastal and Callie bermudagrass. Conrad et al., (1981) observed no differences among the continuous or rotational grazing methods for ADG withing each of the stocking rates used. Pedreira et al., (1999) evaluated the impact of three grazing cycles (7, 21, and 35d intervals) and three grazing heights (8, 16, and 24 cm) in combination with one another in ‘Florakirk’ bermudagrass. They observed that while the nutritive value varied by treatments, the ideal levels of production for both nutritive value and herbage mass were at the 24 cm height with the 21d intervals (Pedreira et al., 1999).

Grazing alfalfa

Traditionally, alfalfa has been harvested as a stored forage product instead of grazing because of its inability to withstand grazing pressure. However, the development of grazing tolerant alfalfa cultivars, such as ‘Alfagraze’ has resulted in the need for further investigation into the grazing of alfalfa (Bouton et al.,1991; Smith et al., 1999). Alfagraze was the first alfalfa cultivar in North America that claimed to have grazing tolerance and high dry matter productivity (Smith et al., 1999). Cameron (1973) and Lodge (1991) both reported that alfalfa does not perform well under continuous grazing management. Van Keuren and Matches (1988) suggest that if grazing alfalfa use a rotational grazing method, most available alfalfa cultivars cannot generally withstand long-term continuous defoliation. Rotational stocking is suggested because the plant needs a rest period to allow for root carbohydrate storage (Smith, 1962). The limitation with using rotational stocking management is that livestock producers may unintentionally overgraze certain paddocks during certain times of the year, but it is still the preferred method of grazing management (Smith et al., 1999).

Grazing alfalfa-bermudagrass mixtures

Research on alfalfa-grass mixtures has focused primarily on stored production, herbage accumulation, and nutritive value. Data are limited on the grazing potential of the alfalfa-grass mixtures, particularly when interseeded into hybrid bermudagrass. Beck et al. (2017*b*,*c*) observed an improvement in the overall nutritive value of the forage base for the bermudagrass treatments that contained alfalfa as compared to the bermudagrass treatments that contained white and red clovers (*Trifolium pratense*) or were supplemented with N-fertilization at 0, 56, and 112 kg N/ha^{-1}. Beck et al., (2017*d*) noted an increase in the early grazing season and a decrease in the later summer grazing season for total herbage mass and carrying capacity in treatments that were interseeded with a legume species. Likewise, Beck et al. (2017*b*) and Biermacher et al. (2012) observed a decline in nutritive value of mixed alfalfa-bermudagrass swards with progression of the summer grazing season in Arkansas and Oklahoma, respectively.

Beck et al. (2017*a*), reported that there was a decrease in the forage production and stocking rates after mid-summer in rotationally grazed mixed alfalfa/bermudagrass pastures. They also observed that the stocking rate of alfalfa-bermudagrass swards were greater than bermudagrass fertilized at 112 kg N ha^{-1} during the early summer, but stocking rates of alfalfa-bermudagrass were similar to fertilized bermudagrass swards in the late summer.

Beck et al., (2017*d*) reported greater forage production in rotationally grazed pastures of alfalfa-bermudagrass mixtures. They observed a greater forage mass which resulted in a greater forage allowance ($P \leq 0.04$) in July and August of Year 1, but they did not observe any differences in Year 2. They also observed greater forage allowance in April, May, and July ($P \leq 0.04$), but no differences in forage allowance for June, August, and September when rotationally grazing alfalfa-bermudagrass pastures.

Along with grazing of alfalfa-bermudagrass mixtures, Beck et al., (2017*c*) did not report any differences in the ADG of steers in any of their treatments. They did observe, regardless of treatment bermudagrass paddocks fertilized with or without N, compared to the paddocks interseeded with legumes, there was an increase in the total liveweight gain per steer in the early summer months.

Rushing et al., (2022) compared the forage mass, nutritive value, and animal performance of stocker steers grazing alfalfa-bermudagrass mixtures, in concurrent production with bermudagrass monoculture pastures supplemented with or without synthetic N over a 3-year evaluation in Mississippi. The nutritive value of the bermudagrass forage base improved when interseeded with alfalfa, compared to the treatments with or without synthetic N supplementation. Additionally, they observed greater animal performance for ADG and liveweight gains for those stocker steers grazing ABG mixtures compared to the other treatments.

In previous research focused on grazing alfalfa interseeded into bermudagrass, the bermudagrass base was either common bermudagrass (Beck et al., 2017*a*,*b*,*c*; Beck et al., 2017*d*) or ‘Midland’ bermudagrass (Rushing et al., 2022). These factors should be examined further in hybrid bermudagrass grazing systems that have been interseeded with alfalfa in the Southeastern United State, to determine the feasibility and viability of this mixture in a stocker cattle grazing system.

Stockpile or Deferred grazing

Many cattle operations in the Southeast US rely on warm-season perennial forages that go dormant or have limited production during the winter months. To overcome this, cattle producers feed hay and supplemental feedstuffs for 90 to 120 days on average to maintain cows during the winter when fresh forages may not be available for grazing (Prevatt et al., 2018). Extending grazing through fall and winter reduces the amount of harvested forage needed to maintain cow performance and can reduce production costs associated with winter feeding along with the high cost of predominate hay-based diets (D’ Souza et al., 1990; Adams et al., 1994; Hitz and Russell, 1998; Rankins and Prevatt, 2012). Grazing can be extended by different forage management practices including stockpiling forage (Matches and Burns, 1985).

Stockpiling refers to the practice of allowing forage biomass to accumulate in the field until it is needed for grazing (Mays and Washko, 1960; Allen et al., 2011; Ball et al., 2015; Griffin et al., 2020). Stockpiling forage for fall and winter grazing has been practiced most extensively with the mixed native warm-season prairie grasses of the Great Plains and with tall fescue (*Lolium arundinaceum* (Schreb) S.J. Darbyshire) in the southeastern and south-central states (Matches, 1979; Spooner and McGuire, 1979; Van Keuren and Stuedemann, 1979). While most stockpile grazing occurs after the first frost of the year; in the extreme South however, the average date of first frost occurs approximately December 15 (if at all) in comparison to November 1 in the northern edge of the bermudagrass-producing areas of the United States (Ball et al., 2015).

Stockpiling Warm-Season Grasses

Traditionally warm-season stockpiled forages are grazed or mowed to a stubble height of 8-10 cm in late July or early August (Ball et al., 2015). Around mid-August the forage is fertilized with N to maximize forage accumulation during the stockpiling period (Scarbrough et al., 2006). Timing of fertilization is crucial, and N fertilizer should be applied as early as possible at the start of the stockpiling period to optimize response of the forages. Delaying fertilization into late September will have minimal effect on stockpiled forage yields (Barnhart, 2013).

The nutritive value of stockpiled bermudagrass is often lower than that of the commonly stockpiled cool-season grasses (Scarbrough et al., 2006; Ball et al., 2015). The ability to stockpile bermudagrass is affected by many factors, such as, variety, length of grazing, climate, and inputs of N fertility. However, this practice may reduce winter input costs depending on the cost of stored forage, the forage production of winter annual forages, as well as the efficacy of harvesting forages in a year (Lalman et al., 2000).

Unfavorable factors associated with the stockpiling of bermudagrass is the lodging of biomass during the stockpiling period and unpredictable weather (Lalman et al., 2000). In general, the tall-growing varieties such as Coastal, Midland, and ‘Tifton 44’ are more prone to lodging than the relatively lower-growing common varieties (Lalman et al., 2000).

Temperature and precipitation also affect the stockpiling of bermudagrass. Freezing serves to truncate bermudagrass forage accumulation, so the average date of initiating the stockpiling period must be adjusted to allow adequate time for optimal forage accumulation and quality (Lalman et al., 2000). Rate of bermudagrass growth is considerably higher when the temperature is above 24°C, and very little growth occurs when the temperature is 15 to 18°C (Burton and Hanna, 1995). Bermudagrass yield is highly sensitive to the availability of moisture (Prine and Burton, 1956), the effects of temperature and date of first frost would be expected to interact with the timing and/or amount of precipitation prior to and during the stockpiling period. Consequently, less growth would be expected in years when autumn temperatures are cooler than normal and when frost occurs earlier than normal (Lalman et al., 2000). However, in years of sustained warmth and delayed frost, the forage is at a more advanced stage of maturity which has a reduced nutritive value, in turn reducing animal performance. Conversely, years of excessive rainfall can create mud issues and pugging, resulting in a decreased efficiency of utilization.

Generally, advancing plant maturity is associated with decreasing protein concentration and DM digestibility (Knox et al., 1958; Burton et al., 1963; Wilkinson et al., 1970). Several studies have shown a decline in *in-vitro* dry matter digestibility (IVDMD) with advanced plant maturity created by less frequent defoliation (Jolliff et al., 1979; Henderson and Robinson, 1982; Monson and Burton, 1982). Similarly, as harvested forage maturity increases, animal performance and in vivo digestibility decline (Chambliss et al., 1999).

Scarbrough et al. (2001, 2006) suggests that producers in the Upper South can best utilize stockpiled bermudagrass by grazing non-lactating, spring-calving beef cows during a window of approximately 60 d. Lalman et al. (2000) conducted a study in Oklahoma in which CP concentration in stockpiled bermudagrass was determined to be adequate for dry, pregnant beef cows. Holland et al. (2018) observed that strip grazing stockpiled Tifton 85 bermudagrass to achieve a level of maintenance is appropriate for cow/calf operations. Energy supplementation may be required when grazing stockpiled bermudagrass to meet nutrient demands of high performing or lactating cattle.

Bivens et al. (2017) conducted a fall grazing trial to evaluate the use of strip grazing stockpiled Tifton 85 bermudagrass with or without supplementation as a replacement for hay during the receiving period for growing steers. They observed that stockpiled bermudagrass may be used as part of a receiving system for stocker cattle as an alternative to hay when adequate supplementation is provided to support maintenance and/or gain. However, in the stocker cattle industry, economical weight gain is needed to sustain profitability (Bivens et al., 2017).

Stockpile Grass-Legume Mixtures

While stockpile grazing is a common practice in many forage grass species, grazing stockpiled legumes not recommended based on the growth pattern and morphology of legumes in general. Stockpiled forages have increased yield and lower quality, along with a lower ability to maintain structural integrity after the growing season has ceased (Riesterer et al., 2000). Alfalfa nutritive value declines more rapidly than many legumes when it is allowed to mature (Buxton et al., 1985). Limited research exists on legumes being stockpiled for grazing as legumes are more fragile than cool- and warm-season grasses and lose a large portion of their leaves after the first killing frost (Rohweder and Albrecht, 1995).

While it is not recommended to stockpile legumes, there is limited research on the stockpiling of grass-legume mixtures. Mays and Washko (1960) found that stockpiled pasture is lower in quality and palatability than that which is produced under rotation grazing management. Mays and Washko (1960) compared the stockpiling ability of Ladino Clover (*Trifolium repens*) and Birdsfoot Trefoil (*Lotus corniculatus*) in grass mixtures and observed that pastures containing a high percentage of birdsfoot trefoil appeared to offer some potential for stockpiling until mid-July in Pennsylvania while swards that contained a high percentage of grass were found to be unsuitable for stockpiling.

The potential to utilize alfalfa as a stockpiled forage has been evaluated primarily in tall-fescue mixed pastures. Alfalfa leaf percentage decreased as autumn and winter advanced (Collins and Taylor, 1980). Hitz and Russell (1998) observed cows grazing tall fescue-alfalfa, smooth bromegrass-red clover, and corn crop residues maintained greater or equal BW and condition scores compared to cows fed large round bales in a drylot but required less stored forage. Allen et al., (1992) reported that the use of alfalfa in stockpiled fescue resulted in an increase in ADG but required approximately three times more stored forage than N-fertilized fescue.

Currently, no data exist on the utilization of ABG as a stockpiled forage. Unlike some regions of the US that stockpile graze forages, in the Deep South the potential to even have a killing frost occur is sporadic, therefore, the utilization of a semi- to non-dormant variety of alfalfa in a bermudagrass mixture, may provide an opportunity for producers to graze this mixture during the transition between warm-season forages to cool-season annuals.

Dual Use Management of Alfalfa-Bermudagrass Systems

Traditionally, to achieve the best production and performance with alfalfa, it is recommended to by harvested as hay or under rotational grazing management (Van Keren and Matches, 1988). However, with the development of more grazing tolerant alfalfa varieties this traditional production system has been called into question (Bouton and Gates, 2003). Bouton and Gates (2003) evaluated and determined from several grazing tolerant varieties, that alfalfa grown in monoculture is the best option for producers that are wanting to graze or make hay. While previous research has focused on dual-use alfalfa in monoculture, data are limited on this same type of performance in a mixture with bermudagrass. Currently, no data exist on the production of ABG mixtures in a dual-use harvesting system (producing baleage and grazing from the same land area).

Non-destructive Forage Estimation

Accurate forage estimations are essential to matching the forage supply to that of the animal needs, and inaccurate estimation results in inadequate stocking rate and grazing duration decisions (Sanderson et al., 2001). Accurate estimates of biomass in rotationally grazed pastures enable producers to prepare feed budgets for their farms that maximize the utilization of feed offered by reducing wastage or overgrazing (Wigley, et al., 2019; Beukes et al. 2019). This process allows for enough forage to be available for cows to graze throughout the year by providing information for decisions on rotation lengths, supplementary feeding requirements, nitrogen fertilizer use and conservation (Wigley et al., 2019). Beukes et al. (2015) suggests that these accurate forage estimations result in less under- and over-feeding, higher milk production and optimized post grazing residuals to maximize pasture regrowth.

There is a need for simple and inexpensive methods for estimating available forage, particularly in pastures or hayfields with multiple forage species (Baxter et al., 2017). Conventional techniques, such as visual estimates and dry weight rank, are subjective, time consuming or require many reference samples (Walker, 1970; Brummer et al. 1994; Bennett et al., 2000; Cougnon et al., 2013; Locher et al., 2005; Rayburn, 2014). There are numerous indirect, nondestructive sampling techniques that can be utilized to estimate forage availability, but these tools vary in accuracy and practicality in the context of the forage species present and the use (i.e., field or research scale; Koenig et al., 2000). Several sensors and data analysis methods exist to measure herbage mass in pastures including ultrasonic transmitters (Hutchings et al., 1990; Kallenbach, 2015; Legg and Bradley, 2020), lasers (Pittman et al., 2015), electronic pasture meter (Yule et al., 2010), stereo-photography (Baxter et al., 2017; Wigley et al., 2019) and satellite images (Woodward et al., 2019; Reinermann et al., 2020).

It has been determined that a trained observer could successfully replicate bite size and selection with hand-harvesting methods, but this was in small grass swards with homogeneity of only a few grass species (Bonnet et al.; 2011). Visual assessment of pasture standing forage mass is inexpensive and fast but also subjective, biased, and can be inconsistent when evaluated by untrained personnel (Haydock and Shaw 1975; Stockdale 1984; Martin et al., 2005; Edirisinghe et al., 2012; Moffet et al., 2012).

Pasture Height

Estimating pasture yield from sward height is an easy, inexpensive techniques to estimate forage availability (Virkajärvi, 1999; Rayburn and Lozier, 2003; Pittman et al., 2015). Michalk and Herbert (1977) concluded that canopy height was sensitive enough to detect differences in forage mass in an alfalfa-dominant pasture, but canopy density was not considered. Canopy height may be measured using a Robel pole (Harmoney et al., 1997) or ultrasonic meter (Fricke and Wachendorf, 2013), but a pasture ruler is the most common tool (Baxter et al., 2017). Regression equations to predict yield as a function of height should be calculated for each forage and location, for pre- and post-grazing events to improve estimation accuracy (Virkajärvi, 1999; Sanderson et al., 2001; Martin et al., 2005). However, this method is sensitive to outliers and may produce irregular results in comparison to direct harvesting estimates (Stewart et al., 2001).

Rising Plate Meter

The use of a rising plate meter (RPM) provides a rapid estimate of herbage mass and can be a useful tool for producers needing to make accurate and efficient grazing management decisions (Bransby et al., 1977). RPM have also been utilized in turfgrass to aid in estimation of height or yield (Cereti et al., 2009; Volterrani et al., 2001). A RPM combines both plant height and density into a single measure (Baxter et al., 2017). The RPM consists of a weighted square or circular plate that slides over a central shaft as the canopy pushes the plate upward to measure a compressed canopy height (Koenig et al., 2000; Moffet et al., 2012). Recording RPM measurements is fast and simple; however, maintaining consistent pressure and angle is key to collecting precise, reliable data (Gourley and McGowan, 1991; Moffet et al., 2012; Edirisinghe et al., 2012).

The RPM is typically calibrated by linearly regressing RPM heights against corresponding forage clippings (Dillard et al., 2016). Traditionally, average recordings of compressed canopy height are correlated to DM yield using a linear model, but recent research has suggested non-linear or quadratic relationships may be more appropriate (Scrivner et al., 1986; Ferraro et al., 2012, Dillard et al., 2016). Typically, a single calibration equation is not consistent throughout an entire growing season since developmental phases in the canopy translate to different slope coefficients throughout the season (Scrivner et al., 1986; Virkajärvi, 1999; Ferraro et al., 2012). While outliers can occur, their significance is minor in RPM readings when compared to pasture height because of the measurement utilizes both plant height and density.

Digital Imaging Analysis

Digital imaging analysis is widely used in plant and turf science (Richardson et al., 2001; Karcher and Richardson, 2003; 2005), range management (Bennett et al., 2000), soil erosion prevention (Olmstead et al., 2004), even green roofs (Durhman et al., 2007), and in pasture situations (Baxter et al., 2017). The development of software which relates color parameters among images has greatly simplified DIA (Roshier et al., 1997; Ewing and Horton, 1999). Use of DIA can measure a two-dimensional area of selected components within a digital photo image (Baxter et al., 2017). This is less time consuming, more consistent, and less biased than the previously discussed procedures (Karcher and Richardson, 2003). Himstedt et al. (2009; 2010) first used DIA to determine the botanical composition of ryegrass and alfalfa, white clover [*Trifolium repens* L.], or red clover [*Trifolium pratense* L.] mixtures.

Xiong et al., (2019) compared two image software ImageJ (http://imagej.nih.gov) and Canopeo (http://www.canopeoapp.com) for the determination of ground cover estimates, their ability to estimate canopy functions, and their time savings for vegetation analysis relative to a manual method for 'WW-B.Dahl' Old World bluestem [*Bothriochloa bladhii* (Retz) Blake] and found that to be successful. Lynch et al., (2015) also found that the use of ImageJ was successful in DIA of perennial ryegrass (*Lolium perenne* L.).

Rayburn (2014) described using photo-point counts in Microsoft PowerPoint (Microsoft, Redmond, WA) to estimate legume content in orchardgrass (*Dactylis glomerata* L.), red clover (*Trifolium pratense* L.), and white clover (*Trifolium repens* L.) pasture. This technique requires inserting a photographic image into a blank PowerPoint® slide, cropping the image to a square corresponding to an exact land area, such as 1 m^2, drawing gridded points on the image, and then counting the points on the image and calculating proportion of hits on the item of interest. Rayburn (2014) determined that the accuracy of photo point counts is influenced by the number of images per pasture, number of points per image, and number of paired samples collected for the linear regression calibration.

Direct Harvesting

While hand–clipping samples is the most direct method of calculating forage mass, results are hindered by the labor-intensive tasks of collecting, drying, and weighing each sample (Moffet et al., 2012; O'Donovan et al., 2002). This method requires clipping the forage to a set stubble height from a known area, placing the sample in a paper or cloth bag, weighing prior to and after drying, and totaling the calculated results to obtain a yield estimate for a predetermined area (Koenig et al., 2000; Moffet et al., 2012). While accurate, precision is determined by pasture variability, sampling efficiency, and number of samples (Harmoney et al., 1997; Koenig et al., 2000), results are also not immediate because the labor intensive process (Moffet et al., 2012).

Potential Use in Alfalfa-Bermudagrass Mixtures

In mixed species stands, species composition and canopy density are variable, and forage mass estimation becomes more challenging. To estimate forage mass in mixed forage stands, measures of stand variability must be considered (Alexander et al., 1962; Baxter et al., 2017). Baxter et al. (2017) conducted a study between five different nondestructive sampling techniques in alfalfa-tall wheatgrass [*Thinopyrum ponticum* (Host) Beauv.], utilizing a pasture ruler, RPM, ImageJ, PowerPoint, and normalized difference vegetation index (NDVI). Baxter et al., (2017) found that the combined linear model, which utilized height and ImageJ, possessed the superior combination of high R^2, low $\mathrm{RMSE}_{\mathrm{cal}}$, and low $\mathrm{CV}_{\mathrm{cal}}$, and best followed the 1:1 reference line indicating a better fit for the external validation data.

While there has been extensive research in the use of nondestructive forage estimation techniques in various forages both monoculture (Lynch et al., 2015; Xiong et al., 2019) and in mixed swards (Mitchell et al., 1982; Dillard et al., 2016; Baxter et al., 2017), there is no current published research on utilizing these techniques in an alfalfa-bermudagrass mixed sward.

Summary and Objectives

Incorporating a legume, such as alfalfa, into a bermudagrass sward, can greatly benefit livestock producers in the Southeastern US. The incorporation of alfalfa into hybrid bermudagrass varieties can aid in reducing the need for synthetic N, improve the nutritive value of the bermudagrass forage base, and also aid in extending the grazing season. The objective of this work is to determine if the incorporation of alfalfa into a bermudagrass base is a viable option for rotationally grazing stocker cattle in the Coastal Plains region. Additionally, this work is focused on determining the best harvest management strategy for alfalfa-bermudagrass mixtures in the region, in relation to the estimation of herbage accumulation, plant and animal performance in different bermudagrass bases, and determine how long the grazing season can be extended using various grazing techniques.

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CHAPTER 3

IMPROVING SOUTHERN BERMUDAGRASS GRAZING SYSTEMS WITH ALFALFA AS AN ALTERNATIVE N-SOURCE

[1] Burt, J.C., L.L. Baxter, C.G. Prevatt, R.L. Stewart, Jr., M.K. Mullenix, and J.J. Tucker. To be submitted to *Grassland Research*

Abstract

Bermudagrass (*Cynodon spp.*) is one of the most common perennial warm-season forage crops grown in the Southeastern US. However, it has a high N fertilizer requirement for optimum production and moderate nutritive value. The incorporation of a legume, such as alfalfa (*Medicago sativa*), into bermudagrass pastures could serve as an alternative source of N while also improving the nutritive value of the forage base. Therefore, a 2-yr grazing evaluation was conducted from May-Sept. 2018 (Y1) and May-Aug. 2019 (Y2) in Tifton, GA, to compare production of alfalfa-bermudagrass mixed pastures (BGA) with bermudagrass monoculture pastures with (BGN) or without (BG) the application of synthetic nitrogen on forage production and animal performance. Grazing treatments were assigned to pastures (0.8-ha) in a randomized complete block design with two replications for each treatment. Pastures were managed using rotational stocking on a 7-10 d interval the using put-and-take stocking method with stocker cattle (Y1 BW=196 ± 22.9 kg; Y2 BW=229 ± 30.0 kg). Stockers were weighed on a 28 to 30 d interval for calculation of ADG and gain ha^{-1}. All pastures were evaluated for total herbage mass, botanical composition, and nutritive value. While there were no differences observed for ADG, the inclusion of alfalfa into the bermudagrass sward increased gain ha^{-1} ($P = 0.02$) and stocking rate ($P = 0.01$) compared to the other two treatments. Furthermore, the inclusion of alfalfa increased forage CP ($P = 0.01$) and TDN ($P = 0.01$) compared to both of the bermudagrass monocultures. Because of these factors, the BGA treatment provided the greatest economic return per hectare in comparison to the other treatments. These data illustrate improved animal carrying capacity and nutritive value of BGA systems and offer a viable option for producers that are seeking an alternative to synthetic N sources for their bermudagrass in the South.

Introduction

Grown on approximately 8.1 million hectares in the Southeastern United States (Redfearn and Nelson, 2003), bermudagrass (*Cynodon spp.*) is one of the most common warm-season perennial grasses utilized in hay and pasture systems. However, high rates of nitrogen (N) fertilization are required to maximize the yield potential of bermudagrass, (Burton et al.,1963; Power, 1980; Osborne et al., 1999; Stringer et al., 1994; Beck et al., 2017*d*; Templeton and Taylor 1975; Johnson et al, 2001). With the rising costs of synthetic N sources, many producers may elect not to apply N in their bermudagrass pasture at all (Doxon et al., 2011; Biermacher et al., 2012; USDA, 2019; Quinn, 2022). Furthermore, bermudagrass nutritive value is moderate (Johnson et al, 2001; Ball et al., 2015; BCNRM, 2016), resulting in poor performance of stocker cattle grazing during the hot and dry midsummer months characteristic of the region (Duble et al., 1971; Utley et al., 1974; Greene et al., 1990). In recent years, interest has grown in the use of legume-grass mixtures in the region to mitigate the need for synthetic N application and improve nutritive value of the forage base in bermudagrass pastures (Rouquette and Smith, 2010; Biermacher et al., 2012; USDA, 2019). The use of legume-grass mixtures is not a novel concept; however, these species combinations should be examined further to determine viability as an alternative N source and to quantify animal carrying capacity.

Growing forage legumes in mixtures with grasses is considered a viable alternative to synthetic N fertilizer application to grass monocultures as these mixtures produce greater seasonal yields and greater economic returns than legume monocultures and N-fertilized grass (Sanderson et al., 2013; Sturludóttir et al., 2014; Humphreys et al., 2012; Adjesiwor et al., 2017; Hendricks et al., 2020). Several studies have evaluated the benefits of utilizing a legume-grass mixture to decrease nitrogen inputs (Wolf and Smith, 1964; Ta and Faris, 1987; Ledgard and

Steele, 1992; Biermacher et al., 2012), to improve the overall nutritive value of the forage base, and aid in increasing the number of grazing days (Bouton et al., 1998; Bouton and Gates, 2003; Cassidia et al., 2006; Beck et al., 2017*b*).

Of the legume species that are available, alfalfa (*Medicago sativa*) is one of the primary perennial legumes that has been successfully interseeded into bermudagrass (Brown and Byrd, 1990; Stringer et al., 1996; Haby et al., 1999; Cassida et al., 2006; Beck et al., 2017*a*,*b*,*c*; Hendricks et al. 2020). In contrast to other cool-season legumes, alfalfa is still productive through the summer months. The alfalfa growth will slow and contribution to the stand will decline in August, but the alfalfa stand rebounds and increases its contribution in the fall (Hendricks et al., 2020). With the development of more grazing tolerant alfalfa varieties, there has been a growing interest in the use of alfalfa-bermudagrass mixtures in grazing systems for improved performance of stocker cattle (Cassida et al., 2006). Beck et al. (2017*b*) confirmed that grazing management should follow previous recommendations for alfalfa production and stand persistence and found that longevity of alfalfa-bermudagrass mixtures is greatest when rotationally stocked. However, there is limited research comparing alfalfa-bermudagrass mixtures with bermudagrass monocultures in relation to pasture productivity and animal performance. Therefore, the objective of this study was to evaluate forage production and animal performance of alfalfa-bermudagrass mixed pastures (BGA) with bermudagrass monoculture pastures with (BGN) or without (BG) the application of synthetic nitrogen when grazed by stocker cattle in the Southeast.

Materials and Methods

This project was approved by the University of Georgia IACUC Committee IACUC AUP #: A2017 01-006-Y1-A0.

Experimental Location

A 2-yr grazing evaluation was conducted during May to September 2018 and May to August 2019 (Year 1 and 2, respectively) on six 0.8-ha pastures previously established in ‘Tifton-85’ bermudagrass at the University of Georgia Tifton Campus Beef Cattle Center located in Tifton, GA (31°30′ N, 83°31 W; 110 m elevation). Soils were characterized as Cowarts loamy sand (fine-loamy, kaolinitic, thermic Typic Kanhapludults, 2-5% slopes). Topsoil (0-15 cm) and subsoil (15-30 cm) samples were collected at the initiation of each season and all paddocks were fertilized with P, K, and micronutrients (B and Mo) according to University of Georgia soil test recommendations (Kissel and Sonon, 2008).

Total rainfall during the two experimental years was variable with respect to amount and timing (Fig. 1A; UGA-AEMN, 2020). The mean long-term (100 yr) annual precipitation was 114 mm for the growing season (UGA-AEMN, 2020). Summer maximum temperatures often exceed 30°C, and peak in July and August (Fig. 1B; UGA-AEMN, 2020).

Pasture Establishment and Management

Pastures were randomly assigned to one of three treatments: bermudagrass receiving no N fertilizer (BG), bermudagrass fertilized with nitrogen (BGN), or bermudagrass interseeded with alfalfa (BGA). Pastures assigned to BG or BGN treatments consisted of an existing stand of Tifton-85 bermudagrass. Pastures assigned to BGN treatment were fertilized with calcium ammonium nitrate (CAN) at a rate of 90 kg ha^{-1}, in split application (45 kg ha^{-1} each application) twice during the season, just prior to grazing initiation (26 April 2018, and 2 May 2019) and midway through the grazing season, immediately after the animals were moved to the next grazing section (27 July to 9 August 2018; 2 August to 9 August 2019). The range in dates for N fertilizer application is a result of application occurring after the animals had been moved to the next grazing section, allowing for a complete 28-30 d grazing cycle.

Pastures assigned to the BGA treatment were prepared for the establishment of alfalfa in October 2017 following UGA Extension recommendations for interseeding alfalfa into bermudagrass (Hancock et al., 2015; Tucker et al., 2021). Bermudagrass was clipped to a 5 cm stubble height. In a hay harvest event to removed excess biomass. Pastures were then sprayed at a suppression rate with glyphosate (2.5 kg a.i. ha^{-1}), to induce dormancy of the bermudagrass. Approximately two-weeks later a semi- to non-dormant alfalfa cultivar ‘Bulldog 805’ (Athens Seed Co., Watkinsville, GA.) was interseeded into the existing Tifton 85 bermudagrass sod using a no till drill (Tye Pasture Pleaser, 2007; AGCO Inc., Duluth, GA) at 28.0 kg ha^{-1} at a soil depth of 1.3 cm and 18 cm row spacing (Hancock et al., 2015).

Scouting for insect pests occurred at establishment and weekly in all paddocks and pesticide applications occurred as warranted. During Y1 and Y2, zeta-cypermethrin (Mustang Maxx [zeta-cypermethrin*S-cyano(3-phenoxyphenyl)methyl (+) cis/trans 3-(2,2-dichloro-ethenyl)-2,2, dimethylcyclopropane carboxylate], FMC Corporation) was applied at a rate of 28 g a.i. ha^{-1} to control three-cornered alfalfa leaf hopper [*Spissistilus festinus* (Say) (Hemiptera: Membracidae)]. Chlorantraniliprole (Prevathon, Corteva Agriscience) was applied once during August of Y1 growing seasons at a rate of 100 g a.i. ha^{-1} for control of fall armyworm [*Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)]. Chlorantraniliprole was not applied in Y2 because of lack of forage growth from drought conditions.

All pastures were clipped twice per year (approximately 30 days prior to study initiation and in between grazing cycle 2 and 3) using a rotary cutter (Woods BB60, Blount International Portland, Oregon) set at a 12.5 cm clipping height. This was for the control of pasture weeds, such as annual ryegrass (*Lolium multiflorum*), crabgrass (*Digitaria sanguinalis*), and dogfennel (*Eupatorium capillifolium*) and encourage growth of desirable forage species.

Experimental Design and Grazing Management

Pastures were arranged in a randomized complete block design with two replications. Replications were spatially defined to account for geographic obstacles (i.e., trees, pond, and slope). The six 0.8 ha pastures were subdivided into three 0.27-ha paddocks to facilitate rotational stocking. Each paddock was grazed for 7 to 10 days, allowing for 14 to 20 days of rest depending on the length of the grazing cycle. A grazing cycle was defined as a complete rotation through all three subsections (Table 3.1).

Yearling crossbred stocker cattle (*Bos taurus X Bos indicus*) were randomly assigned to each experimental unit each year based on animal body weight (BW). Prior to study initiation, stockers were backgrounded on warm season perennial mixed pastures including common bermudagrass and bahiagrass (*Paspalum notatum* Flüggé) at the University of Georgia Alapaha Range Cattle Unit, Alapaha, GA (31°21'0.23"N, 83°13'30.66"W, 83 m elevation). Mean initial body weights (BW) of tester steers were 203 ± 13.9 kg and 220 ± 16.5 kg, year 1 and 2, respectively. This experiment utilized the put-and-take stocking method as defined by Mott and Lucas (1952). Two tester steers were randomly assigned to each paddock and remained on trial for the entire grazing season. Grazers (steers or heifers) were allocated as needed to equilibrate forage allowance (FA) among treatments (target FA: 1 kg DM kg liveweight^{-1} [LW]; Minson, 1990). All stocking decisions were determined based on the forage mass estimated by hand-harvesting biomass one day prior to rotation to a new section (procedure defined in next section) and by using a pasture ruler and rising plate meter (RPM). Grazing was initiated in May each year and was terminated when the forage mass was ≤ 1,120 kg DM ha^{-1} (Table 3.1).

One day prior to study initiation, tester steers were implanted (Synovex-S 200 mg progesterone-20 mg estradiol; Zoetis, Parsippany, NJ). Throughout the trial, all cattle were provided *ad libitum* access to water and shade. All testers and stockers received mineral containing Lasalocid during the study (Ruminant Stimulator-B, Multi-Kare, Inc., Tifton, GA; Lasalocid Sodium = 1.6 g kg^{-1}; Ca = minimum 125 g kg^{-1} and maximum 155 g kg^{-1}; P = minimum 65 g kg^{-1}; NaCl = minimum 185 g kg^{-1} and maximum 215 g kg^{-1}; Mg = minimum 10 g kg^{-1}; K = minimum 20 g kg^{-1}; S = minimum 6.7 g kg^{-1}; Mn = minimum 3 g kg^{-1}; Zn = minimum 4 g kg^{-1}; Cu = minimum 1 g kg^{-1}; Se = minimum 0.023 g kg^{-1}; Co = minimum 0.06 g kg^{-1}; I = minimum 0.07 g kg^{-1};; Vitamin A = minimum 330,693 units kg^{-1}; Vitamin D-3 = minimum 66,138 units kg^{-1}; Vitamin E = minimum 330 units kg^{-1}).

Forage Responses

Pre- and post- grazing forage mass was determined by hand-harvesting the forage from three random locations within the paddock to 3 cm height within 0.1 m^2 quadrats defined by 3-cm diameter polyvinyl chloride (PVC) pipes. All samples were hand separated and divided into alfalfa, bermudagrass, and other components (all other forage species and weeds) before being placed in a forced-air drying oven at 55°C for 4 d to correct for moisture content. The dry weights of each component were summed to determine botanical composition and forage mass per hectare. Forage allowance (kg forage DM kg animal LW^{-1}) was calculated as the average of total herbage mass at pre- and post-grazing divided by the sum of the total average animal weight for each grazing paddock (Allen et al., 2011) Stocking rate (kg LW ha^{-1}) was calculated as the total average animal weight for each grazing paddock divided by the total grazing paddock area (Allen et al., 2011).

After drying, pre-graze samples from the three quadrats were composited by paddock for each date prior to being ground for nutritive value analysis for both years of the study. These samples were ground to pass a 1-mm sieve using a Wiley Mill (Thomas-Wiley Laboratory Mill, Thomas Scientific, Swedesboro, NJ). The sample was then equally split using a sample splitter to create two subsamples, one for wet chemistry and one to be ground to pass through a 1-mm sieve (McIntosh et al., 2022) using a Foss Cyclone Sample Mill (Foss CT293, Foss Analytical, Eden Prairie, MN) in preparation for nutritive analysis via near infrared reflectance spectroscopy (NIRS).

Forage samples were analyzed for concentrations of dry matter (DM), acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), and 48 hour *in-vitro* dry matter digestibility (IVTDMD48) using the 2018 Mixed Hay calibration equations and the 2018 Grass Hay calibration equations, as provided by the NIRS Forage and Feed Testing Consortium (NIRSC, Berea, KY). Samples were analyzed using a Foss DS2500 NIR spectrometer (Foss Analytical, Eden Prairie, MN) that was standardized to the NIRSC master instrument to ensure prediction accuracy. Nutritive value data are reported with predictions fitting the allowable H <3.0 (Murray and Cowe, 2004). Total digestible nutrients (TDN) were calculated using the NIRS output from using the respective equations for grass monocultures (Eq. 1; NRC, 2001) and grass-legume mixtures (Eq. 2; Moore and Undersander, 2002):

$Eq. 1$

$$TDN = (NFC * 0.98) + (CP * 0.87) + (FA * 0.97 * 2.25) + \left[NDFn * \left(\frac{NDFDp}{100}\right)\right] - 10$$

$Eq. 2$

$$TDN = (NFC * 0.98) + (CP * 0.87) + (FA * 0.97 * 2.25) + \left[NDFn * \left(\frac{NDFD}{100}\right)\right] - 7$$

All values used in the calculation of TDN come from the NIRS analysis, where “CP” is crude protein (% DM),“NDFD” is 48-hour *in vitro* digestibility (% of NDF), “FA” is FA = EE - 1 (% DM), “NFC” is non fibrous carbohydrates = 100 – (NDFn + CP + EE + ash) (% DM), “NDFn” is nitrogen free NDF = NDF * 0.93, and “NDFDp” is NDFDp = 22.7 + 0.664 × NDFD (Undersander et al., 2010).

A subset of samples (18%) were analyzed via wet chemistry evaluations to validate the results from the NIRS. Validation samples were analyzed for dry matter (DM) and ash concentration (AOAC, 2000), NDF and ADF (Van Soest et al., 1991; AOAC 2000) using an ANKOM 2000 analyzer (ANKOM Technology, Macedon, NY; Mertens, 2002), *in vitro* true dry matter digestibility at 48 hours (IVTDMD48) was determined using a DaisyII *In Vitro* Incubator and ANKOM 200 Fiber Analyzer (ANKOM Technology, Macedon, NY; Mertens, 2002) as described by Valentine et al. (2018), and CP concentration using a Leco combustion analyzer (model FP628, Leco Corporation, Saint Joseph, MI).

Animal Reponses

All cattle were shrunk (removed from access to feed and water) for 12 hours before weighing at the initiation and termination of the grazing season each year. Animal performance was evaluated by weighing the testers at the conclusion of each grazing cycle (every 28 to30 days) throughout the grazing season. Grazers were weighed immediately prior to addition and after removal from paddocks.

Average daily gain (ADG) was determined by dividing the total weight of the testers by the number of grazing days per cycle. Liveweight gain (LWG) per hectare was attained by dividing the total LWG (sum of gain by testers and grazers) by the total area of each paddock (all three subsections combined).

Economic Analysis

An enterprise budget was developed for each treatment to evaluate the estimated revenue, cost of forage production, and net returns over total specified costs per hectare based on the data collected from the experiment. The cost of each treatment was calculated by multiplying the quantities of inputs used by the market prices available for the region (Butler et al., 2012; Interrante et al., 2012). The costs that were included in the enterprise budgets were seed, fertilizer, lime, machinery and equipment, custom spread applications, hired labor, soil tests, forage tests, miscellaneous expenses, general overhead, land rent, prorated establishment cost, and operating interest. The establishment costs of alfalfa inter-seeded into bermudagrass pasture were amortized over its expected useful life of five years. An assumption made for this economic analysis was that a stocker producer based their purchasing and marketing decisions on utilizing a warm-season forage production program. The average total gain per hectare from each grazing treatment was multiplied by the value of gain from 2018 and 2019 to determine the estimated revenue per hectare. The Georgia Weekly Livestock Summary was used to calculate the value of gain for the time period and steer weights that were evaluated in this study.

Statistical Analysis

Data were analyzed by restricted maximum likelihood using PROC MIXED with an autoregressive (1) covariance structure in SAS v9.4 (SAS Institute. Inc., Cary, NC; Littell et al., 2006). The Autoregressive (1) covariance structure was determined to be the best fit for these models based on the lowest Bayesian's Information Criterion (Littell, et al., 2006). The fixed effects included year, grazing cycle, grazing treatment, and their interaction. Block was considered a random effect. Differences in seasonal forage mass, forage allowance, stocking rate, gain ha, ADG, and nutritive value were analyzed across years and grazing cycles. A Kenwood-

Rogers adjustment was used to correct the denominator degrees of freedom and ensure appropriate standard errors and *F* statistics for each tested model. Means were compared using the LSMEANS procedure with Tukey-Kramer adjustment $P \leq 0.05$. Differences were considered significant at $P \leq 0.10$.

Results and Discussion

Weather

Rainfall exceeded the 100 year average for most of the summer grazing season in Y1, while moisture was limiting throughout most of Y2 (Fig. 3.1A). Both trial years rank in the top ten warmest years on record when compared to the 100-year average, however mean monthly temperatures were generally higher in Y2 than Y1 (Fig. 3.1B; NOAA, 2020). Therefore, there were four grazing cycles in Y1 resulting in 117 d of consecutive grazing and only three grazing cycles in Y2 with 87 d consecutive of grazing.

Pasture Responses

Overall, there was difference for the average forage mass of each grazing treatment ($P<0.001$). The cumulative forage mass for each grazing event was similar for BGA and BGN (1966±100.4 kg ha^{-1} and 2030±100.4 kg ha^{-1}, respectively), with BG having the lowest average forage mass (1364±100.4 kg ha^{-1}). While the values reported are lower than those observed by Rushing et al. (2022), they are similar in that BGA had a greater forage mass compared to BG. The observed average forage mass is also lower than those reported by Hendricks et al. (2020) for both the alfalfa-bermudagrass mixture and the fertilized bermudagrass harvested as baleage.

Stand composition fluctuated throughout the grazing season (Figure 3.2). At grazing initiation in both years, and BG and BGN (Figure 3.2 A and B) systems had a lower percentage of bermudagrass present (BG=54% and 80%; BGN=60% and 76%, Y1 and Y2 respectively);

however, this component increased to approximately 76% or higher starting at C2 through the end of the grazing study. At study initiation in the BGA treatments (Figure 3.2C), alfalfa comprised 80% of the grazing system and steadily declined to approximately 10% by C4 in Y1. In Y2 C1 and C2, alfalfa comprised approximately 30% of the grazing system and declined to less than 10% in C3. As expected, the opposite occurred for BGA treatment bermudagrass presence reporting an increase as the study progressed into the warmer summer months, from 8% at initiation to 56% at conclusion in Y1 and from 42% to 73% for Y2. These changes in the composition of the BGA treatments throughout the grazing season are supported by Hendricks et al., (2020), which illustrates the ebb and flow relationship of alfalfa-bermudagrass mixtures which alfalfa is the predominant species in the cooler months, whereas bermudagrass becomes the dominate species during the hot summer months.

Seasonal forage nutritive value parameters CP, ADF, NDF, IVTDMD48, and TDN were affected by treatment (Table 3.2). Overall, BGA treatments were greatest among all nutritive value parameters ($P < 0.01$), BG and BGN treatments were similar for all nutritive value parameters, apart from CP in which the BG treatment was the lowest.

The recommended average CP for a growing stocker steer is approximately 120 g kg^{-1} (BCNRM, 2016). The seasonal pre-graze forage analyses of all grazing treatments, either met or exceeded these CP recommendations (Table 3.2). Forage CP for BGA treatments was greater than the BG and BGN treatments ($P < 0.01$). The CP values reported for BGA, BGN, and BG treatments in the current study are similar to those reported by Beck et al., (2017*b*), Beck et al. (2017*d*) and Hendricks et al., (2020) for bermudagrass monoculture and alfalfa-bermudagrass mixed pastures.

While the CP was sufficient for growing stocker steers, the minimum TDN requirement for a growing stocker steer was not met. In this study, TDN for BGA treatments was greater than the BG and BGN treatments ($P < 0.01$). The current minimum TDN recommendation for a growing stocker steer is approximately 650 g TDN kg^{-1} (BCNRM, 2016). The reported values were also lower than those reported by Beck et al. (2017*b*), Beck et al. (2017*d*), and Hendricks et al. (2020) for all BG, BGN, and BGA grazing treatments. However, Rushing et al. (2022) reported TDN values that are similar to the current study for TDN, but that are higher than the BG and BGN treatments. The inability for the minimum TDN requirement to be met can be attributed to the increased stocking rate and unequal rest periods for each grazing section.

Forage NDF and ADF values were lower in the BGA treatment ($P < 0.01$; $P < 0.01$, respectively) in comparison to BG and BGN, and were lower than those observed by Beck et al. (2017*b*) for BGA mixtures. The NDF was higher than those reported by Beck et al. (2017*d*); however, the ADF was comparable. Further, the NDF and ADF for both BGN and BGA treatments were higher than those reported by Hendricks et al. (2020). Variation in NDF and ADF values observed in this evaluation could be directly related to the botanical composition of the grazing paddocks coupled with the timing of fertilizer applications.

Overall, in the current study, BGA consistently provided greater nutritive value than the BG and BGN treatments. The results from this study agree with Beck et al. (2017*b,d*), who observed an improvement in the overall nutritive value of the forage base for the bermudagrass treatments that contained alfalfa in comparison to those treatments fertilized or not fertilized with other N sources. Likewise, Hendricks et al. (2020) reported an improvement to the overall nutritive value of the forage base when including alfalfa into Tifton-85 bermudagrass.

The nutritive value of Tifton-85 bermudagrass in the BG and BGN treatments is similar to that observed by Hill et al. (1993), Hill et al. (1997), Corriher et al. (2007), Bernard et al. (2010), and Smith et al. (2020). The similarity in nutritive value between the BG and BGN treatments despite the lack of N application, may be partially related to the significant contribution of other high quality grazeable forages volunteering in the pastures during various times of the year, in this case annual ryegrass (*Lolium multiflorum*) and crabgrass (*Digitaria sanguinalis*).

Animal Responses

Stocker cattle seasonal ADG and liveweight gain ha^{-1} (LWG) are presented in Tables 3.3 and 3.4. Overall, there were differences for ADG ($P = 0.06$) among the grazing treatments, in that the BGA has the greatest ADG (0.78 kg ha^{-1} ± 0.03), compared to BG and BGN 0.68 kg ha^{-1} ± 0.03 and 0.66 kg ha^{-1} ± 0.03, respectively). Additionally, LWG was different ($P = 0.02$), in that BGA had the greatest gain ha^{-1} (138 ± 14.2 kg ha^{-1}), compared to BG and BGN (77 ± 14.2 kg ha^{-1} and 95± 14.2 kg ha^{-1}, respectively). This is similar to Rushing et al., (2022), which observed a difference among the ADG for stocker steers grazing BG, BGN, and BGA pastures. Rushing et al., (2022) observed that stocker steers grazing BGA had a greater ADG compared to BG and BGN. Conversely, Beck et al. (2017*c*) did not report any animal ADG differences among alfalfa-bermudagrass systems under grazing. Tester ADG from the current study for BG and BGN treatments are slightly lower than those reported by Hill et al. (2001).

Differences in the LWG reported in the current study can be attributed to the BGA treatments supporting a greater stocking rate throughout the grazing season as compared to the BG and BGN treatments (Table 3.4). Beck et al. (2017*c*) and Rushing et al., (2022) also observed and increase in total LWG per steer in bermudagrass pastures interseeded with alfalfa compared to bermudagrass pastures fertilized with or without N.

In the current evaluation BGA treatments were able to maintain a greater stocking rate when compared to the BG and BGN treatments ($P < 0.01$; Table 3.4). Stocking rates in this evaluation were slightly lower than those reported by Beck et al. (2017*a*) for all treatments. While not significant there was an observed difference between the BG and BGN treatments, in that the BGN treatments had a higher seasonal stocking rate in comparison to the unfertilized BG treatment. This is supported by Burns et al. (2009) and Beck et al. (2017*a*) who reported that there was a higher stocking rate on bermudagrass pastures fertilized with N, which resulted from the increase in the herbage accumulation.

Forage allowance was only greater in the BGN treatments in comparison to BG and BGA treatments (Table 3.4). This increase in forage allowance is linked to the timing of synthetic N fertilization that occurred. While this was the only instance of differing forage allowance among treatments throughout the study, forage allowance was limiting in the BG and BGA treatments across the grazing season. This was a result of having an increased stocking rate, which in turn increased the grazing pressure and reduced selective grazing. This increase in the grazing pressure alters the features of the forage mass and diet selection (Roth et al., 1990). While forage allowance was only limiting in forage quantity for BG and BGA treatments (target FA: 1 kg DM^{-1} kg liveweight [LW]$^{-1}$; Minson, 1990), this level of allowance did not preclude of cattle grazing BGA treatments from having greater performance for all other parameters measured.

Economics

During 2018 and 2019, feeder steers weighing approximately 211 kg during May were assumed to be purchased and grazed until being marketed during September weighing approximately 293 kg. The average value of gain was $0.51/kg, which is representative for the time period and weights evaluated in this study. The estimated net returns over total specified costs per hectare were calculated by subtracting the estimated cost of forage production per hectare from the estimated revenue per hectare. Estimates of the revenue, cost of forage production, and net returns over total specified costs from each grazing treatment during 2018 and 2019 are provided in Table 3.5. The economic results of this study reveal that the revenues among the treatments ranged from $39.42 to $70.43 per hectare, whereas cost of forage production ranged from $35.97 to $62.49 per hectare. The estimated net returns over grazing costs ranged from −$11.39 to $7.94 per hectare (Table 3.5). The higher net returns observed for the BGA treatments in the current study supports observations by Rushing et al., (2022). The net returns for the BG and BGN treatments do not support the reported net returns of Rushing et al., (2022) for similar treatments.

Conclusion and Implications

The inclusion of a legume into an existing grass monoculture has great potential for the improvement of Southeastern livestock-forage grazing systems. The results from this study indicate that the utilization of an alfalfa-bermudagrass mixture in comparison to bermudagrass monoculture pastures fertilized with or without synthetic N, not only provide a higher quality grazeable forage source to stocker steers throughout the summer months, but also a higher stocking rate in a rotational stocked system which in turn provides greater economic viability. Economic results of this study indicated that alfalfa-bermudagrass and bermudagrass without nitrogen can provide positive economic returns per hectare, while alfalfa-bermudagrass has greater net returns above total specified costs compared to bermudagrass without the inclusion of legumes. Producers looking to utilize alfalfa-bermudagrass mixtures can not only have greater animal performance, but also an economically viable option to reduce their reliance on synthetic nitrogen sources. Other implications from this study indicate that no matter the grazing treatment longer rest periods are required for the forages evaluated to allow for adequate rest and regrowth, particularly when extreme environmental stress occurs (i.e., drought, flood). Further research is warranted in determining the appropriate rest periods required for alfalfa-bermudagrass mixtures in the Southeastern United States. The overall conclusion from this study is that the utilization of alfalfa-bermudagrass mixtures can serve as a viable option for Southeastern stocker cattle producers, especially those looking to reduce dependence on synthetic nitrogen sources.

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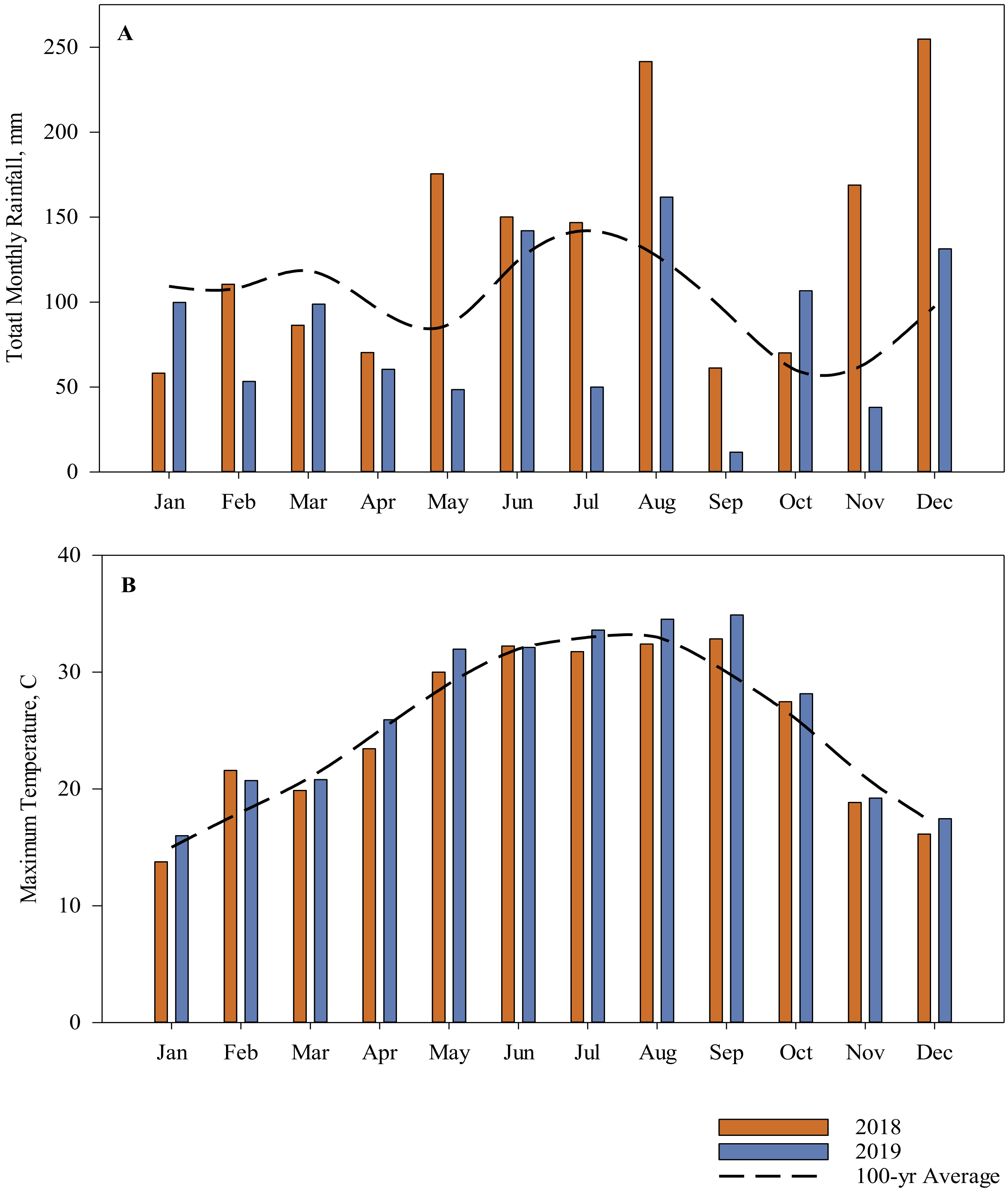

Figure 3.1. (A) Total monthly rainfall (mm) and (B) average monthly temperature (°C) for 2018, 2019, and the 100-year average for May through September in Tifton, GA. Data collected from the University of Georgia Automated Environmental Monitoring Network (UGA-AEMN, 2020).

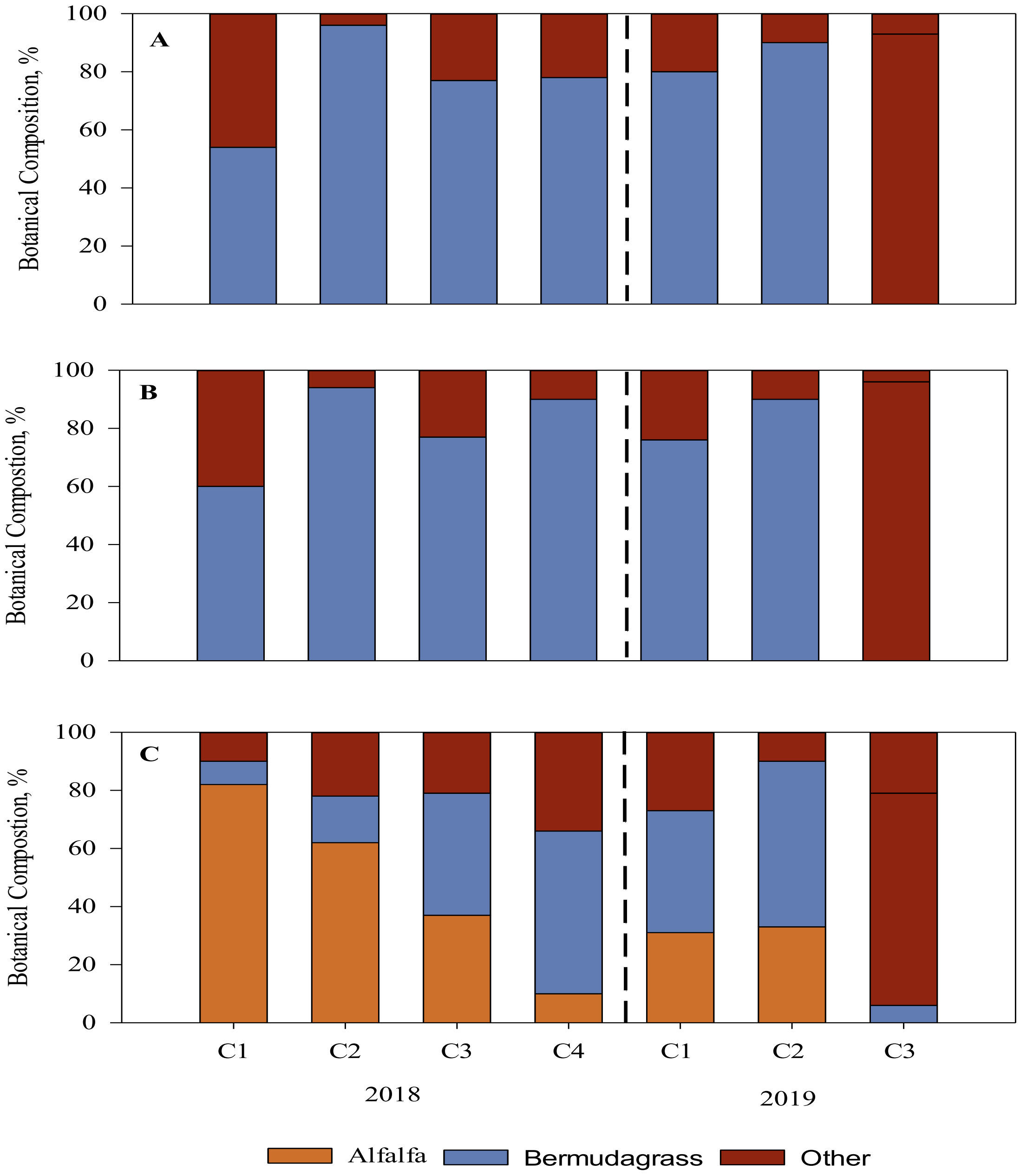

Figure 3.2: Botanical composition (%) of alfalfa, bermudagrass, and 'other' components in (A) unfertilized 'Tifton 85' bermudagrass (BG), (B) 'Tifton 85' bermudagrass supplemented with synthetic nitrogen (89.7 kg ha^{-1}; BGN), and (C) 'Tifton 85' bermudagrass interseeded with 'Bulldog 805' alfalfa (BGA) at each grazing cycle for 2018 and 2019 in Tifton, GA. A grazing cycle is defined as a complete rotation through each pasture on a 28 to 30 day interval.

Table 3.1. Grazing cycle dates for stocker steers grazing bermudagrass monoculture pasture supplemented with or without synthetic N or alfalfa-bermudagrass mixed pastures during the 2018 (Year 1) and 2019 (Year 2) grazing season in Tifton, Georgia.

Year	Grazing cycle[1]	Date
2018	1	21 May - 21 June
	2	21 June – 18 July
	3	18 July – 16 August
	4	16 August – 14 September
2019	1	21 May – 19 June
	2	19 June – 17 July
	3	17 July – 14 August

[1] Grazing cycle: a complete rotation through all three subsections on a 28 – 30 day interval.

Table 3.2. Seasonal pre-graze nutritive value (g kg^{-1}) using near-infrared spectroscopy (NIRS) analyses of bermudagrass monoculture pasture supplemented with or without synthetic N or alfalfa-bermudagrass mixed pastures during the 2018 (Year 1) and 2019 (Year 2) grazing season in Tifton, Georgia.

	Treatments			
Item, g kg^{-1}	**BG**[1]	**BGN**[2]	**BGA**[3]	**SEM**[4]
CP[5]	125^{c}	139^{b}	182^{a}	56.1
ADF	339^{b}	334^{b}	309^{a}	58.5
NDF	680^{b}	673^{b}	487^{a}	119.3
IVTDMD48	692^{b}	707^{b}	757^{a}	86.2
TDN	497^{b}	498^{b}	520^{a}	38.7

Note: Average dry matter was 96 ± 0.15%

[1] BG: Bermudagrass without nitrogen

[2] BGN: Nitrogen (90 kg ha^{-1}) supplemented bermudagrass

[3] BGA: Bermudagrass interseeded with alfalfa

[4] SEM: Standard Error of the Mean

[5] CP: Crude Protein; ADF: Acid Detergent Fiber; aNDF: Neutral Detergent Fiber; IVTDMD48: in-vitro Dry Matter Digestibility at 48h;TDN: Total Digestible Nutrients

BGA total digestible nutrients = (NFC x 0.98) + (CP x 0.87) + (FA x 0.97 x 2.25) + [NDFn x (NDFD /100)] – 7. (NRC, 2001)

BGN and BG total digestible nutrients = (NFC x 0.98) + (CP x 0.87) + (FA x 0.97 x 2.25) + [NDFn x (NDFDp /100)] – 10. (Moore and Undersander, 2002).

[ab] Within a row means without common superscripts differ ($P \leq 0.10$).

Table 3.3. Average liveweights (kg) of tester stocker cattle rotationally grazing bermudagrass monoculture pasture supplemented with or without synthetic N or alfalfa-bermudagrass mixed pastures, for the 2018 (Year 1) and 2019 (Year 2) grazing season in Tifton, Georgia.

		Treatment			
Year	**Cycle**	**BG**[1]	**BGN**[2]	**BGA**[3]	**SEM**[4]
1	Initiation	200	205	203	13.9
	Midpoint	247	251	256	14.7
	Conclusion	273	272	288	15.9
2	Initiation	221	218	220	16.5
	Midpoint	276	274	285	25.0
	Conclusion	304	300	319	18.5

[1] BG: Bermudagrass without nitrogen

[2] BGN: Nitrogen (90 kg ha^{-1}) supplemented bermudagrass

[3] BGA: Bermudagrass interseeded with alfalfa

[4] SEM: Standard Error of the Mean

[ab] Within a row means without common superscripts differ ($P \leq 0.10$).

Table 3.4. Seasonal gain/ha (kg ha), seasonal average daily gain (kg hd), seasonal stocking rate (kg ha), and seasonal forage allowance (kg forage DM/kg steer BW) for stocker steers rotationally grazing bermudagrass monoculture pasture supplemented with or without synthetic N or alfalfa-bermudagrass mixed pastures for the 2018 (Year 1) and 2019 (Year 2) grazing season in Tifton, Georgia

	Treatment			
Item	**BG[1]**	**BGN[2]**	**BGA[3]**	**SEM[4]**
Seasonal Average Daily Gain (kg/hd/d)	0.68^b	0.66^b	0.78^a	0.03
Seasonal Gain/ha (total kg LWG ha^{-1})	77^b	95^b	138^a	14.2
Seasonal Stocking Rate (kg BW ha^{-1})	353^b	398^b	509^a	18.8
Seasonal Forage Allowance (kg forage DM kg steer LW^{-1})	0.53^b	0.71^a	0.44^b	0.04

[1] BG: Bermudagrass without nitrogen

[2] BGN: Nitrogen (90 kg ha^{-1}) supplemented bermudagrass

[3] BGA: Bermudagrass interseeded with alfalfa

[4] SEM: Standard Error of the Mean

^{ab} Within a row means without common superscripts differ ($P \leq 0.10$).

Table 3.5. Economic summary of stocker steers rotationally grazing bermudagrass monoculture pasture supplemented with or without synthetic N or alfalfa-bermudagrass mixed pastures for the 2018 (Year 1) and 2019 (Year 2) grazing season in Tifton, Georgia.

	Treatments		
Item, \$/ha^{-1}	**BG[1]**	**BGN[2]**	**BGA[3]**
Estimated Revenue	\$39.42	\$48.45	\$70.43
Cost of forage production	\$35.97	\$59.84	\$62.49
Net returns over total specified costs	\$3.45	-\$11.39	\$7.94

[1] BG: Bermudagrass without nitrogen

[2] BGN: Nitrogen (90 kg ha^{-1}) supplemented bermudagrass

[3] BGA: Bermudagrass interseeded with alfalfa

CHAPTER 4

EVALUATING PLANT AND ANIMAL PERFORMANCE OF ALFALFA-BERMUDAGRASS SYSTEMS USING TWO DIFFERENT BERMUDAGRASS BASES UNDER VARIED HARVEST MANAGEMENT STRATEGIES IN GEORGIA

[1] Burt, J.C., L.L. Baxter, R.L. Stewart, Jr., M.K. Mullenix, and J.J. Tucker. To be submitted to *Journal of Animal Science*

Abstract

The inclusion of alfalfa (*Medicago sativa* L.) into bermudagrass (*Cynodon* spp.) swards may reduce reliance on synthetic N fertilization while providing high-quality forage for hay, baleage, or intensive grazing. Interseeding grazing tolerant alfalfa varieties into bermudagrass can extend the production season of Southern pasture systems, however data are limited on how long the grazing season can be extended. Data are also limited on the optimal harvest management strategies (HMS) for alfalfa-bermudagrass (ABG) mixture production and persistence. Therefore, a two-year evaluation was conducted to evaluate forage and animal responses in two different ABG mixtures under three HMS in Tifton, GA in 2020 and 2021. Twelve, 1 ha pastures were arranged in a randomized complete block design in a 3 x 2 factorial arrangement. Treatments included: Cut only (CT), Graze only (GR), or Cut and Graze (CG) management of 'Bulldog 805' alfalfa interseeded into either 'Russell' or 'Tifton 85' bermudagrass. All pastures were evaluated for forage, animal, and seasonal production characteristics. There were differences observed by HMS for forage herbage accumulation in CT and CG treatments ($P<0.001$), the observed liveweight gain (LWG) and average daily gain of stocker cattle in GR and CG treatments ($P=0.004$ and $P=0.003$, respectively). However, a difference for the bermudagrass variety was only observed in the LWG ($P=0.02$) in that the Tifton 85 treatments were greatest. While certain aspects reported for the HMS evaluated were better for one single parameter, overall system performance indicates that the strategic management using the CG method optimizes the use of ABG mixtures in the Southeastern United States.

Introduction

Interseeding alfalfa (*Medicago sativa* L.) into an existing bermudagrass (*Cynodon* spp..) sward may decrease reliance on synthetic N fertilization while also providing a high-quality forage for livestock via stored forage production or intensive rotational stocking (Brown and Byrd, 1990; Stringer et al., 1996; Haby et al., 1999; Cassida et al., 2006; Beck et al., 2017a,b,c; Beck et al., 2017d; Hendricks et al. 2020; Burt et al., 20XX). Previous studies have focused on alfalfa under hay or grazing management throughout its growing season (Van Keren and Matches, 1988; Bouton et al., 1988; Smith et al., 1988; Bouton et al., 1997; Bouton and Gates, 2003; Bouton et al., 2006). However, in recent years the development of grazing tolerant, dual-use alfalfa varieties have been proven to work in monocultures as well as in alfalfa-bermudagrass (ABG) mixtures in the region (Bouton and Gates, 1993; Bouton et al., 2003; Haby et al., 1999; Cassida et al., 2006; Beck et al., 2017*a,b,c*; Beck et al., 2017*d*; Hendricks et al. 2020; Thinguldstad et al., 2020; Groce, 2020; Mason, 2020; Rushing et al., 2022; Burt et al., 20XX). While progress has been made with ABG mixtures Southeast as a high-quality forage option, research is still needed to determine the best harvest management strategy (HMS) of the ABG mixture.

To date, previous research has focused on the singular use of ABG mixtures in baleage production systems (Hendricks et al., 2020) or for rotationally grazing beef cattle (Beck et al., 2017*a*,*b*,*c*; Beck et al., 2017*d*; Rushing et al., 2022; Burt et al., 20XX). Limited works has evaluated the combination of stored forage production and grazing production together in the same pasture, but those have focused on grass only monoculture systems (D'Souza et al., 1990). No published data exists evaluating ABG mixtures under stored forage production or grazing management simultaneously or together on the same land area used to grow ABG mixtures.

Furthermore, ABG mixtures have been evaluated for the performance of alfalfa interseeded into common bermudagrass (Beck et al., 2017*a*,*b*,*c*; Beck et al., 2017*d*) and in various hybrid bermudagrass varieties such as 'Coastal', 'Midland', 'Tift 44', and 'Tifton 85' (Haby et al., 1999; Biermacher et al., 2012; Stringer et al., 1994, 1996; Cassida et al., 2006; Groce, 2020. Mason, 2020, Hendricks et al., 2020; Rushing et al., 2022; Burt et al., 20XX). All previous research evaluations have focused on ABG mixtures within a single bermudagrass variety. However, no data currently exists that compares ABG system performance across bermudagrass bases, nor within 'Russell' bermudagrass.

Additionally, previous research evaluations associated on ABG mixtures have not been grazed later than September (Cassida et al., 2006; Beck et al., 2017*d*, Rushing et al., 2022; Burt et al., 20XX). However, Hendricks et al., (2020) produced baleage in October and November, suggesting that ABG mixtures are productive into autumn. Grazing can be extended by grazing stockpiled forage (Matches and Burns, 1985). Stockpiling forage for grazing is a common practice in many grass species and has been successful with bermudagrass (Lalman et al., 2000; Scarbrough et al., 2001, 2006; Bievens et al., 2017; Holland et al., 2018). While stockpiled forages have an increased herbage mass and a lower nutritive value in comparison to actively growing forage (Riesterer et al., 2000), they can still maintain cattle production with little to no supplementation being required (Bivens et al., 2017; Holland et al., 2018). Legumes are more fragile than cool- and warm-season grasses and lose a large portion of their leaves after the first killing frost (Rohweder and Albrecht, 1995; Hitz and Russell, 1998),which can present a challenge for stockpiling. While ABG mixtures have been evaluated agronomically as a potential stockpile forage option (Vasco et al., 20XX), data do not currently exist on the utilization of ABG mixtures as a stockpiled grazing option.

Therefore, the objective of this study was to evaluate forage and animal productivity in two alfalfa-bermudagrass mixtures under three varied HMS to determine the management practice that optimizes the use of ABG mixtures in the Southeastern United States.

Materials and Methods

This project was approved by the University of Georgia IACUC Committee IACUC AUP #: A2019 10-013-Y1-A0.

Experimental Location, Establishment, and Management

A two-year evaluation was conducted on twelve, 1 ha, pastures of hybrid bermudagrass interseeded with alfalfa in a randomized complete block design in a 3 x 2 factorial arrangement. Research was conducted from June to November 2020 (Y1) and April to December 2021 (Y2) at the University of Georgia Tifton Campus Animal Science Farm in Tifton, GA (31˚29′ N, 83˚32 W; 100m elevation). The research site had a 0-5% slope comprised of Tifton loamy sand soils (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) and Fuquay loamy sand soils (loamy, kaolinitic, thermic Arenic Plinthic Kandiudults).

Pastures consisted of hybrid varieties of bermudagrass, either Russell or Tifton 85, which were established via sprigging in May 2017. Pastures were prepared for the establishment of alfalfa in November 2019 following UGA Extension recommendations for interseeding alfalfa into bermudagrass (Hancock et al., 2015; Tucker et al., 2021). Bermudagrass was clipped to a 5 cm stubble height. In a hay harvest event to removed excess biomass. Pastures were then sprayed at a suppression rate with glyphosate (2.5 kg a.i. ha^{-1}), to induce dormancy of the bermudagrass. Approximately two-weeks later a semi- to non-dormant alfalfa cultivar ‘Bulldog 805’ (Athens Seed Co., Watkinsville, GA.) was interseeded into the existing Russell and Tifton 85 bermudagrass sod using a no till drill (Drill Prototype, First Products; Tifton GA) planted at a rate of 16.8 kg ha^{-1} at a soil depth of 1.27 cm and 35.5 cm row spacing. Topsoil (0-15 cm) and subsoil (15-30 cm) samples were collected in each treatment prior to paddock allocation and at the study termination of each year, to determine fertility requirements. All pastures were fertilized according to UGA soil test recommendations (Kissel and Sonon, 2008), with 300 units of K, in the form of muriate of potash split across three applications (223 kg ha^{-1} at each application) annually prior to study initiation, between June to July, and in September (Tucker et al., 2021).

Prior to study initiation, pastures were randomly assigned to the three treatments: cut only (CT), graze only (GR), or cut and graze (CG), and the pastures undergoing grazing were divided into four equal paddocks to be grazed by rotationally stocking stocker cattle. All pastures, approximately 20 d prior to study initiation, were clipped to a 10 cm height and herbage mass was removed from pastures (New Holland Discbine 313 and Krone Fortima V1800 MC), to remove any old forage growth and winter weeds that may have been present. All pastures were harvested when alfalfa was at a 25% bloom stage in May of Y1 and at a 10% bloom stage in April of Y2. In addition to the reset cut that occurred prior to study initiation, Pendimethalin (Prowl H2O [N-(1-ethylpropyl)-3,4- dimethyl-2,6-dinitrobenzenamine], BASF Ag Products) was applied for preemergent control of annual grass weeds at a rate of 1.1 kg a.i. ha^{-1}. Pendimethalin was applied to all treatments prior to study initiation (approximately April), and then applied only to the CT and CG treatments in middle of the growing season (approximately August), and in October for CT only for both Y1 and Y2. All grazing paddock sections of GR were mowed to approximately 10 cm height in between June and July in Y1 and July and August in Y2 using a rotary cutter (Woods BB60, Blount International Portland, Oregon) to remove any overmature forage material and undesirable pasture weeds during active growth of the ABG mixture as a weed control method.

Scouting for insect pests occurred at establishment and weekly in all paddocks and pesticide applications occurred as warranted. During Y1 and Y2, zeta-cypermethrin (Mustang Maxx [zeta-cypermethrin*S-cyano(3-phenoxyphenyl)methyl (+) cis/trans 3-(2,2-dichloro-ethenyl)-2,2, dimethylcyclopropane carboxylate], FMC Corporation) was applied at a rate of 28 g a.i. ha^{-1} to control three-cornered alfalfa leaf hopper [*Spissistilus festinus* (Say) (Hemiptera: Membracidae)] and bermudagrass stem maggot (BSM; *Atherigona reversura* Villeneuve). This was applied to all pastures in the CT and CG (when harvested for baleage) for control of bermudagrass stem maggot as warranted. Chlorantraniliprole (Prevathon, Corteva Agriscience) was applied once during August of both Y1 and Y2 growing seasons at a rate of 100 g a.i. ha^{-1} for control of fall armyworm [*Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)].

The CT treatment was harvested for stored forage as hay or baleage and harvested on a 28 to 35 d interval throughout the evaluation. The GR treatment was initiated 20 d post reset cutting prior to study initiation. Stocker cattle were rotated every 7 d resulting in a 28 d interval within a grazing cycle. The CG treatment was grazed by stocker cattle following the same procedure as previously described for the GR treatment, for the months of June and July in Y1 and May and June in Y2. After which, stocker animals were removed, and pastures were harvested as baleage following the procedure as described for the CT treatments, for the month of July in Y1 and July to September in Y2. Following the last baleage harvest, forage mass was allowed to accumulate in the CG paddocks, to allow for six weeks of regrowth to then undergo stockpile/deferred grazing for the autumn months (Y1=October to November and Y2=October to

December). Specifics for baleage and grazing management are described in the following sections.

Baleage Management

Harvests occurred when alfalfa reached a 10% bloom stage, adapted from the procedure outlined in Mueller and Fick (1989) and maintained a 28 to 35 d cutting interval throughout the evaluation. Harvest began ~1700 h using a mower conditioner (New Holland Discbine 313, New Holland Agriculture). At ~0930 h the morning after cutting, grab samples from each pasture were collected and forage moisture of each bermudagrass base was determined using the microwave moisture test (Ball et al., 2015). Once a target moisture of 55% was achieved, forage was raked into windrows using a rotary rake (Krone Swadro TS680; Krone NA, Olive Branch, Mississippi) and baled and wrapped using a Krone Fortima V1800 MC (Krone NA, Olive Branch, Mississippi). Bales were wrapped with six layers of pre-stretched (55%) polypropylene baleage wrap (Sunfilm Stretch Wrap, TAMA Group). Prior to storage, cores were taken from bales and composited by pasture for nutritive value analysis. The extended length of the evaluation, encompassing the spring, summer, and early fall growing seasons, resulted in expected seasonal fluctuations of specific forage contributions. Therefore, mechanical harvesting events were divided into harvest cycles. A harvest cycle (C) is defined as a complete 28 to 35 d rest period between harvesting events.

Grazing Management

In season Grazing Management and Animal Responses

Yearling crossbred stocker cattle (*Bos taurus X Bos indicus*) were randomly assigned to each grazing treatment replicate each year based on body weight (BW). Prior to study initiation, stockers were backgrounded for approximately 45 d on pastures comprised of primarily annual ryegrass (*Lolium multiflorum*) at the University of Georgia Alapaha Range Cattle Unit, Alapaha, GA (31°21'0.23"N, 83°13'30.66"W, 83 m elevation). Mean starting body weights (BW) of tester steers were 229.2 ± 28.35 kg and 184.6 ± 20.83 kg, Y1 and Y2, respectively. This experiment utilized the put-and-take stocking method as defined by Mott and Lucas (1952). Two tester steers were randomly assigned to each pasture and remained on trial for the entire grazing season. Grazers (steers or heifers) were allocated as needed to equilibrate forage allowance (FA) among treatments (target FA: 1 kg DM kg liveweight^{-1} [LW]; Minson, 1990). All stocking decisions were determined based on the available forage estimated by hand-harvesting biomass one day prior to rotation to a new section and in conjunction with the use of a pasture ruler and a rising plate meter (RPM; Jenquip, New Zealand).

One day prior to study initiation tester steers were implanted (Ralgro; 36 mg zeranol, Merck Animal Health, Kirkland, QC, Canada). Throughout the trial, all cattle were provided *ad libitum* access to water, artificial shade, and mineral containing monensin for bloat prevention (AMPT A RU, ADM Animal Nutrition, Quincy, IL; Monensin = 1.8 g kg^{-1}; Ca = minimum 138 g kg^{-1} and maximum 164 g kg^{-1}; P = minimum 40 g kg^{-1}; NaCl = minimum 192 g kg^{-1} and maximum 228 g kg^{-1}; Mg = minimum 30 g kg^{-1}; K = none added; Co = minimum 0.15 g kg^{-1}; Mn = minimum 3.6 g kg^{-1}; Zn = minimum 4.2 g kg^{-1}; Cu = minimum 1.2 g kg^{-1}; Se = minimum 25 g kg^{-1}; I = minimum 0.2 g kg^{-1}; Vitamin A = minimum 200,000 IU/LB; Vitamin D_3 = minimum 5,000 IU/LB; Vitamin E = minimum 100 IU/LB).

All cattle were weighed using the double-weight method as described by Stuedemann and Matches (1989) at the initiation and termination of the grazing season each year. Average daily gain (ADG) for in-season grazing was evaluated by weighing the testers on a 28 d interval throughout the grazing season. Additional grazers were weighed immediately prior to addition and after removal from paddocks based on herbage availability, for determining liveweight gain per ha^{-1} (LWG).

Average daily gain was determined by dividing the total weight of the testers by the number of grazing days per cycle. Liveweight gain (LWG) per hectare was attained by dividing the total LWG (sum of gain by testers and grazers) by the total area of each pasture (all four subsections combined). Forage allowance (FA; kg forage DM kg animal LW^{-1}) was calculated as the average of total herbage mass at pre- and post-grazing events divided by the sum of the total average animal weight for each grazing paddock (Allen et al., 2011) Stocking rate (SR; kg LW ha^{-1}) was calculated as the total average animal weight for each grazing paddock divided by the total grazing paddock area (Allen et al., 2011). Stocking density decisions were based on forage mass (Allen et al., 2011), using a pasture ruler and RPM (Jenquip, New Zealand).

Grazing was initiated in June of Y1 and April of Y2 and was terminated when available forage was $\leq$ 1,120 kg DM ha^{-1}. The extended length of the evaluation encompassing the late spring, summer, and fall growing seasons and expected seasonal fluctuations in specific forage contributions resulted in grazing events being divided into cycles. A grazing cycle (C) is defined as a complete rotation through all four grazing paddocks resulting in a 28 d rest period between grazing events.

Stockpiled Grazing Management and Animal Responses

Stockpiled grazing ABG mixtures occurred only in CG paddocks. Yearling crossbred stocker cattle (*Bos taurus X Bos indicus*) that had been previously assigned to each CG treatment for in-season grazing, were used for their respective replicate each year. These stockers were grazing on the previously described ABG mixtures or were grazing on pasture comprised of Tifton 85 bermudagrass and supplemented with ABG baleage to maintain their acclimation to the

ABG mixture. Mean starting BW of stockers were 331.6 ± 30.07 kg and 270.2 ± 33.35 kg, year 1 and 2, respectively. A fixed stocking rate comprised of two testers and two grazers for each treatment was utilized to maximize harvest efficiency, thus area provided was adjusted rather than the stocking density. Temporary front and back electrified polywire fences were moved every 2-3d for the animals to have access to a new section of forage as determined by pre- and post-grazing forage mass estimates in conjunction with the use of a pasture ruler. Stockpile grazing sections were determined by using a pasture ruler and taking an average of the canopy height, which was then used calculate the forage mass needed to achieve an estimated DMI of 3% of average animal BW (BCNRM, 2016) and maintain a 75% efficiency of utilization. Cattle were provided *ad libitum* access to water, artificial shade, and mineral as previously described.

Animal performance for stockpile grazing was determined by weighing testers and grazers at the initiation and conclusion of the stockpiling grazing period, using the double weight method as described by Stuedemann and Matches (1989). Average daily gain (ADG) was determined by dividing the total weight of the testers by the number of grazing days for each bermudagrass variety. FA and LWG were calculated as previously described.

Forage Sampling

Prior to harvesting all treatments in baleage production or rotationally stocking stockers for in-season grazing, paddocks were evaluated for herbage mass using a pasture ruler and a rising plate meter (RPM; Jenquip, New Zealand), and botanical composition via hand separation into alfalfa, bermudagrass, and ‘other’. ‘Other’ is defined as any other grazable forage or pasture weed. In stockpile grazing treatments, pre-and post-grazing events, paddocks were evaluated for herbage mass, alfalfa lodging, alfalfa growth stage, and botanical composition.

For all treatments herbage mass was determined by hand-harvesting the biomass to 10 cm height (Groce, 2020) from 0.1 m^2 quadrats defined by 3-cm diameter polyvinyl chloride (PVC) pipes. Samples were taken from five randomly placed quadrats for baleage and in-season grazing treatments, and from three randomly placed quadrats for stockpile grazing treatments. For botanical composition, all samples were hand-separated into alfalfa, bermudagrass, and 'other' components (all other forage species and weeds) before being placed in a forced-air drying oven at 55°C for 4 d to correct for moisture content. The dry weights of each component were summed to determine total plot weight before herbage accumulation per hectare was calculated.

Alfalfa stand density was assessed 60 d post study termination of each year by counting individual alfalfa crowns and stems within ten randomly placed 0.1 m^2 quadrats defined by 3-cm diameter polyvinyl chloride (PVC) pipes, per pasture.

Forage Analysis

All samples were first ground to pass a 1-mm sieve using a Wiley Mill (Thomas-Wiley Laboratory Mill, Thomas Scientific, Swedesboro, NJ). Samples were then equally split using a sample splitter to create two subsamples, one for wet chemistry and one to be ground to pass through a 1-mm sieve (McIntosh et al., 2022) using a Foss Cyclone Sample Mill (Foss CT293, Foss Analytical, Eden Prairie, MN) in preparation for nutritive analysis via near infrared reflectance spectroscopy (NIRS).

Forage samples were analyzed for concentrations of dry matter (DM), acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), and 48 hour *in-vitro* dry matter digestibility (IVTDMD48) using the 2020 Mixed Hay calibration equations and the 2020 Haylage calibration equations, as provided by the NIRS Forage and Feed Testing Consortium (NIRSC, Berea, KY). Samples were analyzed using a Foss DS2500 NIR spectrometer (Foss

Analytical, Eden Prairie, MN) that was standardized to the NIRSC master instrument to ensure prediction accuracy. Nutritive value data are reported with predictions fitting the allowable H <3.0 (Murray and Cowe, 2004). Total digestible nutrients (TDN) were calculated using the equation for grass-legume mixtures (Eq. 1; Moore and Undersander, 2002):

$Eq. 1$

$$TDN = (NFC * 0.98) + (CP * 0.87) + (FA * 0.97 * 2.25) + \left[NDFn * \left(\frac{NDFD}{100}\right)\right] - 7$$

All values used in the calculation of TDN come from the NIRS analysis, where "CP" is crude protein (% DM),"NDFD" is 48-hour *in vitro* digestibility (% of NDF), "FA" is FA = EE - 1 (% DM), "NFC" is non fibrous carbohydrates = 100 – (NDFn + CP + EE + ash) (% DM), "NDFn" is nitrogen free NDF = NDF * 0.93, and "NDFDp" is NDFDp = 22.7 + 0.664 × NDFD (Undersander et al., 2010).

A subset of samples (18%) were analyzed via wet chemistry evaluations to validate the results from the NIRS. Validation samples were analyzed for dry matter (DM) and ash content (AOAC, 2000), NDF and ADF (Van Soest et al., 1991; AOAC 2000) using an ANKOM 2000 analyzer (ANKOM Technology, Macedon, NY; Mertens, 2002), *in vitro* true dry matter digestibility at 48 hrs (IVTDMD48) was determined using a DaisyII *In Vitro* Incubator and ANKOM 200 Fiber Analyzer (ANKOM Technology, Macedon, NY; Mertens, 2002) as described by Pomerleau-Lacasse et al., (2019), and CP concentration using a Leco combustion analyzer (model FP628, Leco Corporation, Saint Joseph, MI).

Calculation of Total System Performance

The determination of total system performance was calculated as described by Baxter et al. (2017). Observed LWG was determined for the GR and CG treatments by weighing testers at the beginning and end of each 28 d grazing cycle, and by weighing grazers prior to and at removal from each grazing paddock as warranted. A predicted LWG was determined for each of the baleage harvests for the CT and CG treatments, by determining herbage accumulation from each baleage harvest every 28 to 35 d. Herbage accumulation was then DM corrected and converted to a predicted LWG as described in Appendix A of the Nutrient Requirements of Beef Cattle (BCNRM 2016, 2022). Total LWG for each pasture was calculated by summing the observed and predicted gains for the respective pastures.

Statistical Analysis

Data were analyzed by restricted maximum likelihood using PROC MIXED with an autoregressive (1) covariance structure in SAS v9.4 (SAS Institute. Inc., Cary, NC; Littell et al., 2006). The Autoregressive (1) covariance structure was determined to be the best fit for these models based on the lowest Bayesian's Information Criterion (Littell, et al., 2006). Differences in seasonal herbage accumulation, forage allowance, stocking rate, gain ha^{-1}, ADG, nutritive value, and their interactions were analyzed. Fixed effects included harvest method, bermudagrass variety, and their interactions. Year and block were considered a random effect. A Kenwood-Rogers adjustment was used to correct the denominator degrees of freedom and ensure appropriate standard errors and F statistics for each tested model. Means were compared using the LSMEANS procedure with Tukey-Kramer adjustment $P \leq 0.05$. Differences were considered significant at $P \leq 0.05$.

Results and Discussion

Weather

Total monthly rainfall and the average maximum monthly temperatures compared to the 100-year average are presented in Fig. 4.1 (A-B; UGA-AEMN, 2022). There were approximately 30 mm more rain in Y2 (133.2 mm) when compared to Y1 (103.2 mm). The overall maximum temperature were similar to or slightly higher than the 100-year average in Y1 and were similar to or slightly lower than the 100-year average for the majority of the growing season in Y2 (Fig. 1B; UGA-AEMN, 2022).

Days of Use

The actual number of days of use for each harvest method and bermudagrass variety varied by year (Fig. 4.2). Y1 had 112 total production days for each treatment distributed across the season which was expected since this was the establishment year. However, Y2 varied in total production days by both the harvest method and bermudagrass base (CT Russell=186 d; CT Tifton85=186 d; GR Russell= 168 d; GR Tifton85=186 d; CG Russell=165 d; and CG Tifton85=189 d). It should be noted that in Y2 the CG Tifton85 treatments were in production in December, whereas their Russell treatments ended production in November.

Forage Responses

Regardless of the harvest method or the bermudagrass variety, stand composition fluctuated throughout the growing season (P<0.001; Fig 3 A-C). In all treatments there was a greater presence of alfalfa early in the growing season and during the autumn grazing cycle. The autumn grazing cycle is defined as the stockpile grazing that occurred from October to November in Y1 and October to December in Y2. Bermudagrass was the dominate forage in the mixture during the hotter summer months. While the alfalfa in the stand declined throughout the growing season in both the GR and CG treatments to below 35%, it was greater than 35% at the beginning of the following year after study initiation. This is supported by Hendricks et al., (2020) and Burt et al. (2022), who both reported changes in the forage canopy with alfalfa being the dominate forage early in the growing season (March to June) of approximately 40% or higher, and then bermudagrass becoming the dominate forage later in the growing season (July to

September) of approximately 50% or higher. However, during the autumn grazing cycle of the GR and CG there was a greater portion of the stand dominated by bermudagrass, (mean=70%), as compared to alfalfa (mean=20%). This is a result of the “ebb and flow” relationship that is observed in ABG mixtures for alfalfa and bermudagrass components (Hendricks et al., 2020). The “other” reported in the present study were predominantly volunteer forages common to the area, such as annual ryegrass (*Lolium multiflorum*) in the early growing season, and crabgrass (*Digitaria sanguinalis*) in the later portion of the growing season.

Seasonal forage nutritive value parameters for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), and 48 hr. *in-vitro* dry matter digestibility (IVTDMD48) were not different among harvest method or bermudagrass variety (Table 4.2). The minimum CP requirements for a growing stocker steer is approximately120 g kg (BCNRM, 2016). The forage nutritive value from both baleage cores and pre-graze forage analysis, indicated that the CP either met or exceeded this recommendation for all harvest methods and bermudagrass varieties (Table 4.2). The CP reported is similar to or greater than those values reported for ABG mixtures by Beck et al. (2017b), Beck et al., (2017*d*), Hendricks et al., (2020), Rushing et al., (2022), and Burt et al., (20XX). Other nutritive value parameters, such as NDF and ADF, were also similar to those observed by Burt et al., (20XX), lower than those reported by Beck et al., (2017*b*), and higher than those observed by Henricks et al., (2020).

While CP, NDF, ADF, and IVTDMD48 were not different by harvest method or bermudagrass variety, or their interactions, TDN differed by the interaction of harvest method and bermudagrass variety (*P* = 0.01; Table 4.2). The minimum TDN requirements for a growing stocker steer is approximately 650 TDN g kg (BCNRM, 2016). The TDN for the present study was different by harvest method and bermudagrass variety (*P* = 0.01; Table 4.2). The TDN values were greatest in the CT treatments for both the Russell and Tifton85 bermudagrass (646.5 ±13.8 g kg and 651.1±13.8 g kg, respectively), and similar in the CG treatment for both the Russell and Tifton85 bermudagrass bases (628.1 ±13.8 g kg and 629.7±13.8 g kg, respectively). Forage TDN was lowest in the GR Russell treatment (620.3±13.8 g kg) whereas the GR Tifton85 treatment was similar to the other harvest methods (636.9±13.8 g kg). Reported TDN values are similar to those observed by Beck et al., (2017*b*), Beck et al., (2017*d*), and Hendricks et al., (2020). Rushing et al., (2022) and Burt et al., (20XX) reported TDN values that were lower than the current study for stocker steers grazing ABG mixtures (570.0±. 6.0 g kg and 520.2±38.71 g kg; respectively). The TDN values observed by Rushing et al. (2022) and Burt et al. (20XX) are attributed to being lower because of the stocking rate and unequal rest periods for each grazing paddock.

The current study follows findings, that regardless of bermudagrass base or harvest method used, the overall nutritive value of the forage base is improved with the inclusion of alfalfa into bermudagrass swards for CP, NDF, ADF, IVTDMD48, and TDN (Stringer et al., 1996; Haby et al., 1999; Biermacher et al., 2012; Cassida et al., 2006; Beck et al., 2017*b*; Beck et al., 2017*d*; Hendricks et al., 2020; Rushing et al., 2022; and Burt et al., 20XX).

At the termination of the study each year alfalfa stand crown and stem counts were taken (Fig. 4.4). There were no differences for the number of alfalfa crowns observed for Y1 or Y2 (P=0.20 and P=0.17, respectively), where the average number of crowns was 1 crown per 0.1 m^2. There were no differences for the interaction of harvest method and bermudagrass variety in Y1 (P=0.14), however, there were observed differences in Y2 (P=0.02) for the average number of alfalfa stems. This difference was observed in the GR Tifton85, which had a reduction in the average number of alfalfa stems decreased from 6.0 to 2.6. This decline in the stand density is reflected throughout the growing season of the mixture, as supported by the observed changes in the botanical composition of the mixture as the growing season progressed (Fig. 4.3A-C). The average number of alfalfa crowns per 0.1 m^2 were lower than that reported by Mason (2020) and the number of alfalfa crowns and stems per 0.1 m^2 reported were lower than those observed by Groce (2020) for ABG mixtures.

Baleage Responses

In terms of total number of baleage harvests for the CT treatment, there were five in Y1 and seven in Y2. In the CG treatments, there was only one in Y1 and three baleage harvests in Y2. Overall, there was a difference between harvest methods of CT and CG ($P < 0.001$) in that the CT had a greater herbage accumulation as compared to CG (11664 ± 304.9 kg DM ha^{-1} and 4115.6 ± 304.9 kg DM ha^{-1}, respectively), for pastures under baleage production. There were no differences observed across the season for the bermudagrass variety (P=0.82). The observed herbage accumulation is lower than the seasonal herbage accumulation for ABG baleage reported by Hendricks et al., (2020). Hendricks et al., (2020) reported a range in the seasonal herbage accumulation for ABG mixtures harvested as baleage for the 2016, 2017, and 2018 harvest season that were higher than that of the current study (14755 ± 642.0 kg DM ha^{-1}, 22654 ± 642.0 kg DM ha^{-1}, and 19211 ± 642.0 kg DM ha^{-1}, respectively).

Animal Responses

Seasonal ADG (kg hd) for stocker steers is presented in Table 4.1. A difference was observed by the harvest method (P=0.003) in that a higher ADG was observed in the CG treatments compared to the GR treatments (1.07±0.09 kg hd and 0.70±0.09 kg hd, respectively). There were no differences among the bermudagrass variety for the seasonal ADG of stocker steers (P=0.41). The observed seasonal ADG for the CG treatments were better than those reported by Beck et al., (2017*c*), Rushing et al., (2022), and Burt et al., (20XX) for stocker steers grazing ABG mixtures, while their observed ADG was similar to the GR treatments. The ADG values during the stockpile grazing cycle were also similar to or greater than those for stocker steers grazing stockpiled Tifton 85 bermudagrass as reported by Bivens et al., (2017). This higher ADG that was observed in CG treatments is a result of the paddocks being dominated primarily by alfalfa in addition to other high quality grazable forages such as annual ryegrass that were present early in the grazing season and the increased presence of alfalfa during the stockpile grazing period (Fig. 4.3).

Seasonal SR and seasonal total LWG by harvest method are presented in Table 4.1. There were no differences reported for the seasonal SR by harvest method or bermudagrass variety (*P*=0.62 and *P*=0.20, respectively). The SR observed for this study were higher than the SR reported by Burt et al., (20XX) and Beck et al., (2017*a*) for stocker cattle grazing-alfalfa-bermudagrass mixtures. While there were no differences reported for SR, there were differences among the harvest methods for the seasonal total LWG (*P*=0.004; CG=282±147.1 kg ha^{-1} and GR=373 ±147.1 kg ha^{-1}). There were also differences observed for the bermudagrass variety for the seasonal LWG (*P*=0.02). There was a greater LWG observed in the ABG mixtures with the Tifton 85 bermudagrass compared to the Russell bermudagrass bases (147±33.5 kg ha^{-1}and 118 ±33.5 kg ha^{-1}, respectively). The results for total LWG are higher for both CG and GR in comparison to Beck et al. (2017*c*) and Burt et al. (20XX) which observed an increase in total LWG in bermudagrass paddocks interseeded with alfalfa. Rushing et al., (2022) observed a LWG similar to the CG treatments of the current study for stocker cattle grazing ABG mixtures, however their reported LWG is lower than the LWG for the GR treatments of the current study. Additionally, the LWG reported for the bermudagrass variety in the current study, a similar to the

LWG reported by Rushing et al. (2022) and Burt et al. (20XX), but higher than the LWG observed by Beck et al. (2017*c*) for stocker cattle grazing ABG mixtures.

Typically, forage allowance (kg forage DM kg steer LW^{-1}) is used in explaining animal performance differences (Sollenberger et al., 2005) when it is below a critical level that results in limited dry matter intake (Beck et al., 2017*d*). The total forage allowance was never limiting at any time during the grazing evaluation in the GR or CG, thus there were no observed differences (P=0.09; 1.01±0.23 kg forage DM kg steer LW^{-1} and 0.9 ±0.23 kg forage DM kg steer LW^{-1}, respectively). There also were no observed differences for the bermudagrass variety being used (P=0.09; Russell=0.9±0.23 kg forage DM kg steer LW^{-1} and Tifton 85=1.0 ±0.23 kg forage DM kg steer LW^{-1}). The forage allowance of the current study is higher than that reported by Burt et al. (20XX), which observed that the forage allowance was limiting for stockers grazing ABG mixtures which they attributed to increased grazing pressure and reduced diet selectivity.

Overall System Performance

Observed, predicted, and total liveweight gain (GAIN) are presented in Table 4.3. The GAIN differed among harvest methods only (P<0.001). The total GAIN was greatest in CT (1163±299.7 kg), compared to GR and CG (357±299.7 kg and 672±299.7 kg, respectively). This was a direct result of their being a greater predicted GAIN for CT treatments, however the CG treatments optimized the production of ABG mixtures by providing a high quality grazable forage and stored forage from the same unit of land. These differences in GAIN can be explained by the efficiency of the system. By mechanically harvesting the forage, as in the baleage production of CT and CG treatments, this method ensures a complete defoliation to a specific height (Holmes, 1962). This is why mechanically harvested forage for stored forage and taking that harvested forage to the animal is considered to be approximately 70% efficient compared to rotationally stocking pastures which has an efficiency of approximately 50% when paddocks are rotationally stocked on a 7 d interval (Anigma, 2014). While the baleage production in the CT and CG treatments is more efficient in comparison to the GR, it does not simulate the grazing stress associated with actual grazing animals (Allen 1985; Counce et al. 1984; Smith et al., 1999). Those grazing stressors are in relation to trampling of forage, bites size of the forage, paddock size, and the excretion of urine and feces (Allen 1985; Counce et al. 1984; Smith et al., 1999; Carter et al., 2019).

Conclusion and Implications

While certain aspects reported for the three harvest management strategies evaluated were better for one single parameter, overall system performance indicates that the strategic management using the CG harvest method for ABG mixtures optimizes the use of the same unit of land. The parameters that are optimized through the strategic management of CG treatment in ABG mixtures are: the improved nutritive value, a similar alfalfa stand density to ABG mixtures harvested as baleage only, a higher ADG compared to the grazing only of ABG mixtures, and it allows for the grazing season to be extended into the late autumn/early winter months when grazed as a stockpiled forage option. While there were no seasonal differences between the bermudagrass varieties utilized, stocking decisions will vary based on the bermudagrass variety utilized in the ABG mixture. Future work should focus on the nutrient cycling throughout the CG system for both animal and forage production to quantify off-farm and animal inputs and returns.

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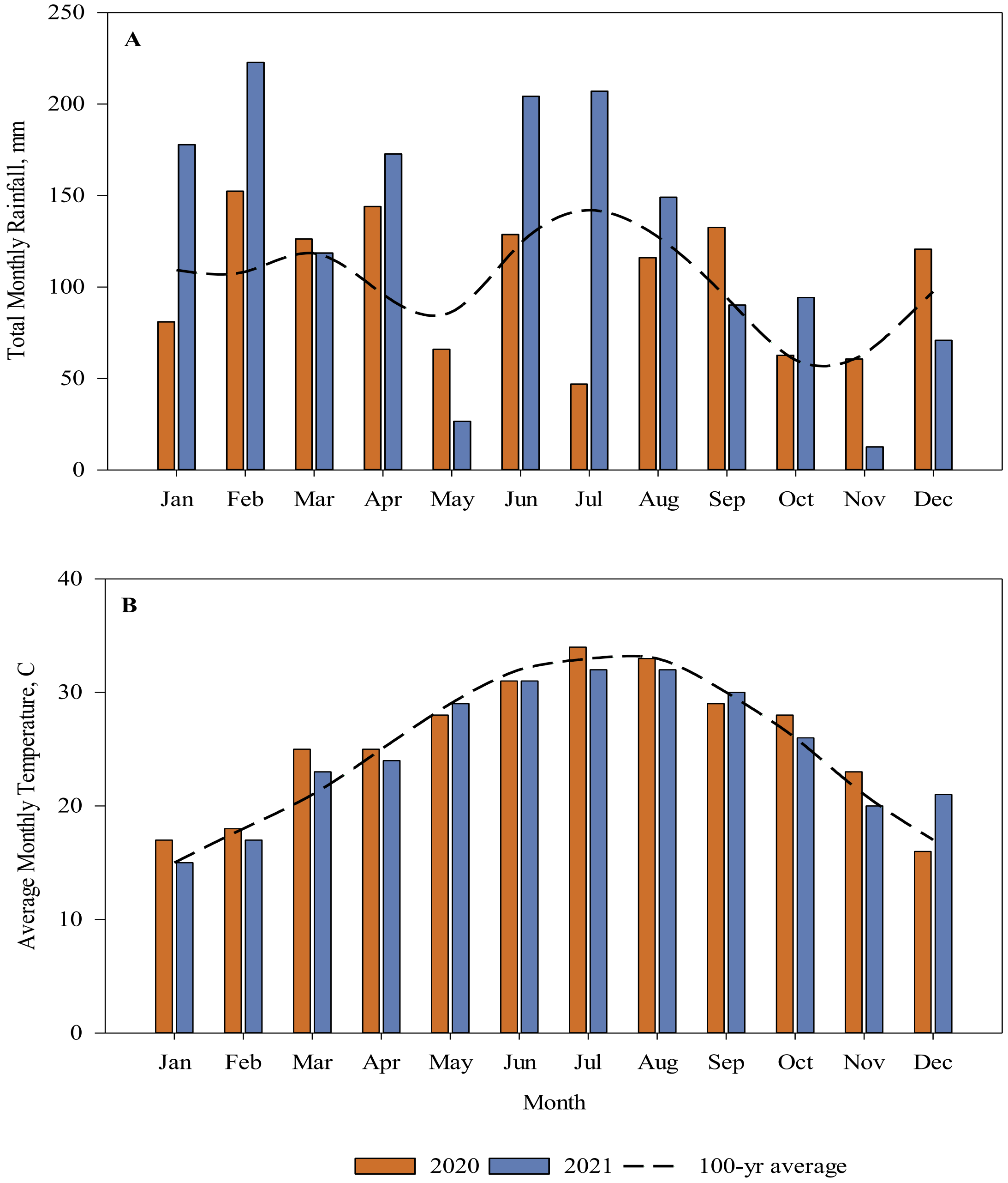

Figure 4.1. (A) Total monthly rainfall (mm) and (B) average monthly temperature (˚C) for 2020, 2021, and the 100-year average for January through December in Tifton, GA. Data collected from the University of Georgia Automated Environmental Monitoring Network (UGA-AEMN, 2022)

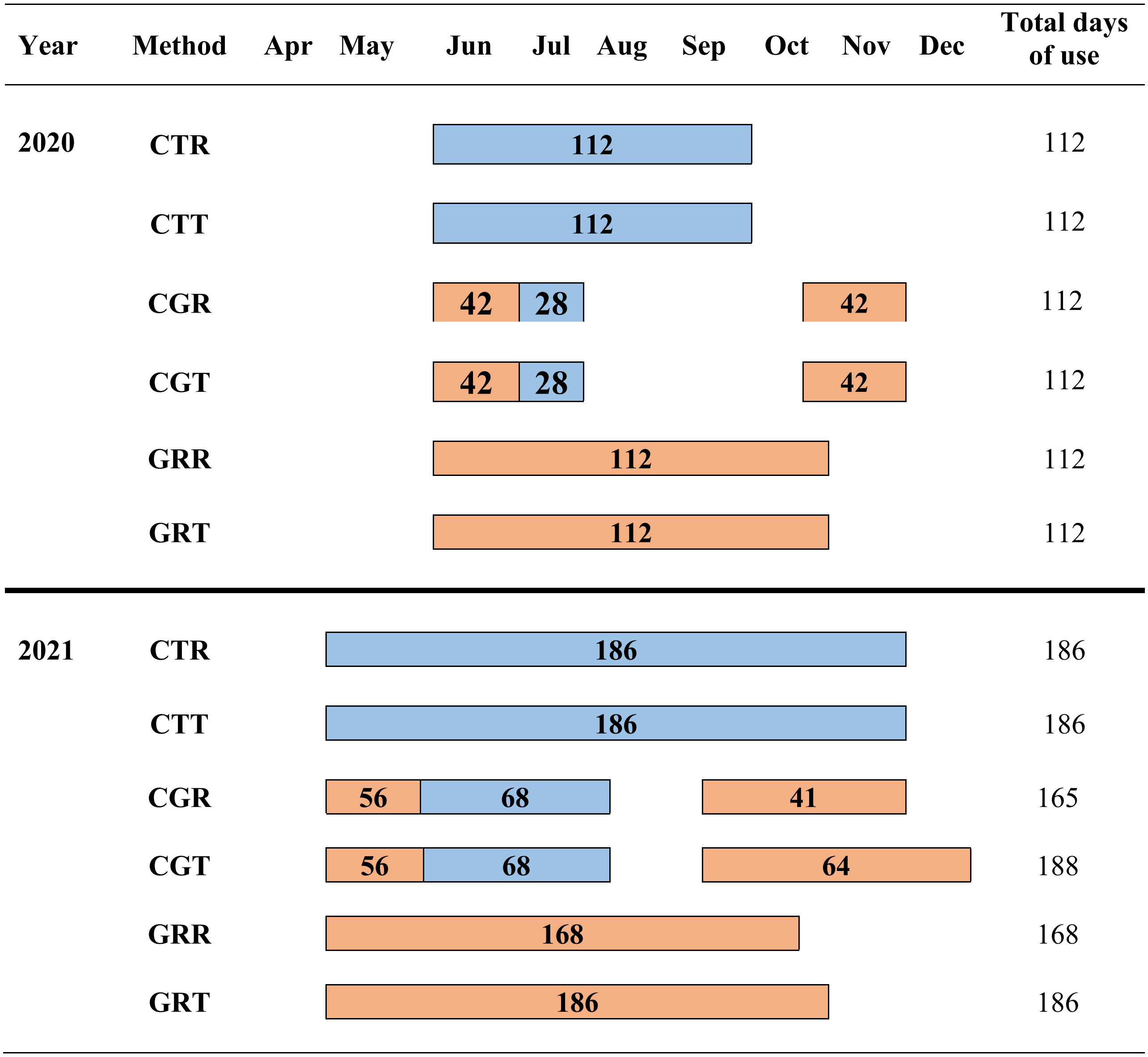

Figure 4.2. Gantt Chart of number of days of use for each harvest method and bermudagrass base by cycle for 2020 and 2021 in Tifton, GA. Treatments include: CTR: Cut Russell; CTT: Cut Tifton85; GRR: Graze Russell; GRT: Graze Tifton85; CGR: Cut and Graze Russell; CGT: Cut and Graze Tifton85.

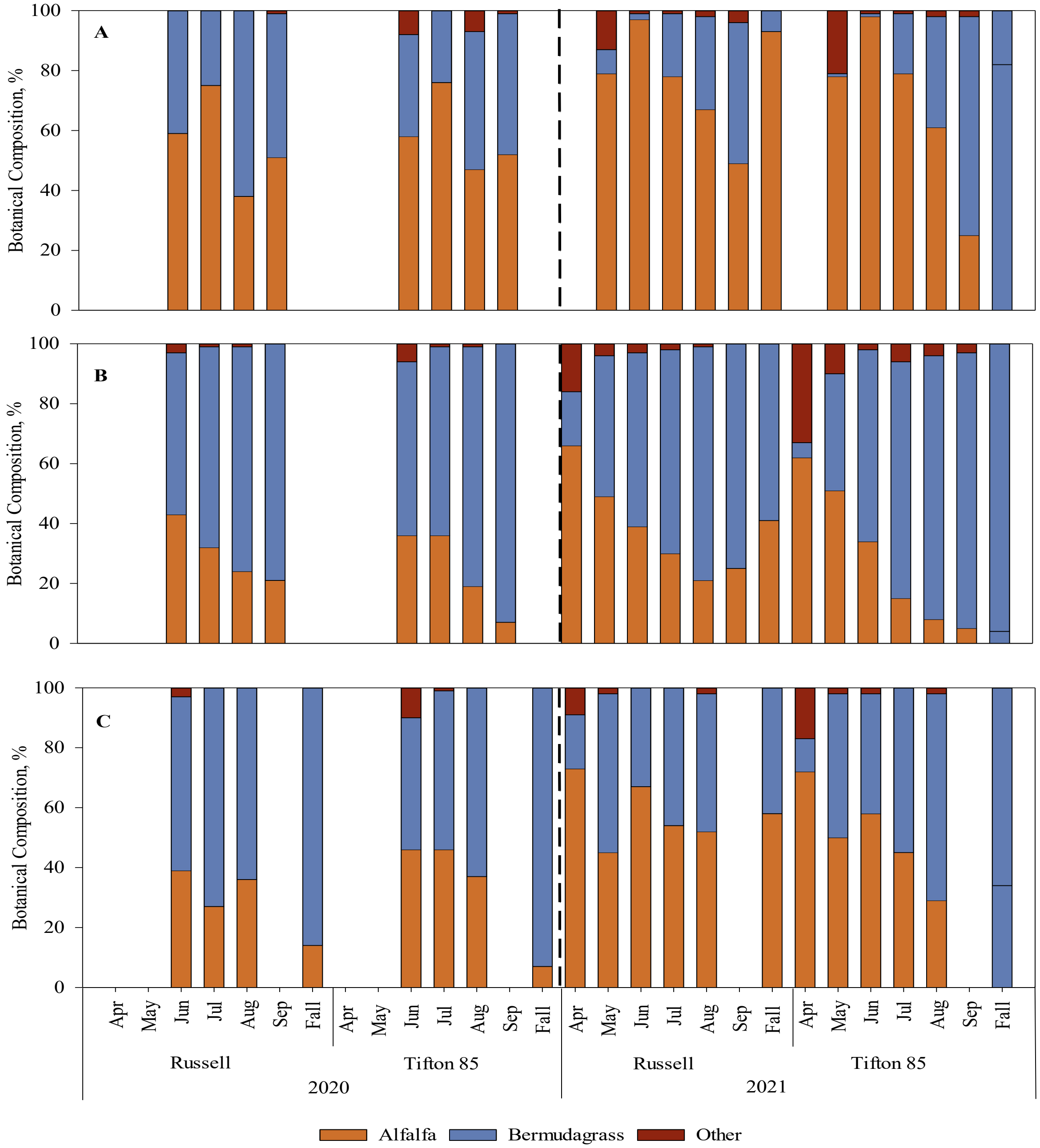

Figure 4.3. Botanical composition (%) of Russell-Alfalfa and Tifton85-Alfalfa mixtures harvested as (A) Cut Only, (B) Graze Only, and (C) Cut and Graze management. Botanical composition represents pre graze forage harvested at each grazing cycle for the 2020 and 2021 growing season in Tifton, GA. Fall cycle, represents overlap of grazing in-season and stockpile grazing.

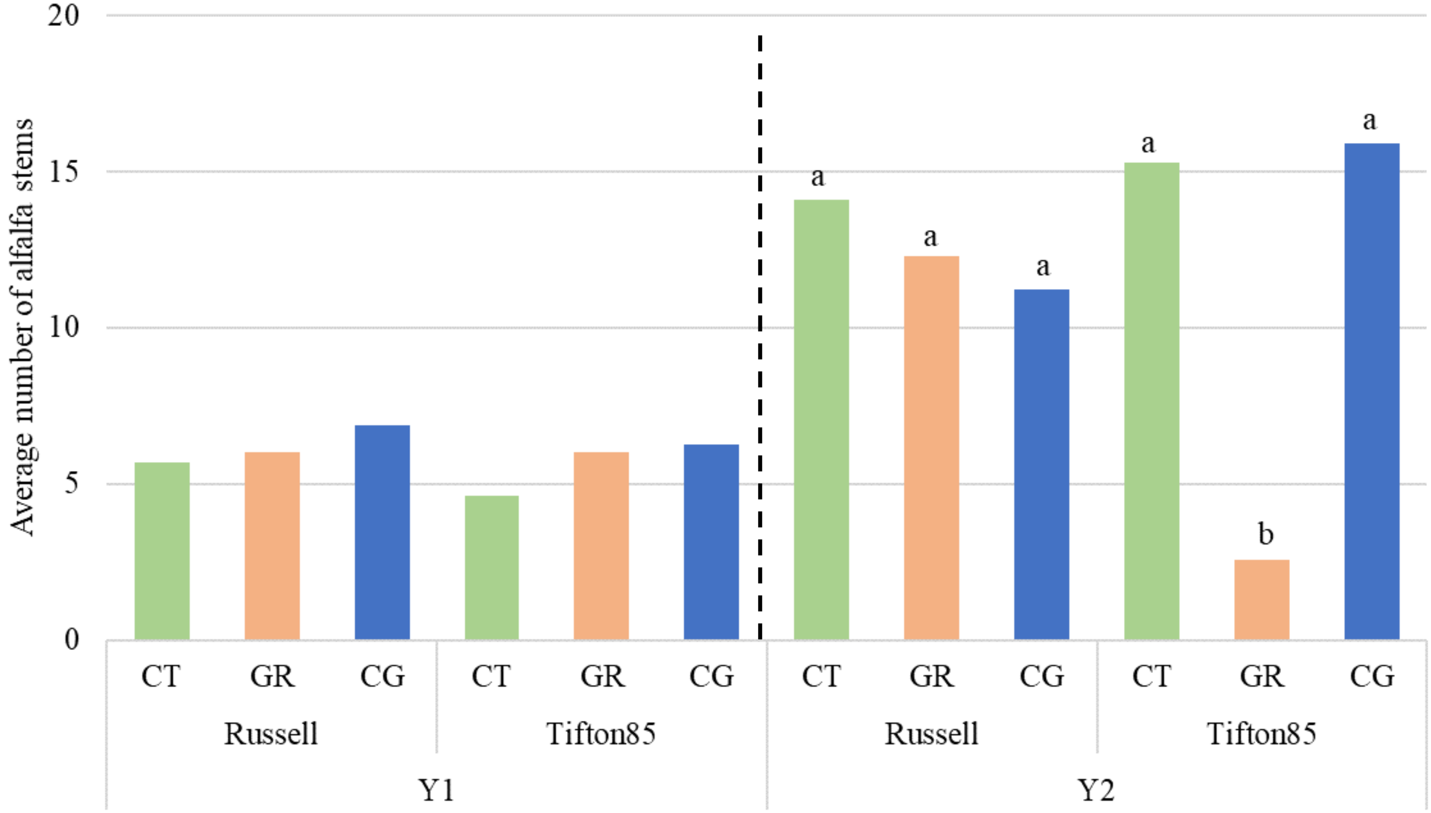

Fig. 4.4. Average number of alfalfa stems taken from 0.1 m^2 quadrats at 60 d post study termination for each harvest method and bermudagrass variety by year for the 2020 (Year 1) and 2021 (Year 2) growing season in Tifton, Georgia. Treatments are: CT: Cut; GR: Graze; CG: Cut and Graze. Standard Error of the Mean for Y1=±1.0 and Y2=±4.9. Bars without common superscripts differ ($P \leq 0.05$).

Table 4.1. Seasonal pre-Graze nutritive value (g kg^{-1}) using near-infrared spectroscopy (NIRS) analyses of Russell+Alfalfa or Tifton85+Alfafla mixed pastures by harvest treatment of cut only, graze only, or cut and graze harvest management during the 2020 (Year 1) and 2021 (Year 2) growing season in Tifton, Georgia.

	Treatments[1]						
Item[2], g kg^{-1}	**CTR**	**CTT**	**GRR**	**GRT**	**CGR**	**CGT**	**SEM[4]**
CP	221.8	212.9	184.7	167.9	182.8	166.3	34.67
ADF	301.5	308.6	325.1	343.1	315.6	336.1	21.15
NDF	453.0	462.1	500.9	552.1	480.3	524.10	49.34
IVTDMD48	792.9	800.2	738.4	749.4	745.4	744.5	30.57
TDN[3]	646.5^{ab}	651.1^{a}	620.3^{b}	636.9^{a}	628.1^{ab}	629.7^{ab}	13.8

[1] Treatments: CTR: Cut Russell; CTT: Cut Tifton85; GRR: Graze Russell; GRT: Graze Tifton85; CGR: Cut and Graze Russell; CGT: Cut and Graze Tifton85.

[2] CP: Crude Protein; ADF: Acid Detergent Fiber; aNDF: Neutral Detergent Fiber; IVTDMD48: in-vitro Dry Matter Digestibility at 48h;TDN: Total Digestible Nutrients

[3] Total digestible nutrients = (NFC x 0.98) + (CP x 0.87) + (FA x 0.97 x 2.25) + [NDFn x (NDFD /100)] – 7. (NRC, 2001)

[4] SEM: standard error of the mean

*Within a row means without common superscripts differ ($P \leq 0.05$).

Table 4.2. Seasonal average daily gain (kg hd), seasonal gain ha (kg LWG ha),and seasonal stocking rate (kg BW ha) of stocker steers rotationally grazing Russell+Alfalfa or Tifton85+Alfalfa mixed pastures for the 2020 (Year 1) and 2021 (Year 2) grazing season in Tifton, Georgia.

	Treatments		
Item	**Cut and Graze**	**Graze**	**SEM^3**
Seasonal Average Daily Gain (kg hd)	1.09^a	0.70^b	0.09
Seasonal liveweight gain ha^{-1} (total kg LWG ha)	282^b	373^a	82.7
Seasonal Stocking Rate (kg BW ha)	850	884	147.1

^{2}SEM: standard error of the mean

*Within a row means without common superscripts differ (*P* ≤ 0.05).

Table 4.3. Mean observed, predicted, and total liveweight gain (LWG) of each harvest method and bermudagrass variety for the 2020 (Year 1) and 2021 (Year 2) grazing season in Tifton, Georgia. Data are averaged across years and replicates.

	Treatments			
Item; kg	**Cut**	Graze	Cut and Graze	**SEM[4]**
Observed LWG	-	357^a	259^b	53.4
Predicted LWG	1163^a	-	414^b	250.9
Total LWG[5]	1163^a	357^c	672^b	299.7

[1] Treatments: CTR: Cut Russell; CTT: Cut Tifton85; GRR: Graze Russell; GRT: Graze Tifton85; CGR: Cut and Graze Russell; CGT: Cut and Graze Tifton85.

[2] Graze Only treatment is the actual LWG observed from stocker steers grazing paddocks

[3] Cut and Graze treatment: is the actual LWG observed from stocker steers grazing paddocks and the predicted LWG from forage mass harvested as baleage

[4] SEM: standard error of the mean

[5] Total LWG: the sum of observed LWG from grazing and Predicted LWG from the harvested baleage

*Within a row means without common superscripts differ ($P \leq 0.05$).

CHAPTER 5

EVALUATING NONDESTRUCTIVE FORAGE SAMPLING TECHNIQUES IN ALFALFA-BERMUDAGRASS MIXTURES IN THE SOUTHEASTERN UNITED STATES

[1] Burt, J.C., L.L. Baxter, and J.J. Tucker. Submitted to *Crop, Forage, and Turfgrass Management*

Abstract

The increased use of legume-grass mixtures in grazing systems has resulted in the need for more accurate forage estimation techniques for these diverse mixtures. In mixed species stands, variation in species composition and canopy density makes herbage mass (HM) estimation more challenging. Three nondestructive sampling techniques (rising plate meter [RPM], pasture ruler, and digital image analysis) were compared with traditional botanical hand separations to determine their effectiveness in predicting herbage accumulation in bermudagrass (*Cynodon dactylon*) and alfalfa (*Medicago sativa*) pastures when harvested to 1- and 4-in. All models calibrated to forages harvested to 1-in failed to meet the formal assumptions of the *F*-test. Height and RPM were moderately successful at predicting HM when calibrated to samples harvested to 4-inches. However, the models were unable to predict HM above 4,000 lbs ac^{-1} in their current form. Future research in this mixture should focus on isolating how HM changes within the canopy and increase the sample area used to collect calibration data.

Need for accurate forage measurements

Improved alfalfa (*Medicago sativa*) varieties interseeded with hybrid bermudagrass (*Cynodon dactylon*) provide an excellent forage source for growing stocker cattle in the Southeastern US. These two forages complement each other in southern forage systems as the inclusion of alfalfa improves forage nutritive value and yield distribution across the season compared to traditional bermudagrass monocultures. Accurate measurements of forage availability are essential to ensuring that enough forage is provided for sustainable stocking rates in forage-based livestock systems (Xiong et al., 2019). While many producers will visually estimate forage availability, there is a clear need for simple, inexpensive methods for estimating available forage especially in pastures with multiple forage species (Baxter et al., 2017; Mason, 2020; Sanderson et al., 2001). However, like many multi-species forage combinations, alfalfa and bermudagrass vary in their plant canopy architecture and growth patterns throughout the season (Ferraro et al., 2012; Hendricks et al., 2020). Traditional methods for estimating herbage mass (HM) may not be appropriate when the canopy structure is highly variable.

While hand–clipping samples is the most direct method of quantifying HM, results are delayed because of the labor-intensive tasks of collecting, drying, and weighing each sample (Moffet et al., 2012; O'Donovan et al., 2002). Utilization of non-destructive harvesting methods can quicken this process and allow producers to set appropriate stocking rates. Michalk and Herbert (1977) concluded that canopy height was sensitive enough to detect differences in HM in alfalfa-dominant pasture, but canopy density was not accounted for. Canopy height may be measured using a Robel pole (Harmoney et al., 1997) or ultrasonic meter (Fricke and Wachendorf, 2013), but a pasture ruler is the most common tool (Baxter et al., 2017). A rising plate meter (RPM) combines both plant height and density into a single measure (Baxter et al., 2017). Digital image analysis (DIA) can quickly quantitatively measure a two-dimensional area of selected components within a digital photo image (Baxter et al., 2017; Karcher and Richardson, 2003). Baxter et al., (2017) concluded that a combined linear model, which utilized height and ImageJ, best predicted HM when used on alfalfa-tall wheatgrass (*Thinopyrum ponticum* (Host) Beauv) mixtures.

Can the RPM work in alfalfa-bermudagrass systems?

Many producers in the Southeast US are interested in using a RPM because of its extensive use in cool-season forage intensive grazing systems in New Zealand (Ferraro et al., 2012). The first objective was to determine if the utilization of a RPM was sufficient at providing accurate HM estimations in alfalfa-bermudagrass mixtures (ABG).

All research was conducted at the University of Georgia's Tifton Campus in Tifton, GA (31˚30′ N, 83˚31′ W; 360 ft. elevation). The research site was nearly level (<2% slope) and was composed of Tifton loamy sand soils (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). Total rainfall for 2019 was 39.47 inches (UGA AEMN, 2021) which was lower than the 100-year average of 48.28 inches (NOAA; 2021).

This initial experiment was conducted in two, 2-acre ABG pastures, nested within a large grazing experiment evaluating strategies to improve Southern bermudagrass grazing systems (Burt et al., 20XX). More information on forage establishment and management may be found in Burt et al. (20XX).

Forage was collected from six random sample locations in each replicate at 30 sampling events. The sample area was defined by a 1-ft^2 PVC quadrat before a manual RPM (Jenquip, New Zealand) was used to measure the compressed forage height. The initial value on the accumulating ticker was recorded before the RPM was placed on the sample area so the plate rested perpendicular to soil surface. The final value on the ticker was recorded then the forage material in the quadrat was clipped to a uniform 1-in height, placed in a paper bag, then dried in a forced-air-drying oven at 130°F for 48 h to correct for moisture and calculate dry HM (DM) per acre.

All observations were utilized in the calibration data set when statistical analyses were conducted using PROC REG (SAS 9.4, SAS Institute. Inc., Cary, NC). Independent variables included average canopy height measured with the RPM and grazing period. Precision of each preliminary model was evaluated with three different statistics. The coefficient of determination (R^2_{cal}) is the variance explained by the calibration model. The root mean square error (RMSE_{cal}) measures the difference between HM estimated by the respective calibration model and actual measured HM. Each of these statistics with transformed data were converted into the same scale as the initial linear models for a direct comparison. The coefficient of variation (CV_{cal}) describes variability in HM estimates relative to mean HM, which allows for comparison across the models.

Pitfalls of the RPM in multi-species forage systems

Information regarding canopy descriptors and independent variables are provided in Table 1. Measured HM was linearly regressed on RPM measurements, however the initial model failed to meet the formal assumptions of normality and independence. The RPM units were then linearly regressed on the natural log of measured HM to linearize their relationships with HM, but this was also unsuccessful at normalizing the residuals (Bowley, 2008). The resulting analysis indicated that a time variable may be required to resolve serial correlation. However, integrating grazing period into the model did not resolve these concerns and the model still failed the formal assumptions of the *F*-test. Finally, the intercepts of the original (untransformed) linear models were forced through 0, based on the methods presented in Dillard et al., (2016). Even though the R^2_{cal} increased ($R^2 = 0.90$), the $RMSE_{cal}$ (595.19 lbs DM ac^{-1}) and CV_{cal} (35.76%) also increased while the residual plots still indicated problems of normality and correlation of variables.

Evaluation of other non-destructive sampling procedures

Based on the results of the initial experiment, additional research was conducted from June-October 2020 and April-October 2021 in a second grazing experiment at the same research center detailed above (Trial 2). The second objective was to compare the predictive accuracy of three nondestructive sampling procedures in predicting herbage accumulation in bermudagrass and alfalfa pastures. This experiment was conducted in 8 replicate, 2.5-ac ABG pastures, nested within a large grazing experiment evaluating various management strategies utilizing ABG. Grazing was initiated in June (2020) and April (2021) each year and was terminated when available forage was ≤1000 lbs ac^{-1}. More information on forage establishment and management can be found in (Burt et al., 20XX). Total rainfall for 2020 and 2021 was 48.75 inches and 62.12 inches, respectively (UGA AEMN, 2021), which were higher than the 100-year average at 48.28 inches (NOAA; 2021).

Eight samples were collected at 44 sampling events, resulting in 914 total samples for analysis. Again, a 1-ft^2 quadrat was used to define the sample area. Images were taken using an Olympus TG-2 (Olympus Imaging Corporation, Tokyo, Japan) mounted on a unipod at 36-inches high. The monopod was tilted to center the camera over the quadrat and leveled with respect to the ground before recording the image and saving as a .JPEG file. Mean growth stage of alfalfa was recorded before canopy height was measured with a ruled meter stick (Kalu and Fick, 1980). A manual RPM (Jenquip, New Zealand) was used to measure compressed canopy height using the same procedure described in the previous trial. It was important to record RPM measurements after the other sampling methods since it compressed the canopy and may introduce unintended error (Baxter et al., 2017). To determine HM, the forage material was clipped to the 1 or 4-inch height depending on the sample's treatment allocation (Groce et al., 2020). Forage was placed in a paper bag, then dried in a forced-air-drying oven at 130°F for 48 h to correct for moisture and calculate DM per acre.

Images were manually cropped to the exact 1-ft^2 sample area before subjecting them to DIA procedures. Images were analyzed as color images instead of grayscale based on conclusions by Himstedt et al. (2012). Cropped images were processed in batches using unique macros developed for ImageJ software (version Fiji; imagej.nih.gov; Baxter et al., 2017).

Thresholds for hue and saturation were permanently set at 0 to 125 and 0 to 255, respectively. Brightness settings varied based on sampling conditions but typically ranged from 30 to 255. Results from the analyzed images were transferred and saved in Microsoft Excel (Microsoft, Redmond, WA) for statistical analysis.

Individual observations within harvest height were randomly assigned to either the calibration or prediction data sets before statistical analyses were performed in SAS 9.4 (SAS Institute. Inc., Cary, NC). Independent variables included average canopy height measured with the pasture ruler (Height) and RPM, percentage of green pixels from ImageJ analysis (ImageJ), and the combination of Height and RPM with ImageJ. Each sampling technique was linearly regressed on measured HM at 1- or 4-in using PROC REG. Even after similar transformations were performed as detailed in the previous section, all four models evaluated at the 1-in height failed to meet the formal assumptions of the *F*-test (Bowley, 2008) including normality and homoscedasticity. The initial analysis of residuals for the 4-inch harvest height models indicated serial correlation, so growth stage was included in all models to normalize the residuals. Finally, RPM + ImageJ and Height + ImageJ were used to create combined linear models similar to the final model suggested by Baxter et al. for use in similar grass alfalfa mixtures (2017). Precision of these calibration models was evaluated with R^2_{cal}, $RMSE_{cal}$, and CV_{cal}.

The calibration models were then applied to the corresponding validation dataset to determine predictive ability of each procedure. PROC CORR and PROC REG were used to determine the relationship between the predicted and measured HM (SAS Institute, 2016). The predicted and measured HM would ideally result in a straight line with an intercept equal to zero and slope equal to one. This was evaluated using a one sample t-test in Microsoft Excel (Microsoft Corporation, Redmond, Washington). Precision of each prediction was evaluated using calculated R^2_{pred}, $RMSE_{pred}$, and CV_{pred} values. The final linear models were fit in PROC REG and selected based on the low Akaike information criterion, low Mallows' C_P statistic, and high R^2 (SAS Institute, 2016; Baxter et al., 2017).

Model Evaluation

Information regarding canopy descriptors and independent variables are provided in Table 5.1. Based on the statistical analysis, the sampling procedures evaluated are not recommended for ABG harvested to a 1-in height and the rest of this manuscript will focus on the forage harvested to a 4-in. The relationship between the independent variables and measured HM harvested to 4-in is represented in Fig. 5.1 A-C. The range in the forage canopy was expected based on the morphological differences between bermudagrass and alfalfa. Height and RPM show a similar linear relationship with the measured HM, but the digital images analyzed in ImageJ were clearly oversaturated as all of the readings were above 80% ground cover.

The calibration equations for each sampling procedure are presented in Table 5.2. The height and RPM models were similar and performed better than the ImageJ model based on the higher R^2_{cal} (0.35-0.38) and lower $RMSE_{cal}$ (538-557 lbs DM ac^{-1}), and CV_{cal} (31-32%). Baxter et al. (2017) found the combination of two or more model parameters is preferred when utilizing nondestructive sampling procedures, specifically when a height and canopy cover measurement are combined. The inclusion of ImageJ increased the R^2_{cal}, but to the detriment of CV_{cal} and $RMSE_{cal}$ (Table 2). The models produced a similar R^2_{cal} and CV_{cal} however the $RMSE_{cal}$ was greater in the RPM + ImageJ model compared to Height + ImageJ (1,7345 lbs DM ac^{-1} and 808 lbs DM ac^{-1}, respectively; Table 5.2).

When the equations were applied to an external data set, their predictive accuracy resulted in a similar trend (Table 5.3). Again, the RPM and Height models had similar R^2_{pred}

(0.38-0.35), $\text{RMSE}_{\text{pred}}$ (542-538 lbs DM ac^{-1}), and CV_{pred} (31-31%), (Table 3). Surprisingly, when ImageJ was applied to the predicted data it resulted in the lowest $\text{RMSE}_{\text{pred}}$ and CV_{pred} but still possessed the lowest R^2_{pred} (Table 3). Again, the inclusion of ImageJ did not significantly improve the model as the R^2_{pred}, $\text{RMSE}_{\text{pred}}$, and CV_{pred} were similar to those of RPM and Height alone (Table 5.3).

The relationship between measured and predicted HM is presented in Figure 5.2 A-E. Regardless of the model used, each regression line had an intercept bigger than zero and slope less than one (Table 4; $P < 0.01$). All equations over predicted HM below 2,000 lbs DM ac^{-1} and severely under predicted above this level. Figure 5.2 illustrates the compression of predicted HM by all nondestructive sampling techniques. Measured HM was as high as 6,570 lbs DM ac^{-1} in the validation set, while the associated predicted values did not exceed 3,057-3,981 lbs DM ac^{-1} (Fig. 5.2 A-E). Further research is required to expand these calibration models beyond their current HM limitations.

Comparing non-destructive sampling procedures

There is limited published research on estimating HM in ABG. Mason (2020) reported a similar response to the present study when plant height was used to predict HM: R^2_{pred} (0.42), $\text{RMSE}_{\text{pred}}$ (567 lbs DM ac^{-1}), and CV_{pred} (51%). Most other available literature on nondestructive determination of HM, specifically using plant height or the RPM, has been conducted on cool season forages (Baxter et al., 2017; Cho et al., 2019; Dillard et al., 2016; Sanderson et al., 2001). In contrast to other cool-season legumes, alfalfa is still productive through the summer months. The alfalfa growth will slow and contribution to the stand will decline in August, but the alfalfa stand rebounds and increases its contribution in the fall as reported by Hendricks et al. (2020). Furthermore, many of these calibration models are farm- or season-specific (Cho et al., 2019;

Dillard et al., 2016; Sanderson et al., 2001). Although they are reported as more accurate than season-long equations, these models cannot be translated to a wide range of forage-livestock producers who need a simple method for quickly and accurately determining HM.

The present study found that there was severe underprediction of HM, especially when measured HM exceeds 2,000 lbs DM ac^{-1}. Similar limitations were found in Mason (2020) where the authors reported the underprediction of HM above 1,338 lbs DM ac^{-1} with the height in ABG. They suggested that the inclusion of a more robust data set may improve the predictions. The number of observations reported in literature has varied but were well below the number of samples collected for the second experiment (n_{total}=914). This compression is attributed to the dynamic growth habits of the alfalfa and bermudagrass in the canopy and more thorough research is required to isolate how HM changes within the canopy.

Baxter et al. (2017) utilized the ImageJ procedure in the alfalfa-tall wheatgrass mixture and found that combination of Height and ImageJ was the best estimator of HM in alfalfa-tall wheatgrass pastures and allowed for a more complete depiction of the forage canopy structure. This procedure had not been previously reported to be used in ABG. Based on the results in the current work, a relatively large sample size is required to determine canopy cover. The majority of forage research trials have found a 1 ft^2 quadrat to be sufficient for HM estimation (Cho et al., 2019; Dillard et al., 2016; Mason, 2020) while Baxter et al. (2017) utilized a 10.7 ft^2 quadrat. The region's climate coupled with the morphological characteristics of the ABG resulted in a dense forage canopy with little bare ground which saturated the images utilized in the ImageJ analysis. This suggests that a larger area (>1 ft^2) may be required to effectively predict the HM of ABG.

Implications and future research

The three nondestructive estimation techniques examined in this study did not reliably predict HM in ABG. While these techniques could be beneficial to producers, the compression of the predicted mass would likely result in inaccurate stocking decisions that could be costly for livestock managers. Future research in this mixture should focus on isolating how HM changes within the canopy and increase the sample area used to collect calibration data.

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Table 5.1. Range and mean of independent model variables, herbage mass (HM), and alfalfa content in alfalfa-bermudagrass pastures harvested to 1-in height during 2018-2019 (Trial 1) and harvested to 1- and 4-in during 2020-2021 (Trial 2), in Tifton, Georgia.

Trial	Harvest height	Variable or canopy descriptor	Minimum	Maximum	Mean
1	1-in	RPM, RPM units [a]	6	43	25
		HM, lbs DM ac-1[b]	224	4260	1665
2	1-in	Height, in[c]	3	25	9
		RPM, RPM units	11	51	26
		ImageJ, % green pixels[d]	66	100	92
		Growth stage ranking[e]	1	9	4
		HM, lbs DM ac^{-1}	240	6588	2138
2	4-in	Height, in	3	26	10
		RPM, RPM units	9	53	28
		ImageJ, % green pixels	61	100	92
		Growth stage ranking	1	9	5
		HM, lbs DM ac^{-1}	51	6570	1763
		Alfalfa content, %	1	100	58

[a] RPM: rising plate meter;

[b] DM: dry matter

[c] Height: height of canopy

[d] ImageJ (http://imagej.nih.gov), percent ground cover

[e] Based on the percent bloom of alfalfa using measurements from Kalu and Fick (1981).

Table 5.2. Calibration equations to predict mass of alfalfa-bermudagrass pastures formed by linearly regressing measured herbage mass (HM) harvested at 4-in by sampling procedure for samples collected in Trial 2 during 2020-2021 in Tifton, Georgia.

Model parameters	**Calibration equation**	$\mathbf{n_{cal}}$	R^2_{cal}	**RMSE**$_{cal}$[a]	**CV**$_{cal}$[b]
				lb. DM ac^{-1}[c]	%
RPM	HM = -941.23 + 62.89R + 204.23S	430	0.45	795	46
Height	HM = -224.68 + 141.81H + 102.91S	429	0.43	809	46
ImageJ	HM = -1680.26 + 23.03I + 280.71S	418	0.21	962	55
RPM + ImageJ	HM = -1774.25+ 62.32R + 9.27I + 204.38S	418	0.46	1735	46
Height + ImageJ	HM = -546.70 + 140.66H + 3.00I + 112.83S	418	0.45	808	47

Note: R: average RPM reading (RPM units); H: average height of the sward; I: number of green pixels from ImageJ analysis; S, Growth Stage based on percent bloom of alfalfa using measurements from Kalu and Fick (1981).

[a] RMSE$_{cal}$: root mean square error of the calibration model

[b] CV$_{cal}$: coefficient of variation of the calibration model

[c] DM: dry matter

[d] RPM: rising plate meter

[e] Height: height of canopy

[f] ImageJ (http://imagej.nih.gov), percent ground cover

Table 5.3. Comparison of predictive accuracy for determining herbage mass of alfalfa-bermudagrass pastures formed by linearly regressing measured herbage mass harvested at 4-in by sampling procedure for samples collected in Trial 2 during 2020-2021 in Tifton, Georgia.

Model parameters	**n_{pred}**	**R^2_{pred}**	**RMSE$_{pred}$†**	**CV$_{pred}$‡**	**C_P**	**AIC**
			lb. DM ac^{-1a}	%		
RPM[b]	424	0.38	542	31	62	5524
Height[c]	420	0.35	538	31	76	5536
ImageJ[d]	410	0.15	428	25	236	5654
RPM + ImageJ	406	0.37	544	32	64	5526
Height + ImageJ	410	0.38	557	32	77	5537

[a] DM: dry matter

[b] RPM: rising plate meter

[c] Height: height of canopy

[d] ImageJ (http://imagej.nih.gov), percent ground cover

Table 5.4. Results from one sample *t*-test for coefficients of linear regression of measured herbage mass and predicted herbage mass by each calibration model from linearly regressing measured 4-in herbage mass by sampling procedure for Trial 2 conducted 2020-2021 in Tifton, Georgia.

	Intercept		**Slope**	
Model Parameters	B_0	*P*-value	B_1	*P*-value
RPM[a]	1065	<0.01	0.37	<0.01
Height[b]	1093	<0.01	0.35	<0.01
ImageJ[c]	1438	<0.01	0.16	<0.01
RPM + ImageJ	1730	<0.01	0.38	<0.01
Height + ImageJ	1075	<0.01	0.36	<0.01

[a] RPM: rising plate meter

[b] Height: height of the canopy

[c] ImageJ (http://imagej.nih.gov), percent ground cover

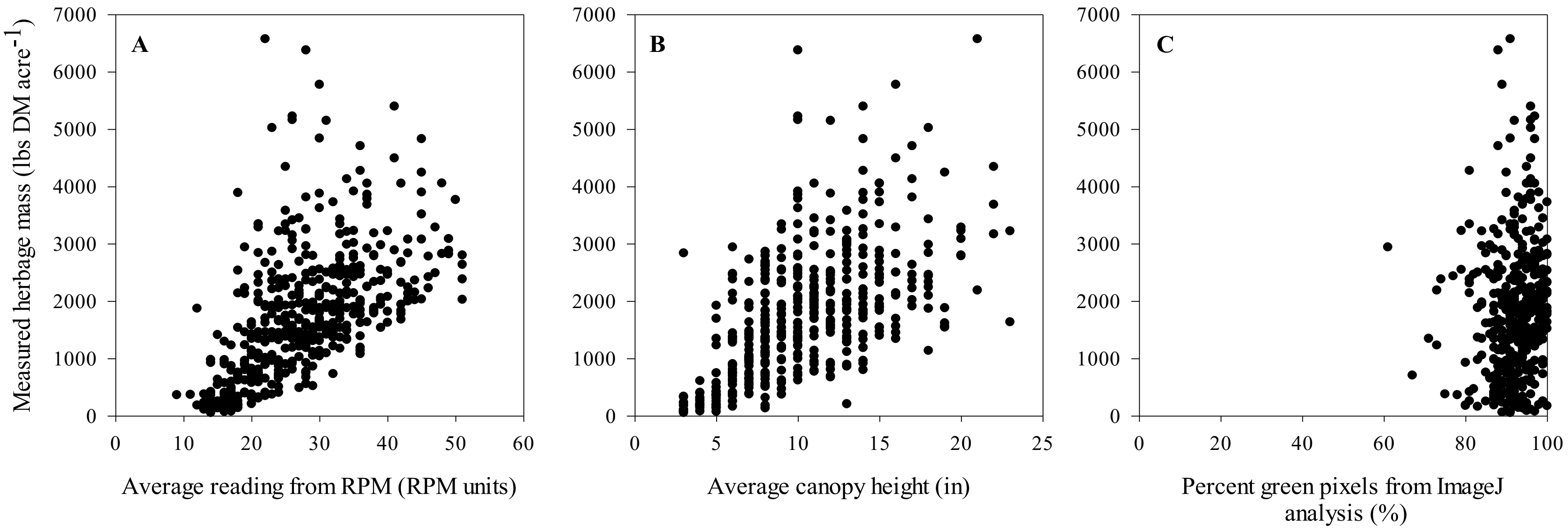

Figure 5.1. Relationship between the results from each nondestructive sampling procedure and measured herbage mass when harvested to 4-in: (A) rising plate meter, (B) height, and (C) ImageJ.

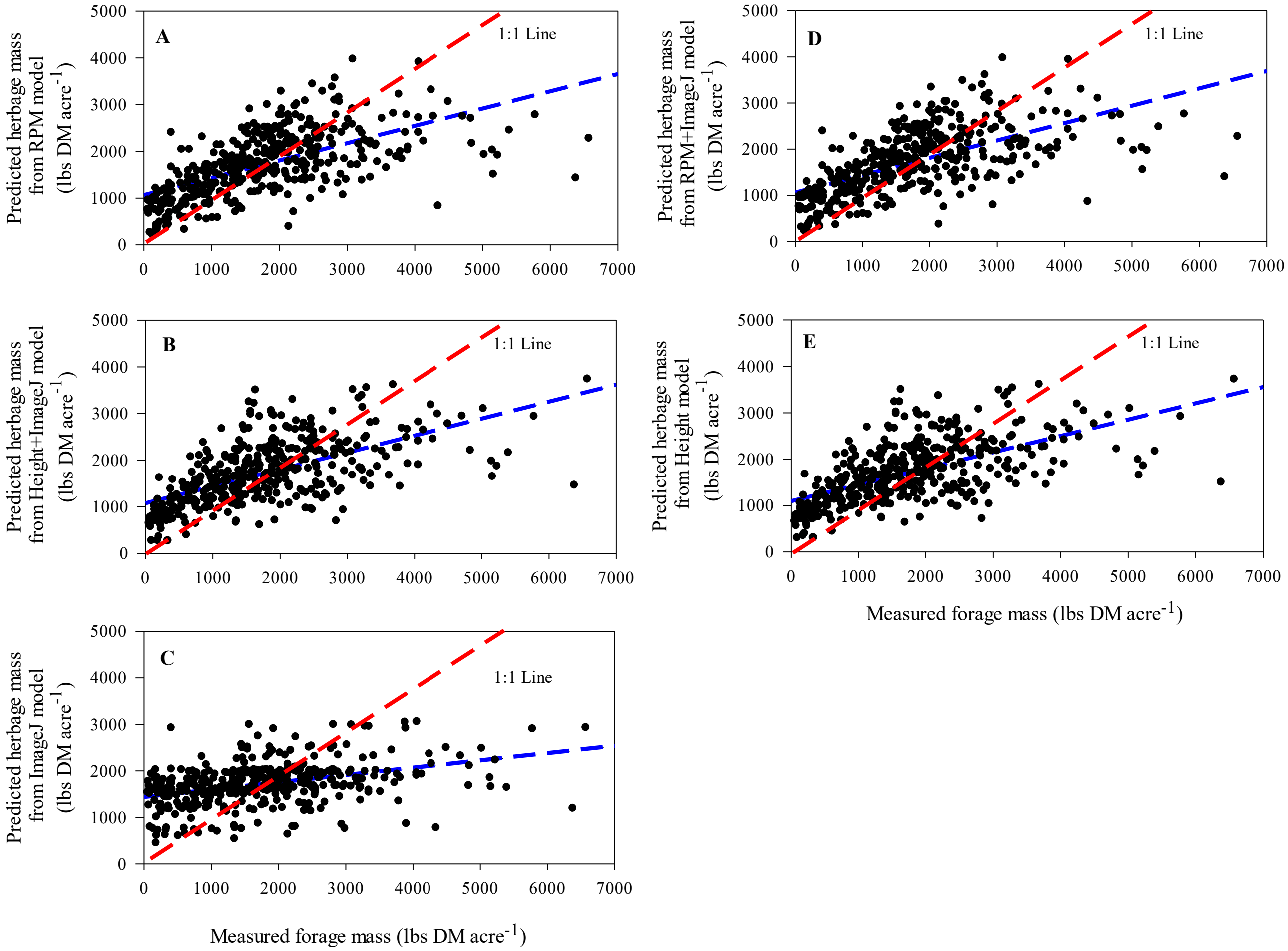

Figure 5.2. Relationship between measured herbage mass and predicted herbage mass by each calibration model harvested to 4-in: (A) rising plate meter (RPM), (B) height, (C) ImageJ, (D) RPM + ImageJ, and (E) height + ImageJ. The dashed blue line represents the relationship between the two variables. The dashed red line represents a 1:1 line for comparison.

CHAPTER 6

CONCLUSIONS AND IMPLICATIONS

In the Southeastern United States, livestock production is unique, and has many associated challenges and opportunities that are not experienced nationwide. While the environmental conditions are optimal for forage production, which provide long growing seasons, the rising costs associated with livestock production has producers seeking alternative ways to increase forage productivity while also reducing the input costs, specifically those associated with feeding livestock.

Livestock producers in the Coastal Plains region utilize perennial warm-season forages in combination with supplemental feedstuffs to meet livestock production needs. Pastures in this region are dominated by warm-season perennial grasses, with bermudagrass (*Cynodon dactylon*) being one of the most common. Bermudagrass has a high-N fertility requirement for optimal production. The inclusion of a legume, such as alfalfa (*Meticago sativa*), into an existing bermudagrass monoculture has potential to improve Southeastern livestock-forage grazing systems in terms of nutritive value.

In this study the production of alfalfa-bermudagrass (ABG) mixtures in comparison to bermudagrass monoculture pastures supplemented with (BGN) or without (BG) synthetic N fertilizer for grazing stocker cattle were evaluated. Upon analysis it was observed that the ABG mixture not only provide a higher quality grazeable forage source to stocker steers throughout the summer months, but also a higher stocking rate in a rotational grazing system which in turn provides greater economic viability. The overall conclusion from this study is that the use of alfalfa-bermudagrass mixtures can serve as a viable option for Southeastern stocker cattle producers, especially those looking to reduce dependence on synthetic nitrogen sources.

While the utilization of ABG mixtures have proven to be both a viable forage option for grazing and stored forage production in the region, several questions still remain on the optimal harvest management strategies for this mixture. Other questions that also remain are associated with how these mixtures respond when alfalfa is interseeded into different bermudagrass bases and how long can the grazing season be extended. Additionally, the development of harvest height and frequency recommendations have not been fully evaluated on a larger scale production system.

Based on the overall system performance, strategic management of the CG harvest management strategy optimized the production of ABG mixtures. Results of the CG treatment being the optimal harvest management strategy, allows the ABG mixtures to produce both a high-quality grazeable forage as well as a high-quality stored forage for later, while also extending the grazing season well into the autumn months, all from the same paddock. It was also observed that not only does the CG treatments extend the grazing season into a time when grazable forage may be limited, there were also more production days of the CG Tifton85 treatment compared to the CG Russell treatment.

In addition to determining the viability of ABG mixtures in the Southeastern US, there is a need for accurate and reliable forage estimation techniques. This is a result of producers needing to make stocking management decisions in the same day, that the forage is ready to be grazed and provide them with an estimated number of days their livestock can graze these ABG mixtures. This study evaluated three nondestructive forage estimation techniques, pasture ruler, rising plate meter (RPM), and digital technology (ImageJ) in ABG mixtures when harvested to two different heights of 1- and 4-in. It was determined that estimation of forage to the 1-in heights was not a statistically valid for estimation of forage mass, and therefore it should be omitted from forage estimation of ABG mixtures. While the forage mass estimation when harvested to the 4in height produced statistically valid models, it did not reliably predict herbage mass for ABG mixtures.

In conclusion, strategic management of ABG mixtures is crucial to their success in the Southeastern United States. While ABG mixtures can provide a viable high-quality forage for livestock and provide an alternative for producers wanting to reduce their reliance on synthetic N sources, they can also produce grazeable forage and stored forage form the same pastures within a growing season. Future research with ABG mixtures should evaluate the nutrient cycling throughout the entire system, specifically with the dual-use harvest management strategies. Future research in ABG mixtures should also focus on isolating how the herbage mass changes within the canopy to estimate the herbage mass more reliably and accurately.