RESTORING SOUTHEASTERN BERMUDAGRASS PASTURES: AN EVALUATION OF ALFALFA ESTABLISHMENT TIMING AND CRABGRASS INCLUSION

by

KENDALL WHATLEY

(Under the Direction of Jennifer J. Tucker)

ABSTRACT

Inclusion of alfalfa (*Medicago sativa*) in bermudagrass *(Cynodon dactylon)* pastures improves nutritive value, increases grazing days, and reduces need for synthetic nitrogen fertilizer. Crabgrass (*Digitaria sanguinalis*) is a common weed, requiring pre-emergent herbicide application to control. However, in a grazing system, crabgrass could be a valuable forage, being a palatable warm-season annual grass with high nutritive value and prolific reseeding ability. The objective of this research was to evaluate the impact of alfalfa establishment timing and crabgrass inclusion in alfalfa bermudagrass pastures on nutritive value, botanical composition, and forage mass. This two-year study conducted in Tifton, GA utilized 4 replications of 6 treatments: bermudagrass + fall alfalfa + crabgrass, bermudagrass + fall alfalfa, bermudagrass + spring alfalfa + crabgrass, bermudagrass + spring alfalfa, bermudagrass + synthetic N, and untreated bermudagrass control. Data was collected on a 28 to 35-day interval to determine botanical composition, forage mass, and nutritive value.

INDEX WORDS: Alfalfa, bermudagrass, alfalfa-bermudagrass mixtures, crabgrass, pasture restoration

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DEDICATION

This work is dedicated in memory of Ricky Singleton and in honor of Nash and Brooklyn Dunn, and Kennedy Singleton.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Cattle Industry in Georgia

Beef cattle are raised in all 159 counties in Georgia, and the beef industry ranks 4th for the top commodities in Georgia, accounting for $666.1 million of agriculture contributions (Kane, 2021). Cattle producers in the Coastal Plains usually fall into the "cow-calf" sector of the industry, maintaining a cow herd and producing calves to retain in herd or sell in replacement heifer and/or beef markets. Regardless of sector (commercial cow-calf, purebred, stocker, etc.), forages are the main component of the beef animal's diet, with an estimated over 24 million hectares of perennial pasture and over 7.5 million hectares of annual pastures in the South (Ball et al., 2015). Cattle energy requirements vary throughout the year within these different sectors. The subtropical climate in the southeastern United States provides opportunity for nearly year-round grazing, however it requires intensive management and careful consideration of forage species, varieties, and mixtures.

Forages of the Coastal Plains

Forage systems for beef cattle production in the coastal plain region have traditionally been dominated by warm-season perennial grasses, such as bermudagrass (*Cynodon dactylon*) and bahiagrass (*Paspalum notatum*), which account for an estimated 24.3 million hectares, or about 75% of pasture in the south (Ball et al., 2015). These grasses produce abundantly during the warmest months of the year, but production drops off during the transition into the fall months and stays dormant until late spring. The challenge in working toward year-round grazing is filling the forage gap during the fall months before the establishment of winter forages, commonly winter annuals like cereal rye (*Secale cereal)*, wheat (*Triticum aestivum*), triticale (x*Triticosecale* Wittmack), annual ryegrass (*Lolium multiforum*), and oats (*Avena sativa)*, become available in late fall (Blount 2017).

Bermudagrass

Once considered a weed, bermudagrass is a warm-season perennial first introduced from Africa approximately 400 years ago (Ball et al., 2015). Bermudagrass is a high-yielding forage well suited for grazing or hay production (Lee et al., 2017). It is sod-forming and deep-rooted, best adapted to fertile, well drained soils (Lee et al., 2017). Bermudagrasses planted early in the warm months (March, April, May) are more likely to survive winter than those planted in late summer, as the rhizomes are better established. Bermudagrass stands require management for soil fertility maintenance, grazing and/or cutting, in addition to stocking rate, intensity, and duration to be successful (Rouquette, 2017). Bermudagrasses grow best in a pH range of 5.5 to 6.5, requiring frequent lime applications for nitrogen fertilizer absorption (Lee et al., 2017). The frequency of both lime, nitrogen, and potash applications will depend on use, variety, and location of crop.

There are several cultivars of bermudagrass utilized in Georgia, including Coastal, Russell, and Tifton 85. Hybrid bermudagrasses do not produce viable seed, so they must be planted via vegetative propagation, using "sprigs" made of either root pieces or rooted stolons or runners ("tops") (Stichler & Bade, n.d). Hancock, Hicks, et al. (2015) report that these hybrid cultivars, when provided with adequate fertilizer, can produce 9-13 Mg ha^{-1} and are longer lived than seeded cultivars. ‘Coastal’, the first commercially released hybrid bermudagrass, had been planted in over 4 million hectares across the south, after development by Dr. Glenn Burton with USDA in Tifton, GA, released in 1943 (Burton et al., 1943). ‘Tifton-85’, a hybrid cross between ‘Tifton-68’ and stargrass (*Cynodon nlemfuensis* Vanderyst) (Burton et al., 1993), and provides greater dry matter accumulation and nutritive value than other commercially available bermudagrass varieties to date (Liu et al., 2010). In contrast with Coastal, Tifton 85 has larger and darker green stems, wider leaves, and a reduced number of rhizomes (Hill, Gates, & West, 2001a). Additionally, greater dry-matter and fiber digestibility is noted for Tifton-85, with greater digestibility in the rumen due to lower ether-linked ferulic acid concentrations and decreased ether bonding in lignin (Mandebvu et al. 1999; Hill et al., 2001a, 2001b).

Although bermudagrass grows well in the Coastal Plains, it often requires intensive and expensive management compared to other warm-season perennial grasses in this region, such as bahiagrass. Nitrogen fertilization is a key component to a successful bermudagrass stand, and high rates are required to maximize yield potential (Beck et al., 2017; Burton et al., 1963; Johnson et al., 2001; Osborne et al., 1999; Power, 1980; Stringer et al., 1994; Templeton and Taylor, 1975). Herbage accumulation and dry matter (DM) are affected by N application (Alderman et al., 2011; Burton et al., 1969; Silveria et al., 2007). Furthermore, N fertilization improves protein levels, as nitrates are necessary for forming amino acids. Crude protein (CP) content of hybrid bermudagrasses increases as N fertilization increases (Prine and Burton, 1956). A study by Burton et al. (1963) reported that fertilizing with up to 1008 kg ha^{-1} results in increased CP content up to 2827 kg ha^{-1}. These findings are supported by research conducted by Alderman et al. (2011) and Johnson et al. (2001). Alderman et al (2011) conducted a study on existing Tifton 85 bermudagrass, using N rates of 0, 45, 90, and 135 kg N ha^{-1} regrowth period^{-1}, and reported a linear increase in CP concentrations in response to increased N fertilization. Research by Johnson et al. (2001) compared Tifton 85 bermudagrass, Florona stargrass, and Pensacola bahiagrass fertilized with five different rates of N fertilizer (0, 39, 78, 118, and 175 kg N ha ^{1}). Similar to the trial by Alderman et al. (2011), Johnson et al. (2001) observed a linear increase in true protein in the Tifton 85 bermudagrass. In addition to increased herbage accumulation and CP levels, N fertilization serves to improve digestibility of bermudagrass. Studies by Rao et al. (2007) and Beck et al. (2017c) reported a linear increase in total digestible nutrients (TDN) as N fertilization increased.

Managed for grazing closely between 5 to 15 centimeters, hybrid bermudagrass varieties can provide good yields of high-quality forage (Hancock, 2013). When comparing two hybrid varieties, ‘Tifton 85’ and ‘Tifton 78’, Hill et al. (1993) reported body weight gain per hectare of steers grazing Tifton 85 was 1,156 kg versus 789 kg for steers grazing Tifton 78. In an evaluation comparing three different bermudagrass hybrids (‘Alicia’, ‘Jiggs’, and ‘Tifton-85) under low stocking rate (six steers per 2.66 ha) as forage and hay sources, average daily gains were greater for Jiggs (0.51 kg) and Tifton-85 (0.55 kg) than for Alicia (0.36 kg), in addition to greater body weight gain per hectare for Jiggs and Tifton-85 (258 and 279 kg/ha, respectively) over Alicia (184kg/ha; Scaglia and Boland, 2014).

Non-hybrid bermudagrasses can spread via seed, in addition to stolon and rhizome spread, making it difficult to eradicate once established (Hancock, 2013). Weeds can pose issues for bermudagrass stands, but the best line of defense is a well-established, well-maintained stand. Insects can also pose a problem for bermudagrass swards. Bermudagrass stem maggot (*Atherigona reversura*), fall armyworms (*Spodoptera frugiperda*), chinch bugs (*Blissus leucopterus*), grubworms (*Cyclocephala spp.*), mole crickets (*Gryllotalpa orientalis),* and billbugs (*Sphenophorus spp.*) are all common insects effecting bermudagrass stands, requiring intensive management and mitigation strategies to minimize damage and loss (Mislev and Dunavin, 1993).

Alfalfa

Originating in Iran and central Asia, alfalfa (*Medicago sativa* L.) is a cool-season perennial legume known to stand erect with many leafy stems growing from large crowns at the soil surface (Ball et al., 2015). It is the fourth most widely grown crop in the U.S., with 10.5 million hectares being cut for hay per year (ARS, 2020). Historically in the southeastern U.S., the high humidity, higher temperatures and insect pressures, in addition to poor soil fertility and low soil pH common to this region were not conducive to alfalfa growth (Haby and Leonard, 2005; Terrill et al. 1996; Lacefield et al., 2009). Alfalfa requires a relatively neutral soil pH (6.5-6.8) and non-limiting levels of essential nutrients. It is especially sensitive to potassium (K), phosphorus (P), boron (B), and molybdenum (Mo) deficiencies (Hancock, Buntin, et al., 2015). Coupled with inexpensive N fertilizer and transportation costs, as well as the introduction of the alfalfa weevil, stands of what was once the most popular legume crop in the south dwindled significantly during and after the 1950s (Lacefield et al., 2009).

With the development of alfalfa varieties capable of withstanding the climatic challenges of the southeast, alfalfa production is increasing (Brown et al., 1990; Bouton and Gates, 2003; Haby and Leonard, 2005; Thinguldstad et al., 2020). Alfalfa grazing varieties, like Bulldog 805, Bulldog 505, and Alfagraze 600 RR, developed by Dr. Joe Bouton at the University of Georgia (Bouton and Gates, 2003) are considered “dual purpose” because they can be utilized as harvested forage (hay or baleage), as well as grazed by livestock (Funderburg, 2009).

In contrast with traditional alfalfa varieties, ‘Alfagraze’and other grazing tolerant varieties were developed specifically to withstand heavier grazing and animal pressure. Beck et al. (2017), Funderburg (2009), and Cassida et al. (2006) reported that these varieties are best suited in a rotationally stocked system. Cassida et al. (2006) observed across 2 years that stocker calves grazing either common bermudagrass or an alfalfa monoculture, the animals grazing alfalfa pasture gained the same amount of liveweight in less time than their counterparts grazing bermudagrass. Body weights were no different between heifers grazing bermudagrass vs those grazing alfalfa, but heifers grazing alfalfa made that gain in 38 less days in year one and 12 fewer days in year two (Cassida et al., 2006). A three-year study in central Georgia compared grazing of low, medium, and high forage allowances of two alfalfa cultivars, ‘Alfagraze’ vs. ‘Apollo’. It was reported that after three years of grazing and averaged over all forage allowances, Alfagraze maintained 5.5 plants/square foot, while Apollo stands decreased to 1.5 plants/square foot (Bates et al., 1996), noting the improved grazing tolerance of Alfagraze.

Legumes like alfalfa have the ability to biologically fix N, making them a viable option to replace N fertilizer in mixtures with grasses (Biermacher et al., 2012; Rouquette & Smith, 2010), as producers are looking to decrease input costs while maintain forage production, especially in the current economy where N fertilizer prices are near record levels (FAS). Additionally, alfalfa is known for its nutritive value. Lacefield et al. (2009) report that alfalfa in early bloom can provide 180-220 g kg^{-1} CP, 420 – 500 g kg^{-1} neutral detergent fiber (NDF), 320 – 360 g kg^{-1} acid detergent fiber (ADF), and 610 – 640 g kg^{-1} TDN.

Crabgrass

Crabgrass is a warm-season annual grass and is commonly considered a weed but has greater nutritive value when compared to warm-season perennial grasses. Crabgrass has a clump-like growth habit and can grow up to approximately 61 cm tall. This forage with African origins has several forms, but large or hairy crabgrass (*Digitaria sanguinalis*) and smooth crabgrass (*Digitaria ischaemum*) are most common. Large or hairy crabgrass usually has a pale green seedling with wide leaves covered in coarse, white hairs (Blount et al., 2017). Smooth crabgrass is easily distinguishable by its short, wider leaf, blackish-brown bract, and lack of the characteristic hairs seen on hair crabgrass, but has little forage potential (Blount et al., 2003). For the purposes of this review, hairy crabgrass will be the only focus. Crabgrass can compete well with other plants in forage systems because of its prostrate growth habit (Kichler, 2018), its adaptation to varying environmental conditions, including drought (Dalrymple et al., 1999), and its prolific reseeding ability.

Although it is an annual species, it can be managed to achieve stands in consecutive years through reseeding and can be of substantial benefit in pasture systems whether volunteer or intentional planting (Poore 2017). Planting crabgrass fits well in annual rotations where planting annual winter forages, such as cereal rye, wheat, triticale, annual ryegrass, oats, or clovers for early grazing is the goal. The seasons for winter annuals and crabgrass are complementary and allow for slight overlap in seasonal forage production, as crabgrass growth typically declines by late August to early September (Blount et al., 2017). Establishment should occur between mid-April and early June into soils with a pH between 5.5 and 7.5 (Peavey, et al. 2022). Nitrogen fertilization is recommended after emergence and after grazing, if necessary (Peavey, et al. 2022). The crabgrass must be allowed to flower and produce viable seeds in order to reseed itself year after year (Blount et al., 2003). Reseeding crabgrass can be a low-cost summer annual grass option for pastures, especially when managed to volunteer after winter annuals (Ball et al., 2015).

Crabgrass hay has been reported to have between 10.6% and 14.1% CP (Beck et al., 2007). Research by Ogden et al., (2005) observed that whole plant crabgrass harvested on seven different dates had more rapid ruminal disappearance rates of dry matter than bermudagrass (crabgrass range: 0.069 to 0.084 h^{-1}, bermudagrass average: 0.054 h^{-1}) and NDF disappearance rates were more rapid for crabgrass than bermudagrass (overall crabgrass range: 0.069 to 0.086 h^{-1}, bermudagrass average: 0.057 h^{-1}). However, crabgrass is considered a nuisance when it volunteers in hay production systems, as it increases dry-down times, increasing potential for spontaneous heating and molding (Dalrymple, 1999). Further, many hay producers have difficulty marketing hay with a higher percentage of crabgrass because of the color and texture, making it displeasing to the eye (Andrae, 2002). For these reasons, many hay producers will choose to control crabgrass and other annual “weeds” with a pre-emergent herbicide like Pendimethalin.

In pastures where crabgrass is intentionally managed for grazing, improved varieties like ‘Red River’ (Noble Foundation), ‘Impact’ (Barenbrug, USA), and the commercial blend ‘MOJO’ (Barenbrug USA) may be utilized. With adequate N fertilization, crabgrass can be grazed within 30 to 40 days of planting, or when it has reached a height of 30 to 38 cm and a stocking rate of 363 to 544 kg of live weight per acre can be reached (Peavey et al., 2022). Additionally, as crabgrass is tolerant of defoliation, it can be grazed to as low as 7.6 cm (Blount et al., 2003). Dalrymple (1980) reported in a single replication demonstration, calves with initial weights ranging from 195 to 212 kg that grazed good to lush crabgrass gained an average of 0.94 kg per day and calves that grazed fully seeded mature crabgrass averaged up to 0.41 kg of daily gain, noting that even poor crabgrass pasture resulted in weight gain.

Poor Bermudagrass Pastures/Pasture Restoration

Although bermudagrass varieties have been developed to be well adapted to the Coastal Plains region (Burton 1947; Burton et al., 1993), nutritive value is moderate at best (Johnson et al., 2001; Ball et al., 2015; BCNRM, 2106). Additionally, the intensive nature of management for bermudagrass pasture success, including soil nutrient management, and stocking rate, intensity and duration (Rouquette, 2017), has led to an abundance of poor bermudagrass stands, where bermudagrass is thinning and weeds are encroaching. Pasture renovation refers to the "renewing" of poor pasture by introducing desired species to the stand, often requiring partial destruction of existing sod, liming and fertilizing, controlling weeds, and seeding a legume or legume-grass mixture (Johnson, Rhykerd, & Hertel, 2003). Renovation of pasture should occur when pasture has been severely overgrazed and weed growth is dominant (Hautau, 2016). One must consider how much desirable forage is still left before undertaking renovation, as complete renovation is expensive and may not be necessary. If an adequate density of desirable forages is still present, restoration by overseeding with another forage, improved grazing management, and addressing soil fertility with a soil test may be the most efficient option (Lemus, 2021).

Restoring or renovating pasture does not imply, however, that a mixture of species isn't beneficial. Biodiversity of plant species in grassland systems have been reported to include increased forage production, greater ecosystem stability in response to disturbance, and reduced invasion by exotic species (Sanderson et al., 2007). Sanderson et al. (2013) note pasture-scale studies that have shown forage mixtures of 3 to 9 species yielded more herbage mass than binary grass-legume mixtures or monocultures (Sanderson et al., 2005; Skinner et al., 2006). However, these studies included intentionally planted complex systems of multiple species.

Warm-Season Perennial Grass and Cool Season Legume Mixtures

Restoring bermudagrass pasture by use of cool season forages is not a novel concept. Studies with tall fescue (*Festuca arundinacea*) -bermudagrass mixtures have been evaluated (Burns et al., 1973; Franzleubbers, 2003; Franzluebbers et al., 2013; Fribourg and Overton, 1973; Hoveland et al., 1997; Kallenbach et al., 2012; Mitchell et al., 1986), however tall fescue has had limited application in the Coastal Plains due to prolonged periods of higher temperatures and sporadic moisture availability, which contribute to inducing water deficit stress severe enough to limit plant persistence (Sleper and West, 1996). Winter-annuals are more commonly overseeded onto dormant bermudagrass pastures because of the limited overlap in growing season and less competition (Fribourg and Overton, 1973; Decker et al., 1974), however this does not improve the bermudagrass base and seeding must take place each year (Hall et al., 2020), excluding volunteer ryegrass. Inclusion of a cool-season perennial legume like alfalfa, however, can extend the grazing season, improve nutritive value of the forage base, and decrease the dependence on N fertilizer, while requiring similar soil fertility conditions and management recommendations (Tucker et al., 2021). Utilizing the N-fixing capabilities of cool-season legumes can have substantial monetary benefits for producers, especially during times of high fertilizer N cost (Rouquette and Smith, 2010).

Cool-season legumes grown with warm-season grass pastures will extend the grazing season and help reduce cost of feeding stored forage (hay or baleage) as the cool-season legumes can carry grazing further into the winter months (Beck et al., 2017a; Bouton et al., 1998; Cassida et al., 2006). This extension of grazing coupled with the improved forage quality can be helpful during the time stockers need to continue growing or females are required to raise a calf at side while maintaining a pregnancy (Burton, 1976). Bermudagrass is abundant throughout Georgia (Hancock, Hicks, et al., 2015), however its moderate nutritive value and seasonal dormancy often means additional supplementation will be required to meet animal needs (Johnson et al., 2001; Ball et al., 2015; BCNRM, 2106).

Integrating alfalfa can also add N to the forage system. The indirect effects of biological N fixation can reduce or eliminate the need to add supplemental N in alfalfa-bermudagrass mixtures (Heichel and Henjum, 1991; Stringer et al., 1994; Haby et al., 1999; Beck et al., 2017a). The legume component of these mixtures should exceed 30% to provide adequate nitrogen levels (Heichel and Hejum, 1991). Alfalfa has the potential to contribute 42 to 91% of the total plant N in the alfalfa bermudagrass system (Haby et al., 2005), however this transfer of N from the alfalfa to the grass happens during the later stages of the growing season, not immediately (Beck et al., 2017a; Knight, 1970; Morris et al., 1990).

Establishment of mixture

Incorporating alfalfa into an existing stand of bermudagrass starts with proper site selection. The field must be well-drained and have a pH range of 6.5 to 7 prior to planting (Tucker et al., 2021). Once a suitable site is chosen, it is important to remember that pH changes via lime will not be an overnight fix, so it may require applications 6 months or more before planting (Henning and Lacefield, 1999). Maintaining this soil pH and ensuring proper fertilization with phosphorous (P) and potassium (K) are vital to mixture success, in addition to micronutrients, like boron and molybdenum (Tucker et al., 2021). Tucker et al. (2021) also shown that previous weed control and/or recurring hard to control weeds must be taken into consideration for site selection. Application of a product with short-term residual, like dicamba (3,6-dichloro-2-methoxybenzoic acid) in the spring before fall alfalfa establishment is considered safe, but delayed planting of 4 to 12 months may be required for long-term residual chemistry options, like sulfonylureas.

Bermudagrass should be harvested via intense grazing or mowing to 1 to 2 inches just prior to interseeding with alfalfa. Sod should be suppressed through an application of a light rate of a non-selective herbicide (such as glyphosate) after harvesting to induce dormancy in the bermudagrass, reducing competition during alfalfa establishment (Tucker et al., 2021). Since bermudagrass growth slows dramatically in the fall when nightly temperatures drop into the 40s and 50s, it is advantageous to reduce the competition of bermudagrass by planting the alfalfa into the mixture at this time (Jennings, Simon, Philipp, & Beck, 2016; Tucker et al., 2021).

After site selection, preparation of soil, and choice of variety and timing of establishment, it is important to distinguish row spacing for interseeding alfalfa. Tucker et al. (2021) recommended a row spacing of 35 to 38 inches for optimal growth of both the alfalfa and bermudagrass. If alfalfa rows are planted closer together at a row spacing of 18 to 23 cm, the alfalfa can shade out bermudagrass. The opposite effect will be observed with a wider 61 cm row, with the bermudagrass outcompeting the alfalfa (Tucker et al., 2021). A study using Tifton 44 bermudagrass interseeded with Cimarron alfalfa at 20, 40, and 60 cm row spacings reported increased bermudagrass percentage as alfalfa row spacing increased, and bermudagrass concentration declined rapidly in the 20cm alfalfa row spacing (Stringer et al., 1994). Beyond row spacing, the same study by Stringer et al. (1994) found that, even at a wider row spacing, the alfalfa converted enough N to replace at least 448 kg fertilizer nitrogen ha^{-1} in producing herbage protein in bermudagrass (Stringer et al., 1994). However, row spacing made no difference in herbage accumulation in a study by Brown and Byrd (1990), where both the alfalfa monoculture and alfalfa-bermudagrass mixture had higher yield than bermudagrass monoculture treatments fertilized with 100 kg N ha^{-1}.

Establishing alfalfa into an existing stand of bermudagrass requires careful consideration of timing to ensure establishment success. Tucker et al. (2021) reported that suppression of bermudagrass is key, therefore alfalfa should be planted in the fall when bermudagrass is dormant, when soil temperatures range from 65° to 80° F, and when plenty of soil moisture is present. This is further recommended by Ball et al. (2015), who note that September – October is the best time to plant in the Coastal Plains, and spring establishment of alfalfa should be reserved for areas with a mean annual air temperature of 65° F or below. Stringer et al. (1994) note that deeper rooting of alfalfa can prolong the growth advantage of alfalfa when moisture is lacking, thus the added time for establishment when planting in the fall would be of advantage to alfalfa persistence.

An alfalfa-bermudagrass system typically calls for a preemergent herbicide such as Pendimethalin (Prowl H2O [N-(1-ethylpropyl)-3,4- dimethyl-2,6-dinitrobenzenamine}, BASF Ag Products) for control of annual grass weeds in stored forage production systems (Burt, 2022). In doing so, beneficial pasture species like crabgrass or annual ryegrass are suppressed along with the extra cost for product, time and labor is incurred, when those species may be beneficial in grazing systems.

Botanical Composition of Alfalfa-Bermudagrass Mixtures

Ideally, there is an ebb and flow relationship in alfalfa-bermudagrass (ABG) mixtures. Alfalfa dominates in spring before bermudagrass green-up, as observed by Hendricks et al. (2020) and Burt et al (2022). Their research reported alfalfa's greatest contribution to the mixture early in the growing season, comprising 40% or more of the mixture, with bermudagrass being a greater component later in the season at approximately 50% or more. Both Burt et al. (2022) and Hendricks et al. (2020) report changes in the forage canopy, with alfalfa dominating from approximately March to June and dominance favoring bermudagrass from July to September. Brown and Byrd (1990) compared 'Apollo' alfalfa interseeded into Coastal bermudagrass at 15-cm and 30-cm rows with species monocultures to evaluate herbage accumulation and botanical composition. Their research confirmed the findings of Hendricks et al. (2020) and Burt et al. (2022) in that before bermudagrass had broken dormancy entirely in the Spring, alfalfa dominated the stand regardless of row spacing.

Crabgrass is often an inevitable component of alfalfa-bermudagrass mixtures. It is prevalent throughout pastures in the southeastern United States and has traditionally been labeled a nuisance in ABG hay systems because of increased dry-down times (Dalrymple, 1999). Crabgrass will tend to show up later in the growing season, when other species like annual ryegrass have played out (Burt 2022). Alfalfa-bermudagrass management plans will often call for a preemergent herbicide to control annual weeds (Tucker et al., 2021), but in doing so, potentially beneficial species like crabgrass are controlled. In a pasture setting, allowing crabgrass to persist in the system could be beneficial.

Summary and Objectives

Alfalfa-bermudagrass systems can serve great benefits for livestock producers across the southeast, including an increase in grazing days, stocking rate, less use of synthetic nitrogen fertilizer, and increased animal performance. Crabgrass is an inevitable component of these systems, but pre-emergent herbicide can be costly in product, time and labor. Potential exists for allowing crabgrass to persist without negatively impacting the system. Producers in the Coastal Plains often attempt to establish alfalfa in the spring, however, bermudagrass competition proves challenging. The following research intends to identify how different management strategies impact herbage accumulation and forage nutritive value of poor bermudagrass stands in need of restoration, including the addition of alfalfa, impacts alfalfa establishment timing, and crabgrass inclusion.

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CHAPTER 2

EVALUATING THE IMPACTS OF OVERSEEDED ALFALFA ESTABLISHMENT TIMING AND CRABGRASS COMPETITION IN RESTORING SOUTHERN BERMUDAGRASS PASTURES

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Abstract

Inclusion of alfalfa (*Medicago sativa*) in bermudagrass *(Cynodon dactylon)* pastures improves nutritive value, increases grazing days, and reduces need for synthetic nitrogen fertilizer. In the coastal plains, establishing alfalfa in the fall versus the spring allows seeds to germinate and grow with less bermudagrass competition. Crabgrass (*Digitaria sanguinalis*) is a common weed requiring pre-emergent herbicide application to control. However, crabgrass could be a valuable forage in a grazing system, as it is a palatable warm-season annual grass with high nutritive value and prolific reseeding ability. The objective of this research was to evaluate the impact of alfalfa establishment timing and crabgrass inclusion on establishment year nutritive value, botanical composition, and forage accumulation in an alfalfa – bermudagrass pasture restoration strategy. This two-year study conducted in Tifton, GA utilized 4 replications of 6 treatments: bermudagrass + fall alfalfa + crabgrass, bermudagrass + fall alfalfa, bermudagrass + spring alfalfa + crabgrass, bermudagrass + spring alfalfa, bermudagrass + synthetic N, and untreated bermudagrass control. Establishment data was collected on a 28 to 35-day interval to determine botanical composition, forage mass, and nutritive value. This research reported increases for fall established alfalfa treatments, regardless of crabgrass inclusion, in percent alfalfa contribution ($P < .0001$), herbage mass ($P < .0001$), CP ($P < .0001$), and IVTDM ($P < .0001$), supporting the current recommendation of fall establishment of alfalfa in the Coastal Plains. Crabgrass inclusion did not cause differences in the present study. Utilizing overseeded alfalfa into existing bermudagrass pastures, and allowing annual forages to persist in the system, could be a restoration strategy for poor pastures across the Southeastern United States.

Introduction

Bermudagrass (*Cynodon* spp.), one of the most predominant warm-season perennial grasses in Georgia, is grown on approximately 8.1 million hectares in the Southeastern United States (Redfearn and Nelson, 2003). Although bermudagrasses have been developed to be adapted to the Coastal Plains region (Burton 1947; Burton et al., 1993), nutritive value is moderate at best and doesn't always meet nutritional needs of cattle at various stages of development (Johnson et al., 2001; Ball et al., 2015; BCNRM, 2016). Additionally, bermudagrass requires intense management for pasture success, including soil nutrient management, and stocking rate, intensity and duration (Rouquette, 2017). Lack of proper management, and often prolonged periods of drought conditions, has led to an abundance of poor bermudagrass stands (Rouquette, 1993). Renovation of pasture should occur when pasture has been severely abused, neglected, or overgrazed and weed growth is dominant (Hautau, 2016). One must consider how much desirable forage is still left before undertaking renovation, as complete renovation may not be necessary. If an adequate density of desirable forages is still present, restoration by addressing soil fertility with a soil test, through improved grazing management, and overseeding with another forage may be the most efficient option (Lemus, 2021).

Overseeding bermudagrass pasture with cool season forages is not a novel concept. Winter-annuals are common to overseed onto bermudagrass pastures because of the limited overlap in growing season and less competition (Fribourg and Overton, 1973; Decker et al., 1974); however, this does not improve the bermudagrass base and seeding must take place each year (Hall et al., 2020). Utilizing the nitrogen-fixing capabilities of cool-season legumes can provide a monetary benefit for producers (Rouquette and Smith, 2022). Inclusion of a cool-season perennial like alfalfa (*Medicago sativa*), however, can extend the grazing season, improve nutritive value of the forage base, and decrease the dependence on nitrogen fertilizer, while requiring similar soil fertility conditions (Tucker et al., 2021). Therefore, overseeding bermudagrass pasture with a cool season annual legume can be a restoration option.

Alfalfa-bermudagrass systems have been reported to provide beneficial results in grazing scenarios. In a grazing study comparing bermudagrass + nitrogen fertilization with alfalfa + bermudagrass, the alfalfa + bermudagrass treatment had greater stocking rate and gain of beef animals when grazing (Burt et al., 2022). Rushing et al. (2022) observed that cattle grazed on alfalfa + bermudagrass had greater average daily gain (ADG; 0.83 kg hd^{-1} day^{-1}) and total gain per hectare (GAIN; 311.60 kg ha^{-1}) as compared to animals grazing bermudagrass fertilized with 112 kg ha^{-1} yr^{-1} of nitrogen (ADG: 0.56 kg hd^{-1} day^{-1}; GAIN: 237.62 kg ha^{-1}).

Bermudagrass growth slows in the fall when nightly temperatures drop into the 40s and 50s, it is advantageous to reduce the competition of bermudagrass by planting the alfalfa into the base at this time (Jennings et al., 2016; Tucker et al., 2021). Utilizing fall establishment of alfalfa allows the seed to germinate and grow during bermudagrass dormancy, reducing competition during establishment. However, some producers in the Coastal Plains will attempt to establish alfalfa into an existing bermudagrass stand in early spring because cooler temperatures are still present. Successful stands have been achieved with spring planting, with reports of 22,654 kg ha^{-1} DM, however this is after the establishment year (Hendricks et al., 2020).

Weed management is often a necessary step in pasture restoration. Crabgrass (*Digitaria sanguinalis*) is prevalent throughout pastures in the southeastern United States and has traditionally been labeled a nuisance in hay systems because of increased dry-down times (Dalrymple, 1999). It is often an inevitable component of alfalfa-bermudagrass mixtures.

Alfalfa-bermudagrass management plans will often call for a preemergent herbicide to control annual weeds (Tucker et al., 2021), but in doing so, potentially beneficial species like crabgrass are controlled. Crabgrass has a greater nutritive value when compared to warm-season perennial grasses (Peavey et al., 2022). In a pasture setting, allowing crabgrass to persist in the system could be beneficial by reducing cost, time, and labor of herbicide application, and filling in open spaces in ground cover that might otherwise be taken up by species undesirable to grazing animals, while not negatively impacting herbage accumulation or nutritive value of the stand. Dalrymple (1980) reported in a single replication demonstration, calves that grazed good to lush crabgrass gained an average of 0.94 kg per day and calves that grazed fully seeded mature stage crabgrass averaged up to 0.41 kg of daily gain, noting that even poor crabgrass pasture produced gain. It has been observed that crabgrass harvested on seven different dates had greater dry matter and neutral detergent fiber (NDF) digestion rates and less fiber content than bermudagrass (Ogden et al., 2005).

Therefore, it was hypothesized that using overseeded alfalfa, in addition to utilizing crabgrass, would be a suitable restoration option for poor southeastern bermudagrass pastures. Fall planting of alfalfa would allow better establishment than spring planting and crabgrass in the alfalfa-bermudagrass mixture would not affect nutritive values or herbage mass. The objective of this study was to identify how different management strategies of restoring poor bermudagrass pastures with alfalfa will impact herbage mass and forage nutritive value of poor bermudagrass, including the impacts of alfalfa establishment timing and crabgrass inclusion.

Materials and Methods

Experimental Location, Plot Establishment and Maintenance

This study was conducted at the University of Georgia Better Grazing Program in Tifton, GA (31.49° N, -83.54° W; 104m elevation) during the growing seasons of 2021 and 2022 on Tifton loamy sand type soils with 2 to 5% slopes (USDA, 2021). Two sets of identical plots were established in consecutive years in adjacent locations, approximately 6 meters apart. Twenty-four 9.3 square meter plots were established per location, utilizing a randomized complete block design with 6 treatments and 4 replications (n = 4 plots/treatment in each location). Existing 'Tifton-85' bermudagrass was interseeded with 'Alfagraze 600 RR' alfalfa and 'MOJO' crabgrass, depending on the treatment. Topsoil (0-15 cm) and subsoil (15-30 cm) samples were collected at the initiation of each season and all plots were fertilized with P, K, and micronutrients (B and Mo) according to University of Georgia soil test recommendations (Kissel and Sonon, 2008).

Treatments evaluated were: bermudagrass fertilized with nitrogen (BG + N), bermudagrass overseeded with fall-established alfalfa (FA), bermudagrass overseeded with and fall-established alfalfa and crabgrass (FA + CG), bermudagrass overseeded with spring-established alfalfa (SA), bermudagrass overseeded with spring-established alfalfa and crabgrass (SA + CG), and an unfertilized bermudagrass control (CON). Alfalfa in fall establishment treatments were planted on October 23, 2020 for Location 1 and October 12, 2021 for Location 2. Spring established treatments were planted on February 26, 2021 and February 25, 2022 for Locations 1 and 2, respectively. In preparation of establishment, plots were mowed to a 7.6 cm stubble height and thatch removed seven days prior to planting, and a suppression rate of glyphosate (Round-Up Power Max [N-(phosphonomethyl)glycine; Bayer] 9 ounces per acre of

5.5 lb. active ingredient formulation) was applied to induce bermudagrass dormancy. Alfalfa was planted on a 35.5 cm row spacing at 16.8 kg ha^{-1} seeding rate. After alfalfa emergence, 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 insect pests. At four points during both summers, army worm and bermudagrass stem maggot pressure was addressed using Chlorantraniliprole (Prevathon, Corteva Agriscience) at a rate of 100 g a.i. ha^{-1} and zeta-cypermethrin (Mustang Maxx, FMX Corporation) at a rate of 28 g a.i. ha^{-1}. Crabgrass was planted in assigned plots at Location 1 on May 27, 2021 and June 8, 2022 at Location 2 at a rate of 9 kg seed ha^{-1}, on a 35.5 cm row spacing off-set from alfalfa rows. Planting of crabgrass was only done to ensure its presence in the system.

Nitrogen was applied to BG + N treatments in the form of calcium ammonium nitrate (CAN) at a rate of 56 kg ha^{-1} on May 27, 2021 at Location 1 and June 8, 2022 at Location 2. Nitrogen fertilizer was only applied once per growing season to more closely simulate a pasture situation in the coastal plains, where one application of fertilizer, if any, is utilized. Pre-emergent herbicide was not used in this evaluation to observe efficacy of pasture restoration management techniques without the use of pre-emergent herbicide technology.

Data Collection

Establishment data on all plots was collected during the growing seasons of 2021 and 2022 on a 28-to-35-day interval beginning when the alfalfa had reached 25% bloom stage, from approximately May through October. Three randomly placed 0.1 m^2 quadrats within each plot were utilized to measure vegetative cover by species and the quadrat was destructively harvested for species separation and to determine botanical composition. Samples were separated into one of four categories: alfalfa, bermudagrass, crabgrass, and other forage components (all other forage species and weeds), and then forced-air dried at 55°C for four days to correct for moisture content, and dry weights were used to determine species component contribution. Herbage accumulation was determined by mowing a 3.25 m^2 strip from each plot, cut at a 7.6 cm stubble height. The mower bag was tared and weighed on a hanging scale to assess weight from the mowed strip, after which a subsample was collected for dry matter determination and nutritive value analysis. Subsamples taken from each plot were also dried at 55°C in a forced air dryer for four days. All samples were ground through a Wiley Mill (Thomas Scientific, Philadelphia, PA) 1-mm screen. Samples were then split using a sample splitter. One subsample was analyzed via wet chemistry and the second one was ground through a Foss CT-293 Cyclotec Cyclone Mill (Foss Analytics, Eden Prairie, MN) 1-mm screen (McIntosh et al., 2022) for nutritive value analysis via near infrared spectroscopy (NIRS). Post data collection, residual forage was removed to the same 7.6 cm height.

The 2022 Mixed Hay and Grass Hay calibration equations, as provided by the NIRS Forage and Feed Testing Consortium (NIRSC, Berea, KY), were used to analyze 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). Sample analysis was conducted using a Foss DS2500 near infrared spectrometer (NIRS; Foss Analytical, Eden Prairie, MN) that was standardized to the NIRSC master instrument to ensure prediction accuracy. Moisture content was assessed initially for forage sample sets to ensure consistent scanning and results across all samples on a NIRS (McIntosh et al., 2019; McIntosh et al., 2022). Nutritive value data were reported with predictions fitting the allowable global $H < 3.0$ statistical comparison with the overall calibration population (Murray and Cowe, 2004). A subset of samples (18%) was randomly selected from each harvest for validation of nutritive value parameters through the University of Georgia Tifton Animal and Dairy Science Laboratory. Wet chemistry was used for validation of NIRs results using traditional techniques for CP, digestibility, ADF and NDF (Pomerleau-Lacasse et al.; 2018, AOAC, 1990; Goering and Van Soest, 1970). Total monthly rainfall and average maximum and minimum temperatures for the experimental period were collected from University of Georgia weather station records (UGA-AEMN, 2023) and historical weather data (30-year average) were collected from the NOAA (NOAA 2023) and presented in Figure 1.

Statistical Analyses

Data were analyzed as a randomized complete block design with repeated measures using PROC MIXED (Littell et al., 2006) and PROC PLM in SAS 9.4 (SAS Instit. Inc., Cary. NC). The model included the fixed effects of harvest, treatment, and their interactions, and the random effect of block. Plot was the subject and the covariance structure used for all varaibles was first-order autoregressive based on the smallest Bayesian's Information Criterion (Little et al., 2006). Differences in herbage mass, nutritive value, and botanical composition were evaluated within harvest and location. The Kenward-Roger adjustment was used to correct the denominator degrees of freedom and ensure appropriate standard errors and F statistics. Means were compared using the LSMEANS procedure with Tukey-Kramer adjustment. Data were sliced by harvest and adjustments were made with Tukey slices. Differences were considered significant at $P \leq 0.05$.

Results and Discussion

Weather

Monthly rainfall and average monthly temperature compared to the 30-yr average is presented in Figure 1 (NOAA, 2023; UGA-AEMN, 2023). Establishment conditions were different in terms of moisture for each location. Fall established alfalfa in location 1 was planted in October of 2020, where rainfall was slightly below the 30-year average and temperature was 2°C above historical average. Spring established alfalfa in location 1 was planted in February 2021, which reported rainfall 111mm over the 30-year average. Meanwhile for location 2, for fall established alfalfa planted in October 2021 rainfall and temperature were above average. Spring established alfalfa in location 2 was planted in dry conditions and showed rainfall 41 mm below the 30-year average. The harvesting season (May – October) for both locations began dry, reporting between 26.7 and 32.2 mm of rainfall (2021 and 2022, respectively) in the month of May, compared to the 30-yr average of 67.8 mm (NOAA, 2023). However, June and July in Location 1 had an average of 206 mm of rainfall, in contrast with Location 2 in June and July which averaged 120 mm. Location 2 did not receive a significant rain event until August, where the monthly rainfall rose to 207 mm. Overall drier conditions were reported for Location 2, as compared to Location 1. The average monthly temperatures were similar to or slightly greater than the 30-year average in both locations throughout the study. Weather impacts caused variability in results between Location 1 and Location 2, therefore discussion will occur separately by Location.

Botanical Composition

Location 1 and Location 2 data in all parameters will be discussed separately, as they were conducted as two separate experiments. Botanical composition for both locations is reported across May, June, July, August, September, and October harvests for all treatments (Figures 2.2 and 2.3). Alfalfa contribution fluctuated across harvests as expected in both locations. Fall alfalfa treatments had a greater proportion of alfalfa, as opposed to spring alfalfa treatments. For FA and FA + CG, 72% and 81% alfalfa component, respectively, was reported at the May harvest in location 1. As expected, due to the "summer slump" alfalfa experiences, alfalfa contribution slowly declined over the growing season to its least at the September harvest, recording 24% and 37% for FA and FA + CG, respectively. Percent alfalfa increased at the last harvest in October, concurrent with bermudagrass decline. For location 1 October harvest, 62% and 66% alfalfa for FA and FA + CG, respectively was reported. Location 2 fall alfalfa treatments had greatest alfalfa contribution at the May (FA= 97% and FA + CG = 93%) and October (FA= 79% and FA + CG = 62%) harvests. Spring-established alfalfa treatments reported a lesser alfalfa percentage, with the greatest contribution observed at the October harvest in location 1: 14% in SA and 15% in SA + CG. Location 2, however, had the greatest alfalfa contribution in May, at 24% and 32% alfalfa respectively for SA and SA + CG. This is presumed to be because drier planting conditions of location 2 allowed for better establishment of alfalfa, as opposed to Location 1 that received well above average rainfall during February planting time period (Figure 1). Alfalfa cannot perform well under prolonged periods of wet soil conditions (Haby et al., 1997); therefore, the high moisture during spring planting in location 1 likely contributed to the reduced alfalfa component at the May harvest. Alfalfa proportions in SA and SA + CG in all remaining harvests declined to less than 5% and 11%, respectively.

Differences in spring versus fall established alfalfa are observed as a result of better establishment conditions in the fall. This is not surprising as fall planting allows for less bermudagrass competition as alfalfa is germinating and growing (Haby et al., 1997).

Bermudagrass contributions in CON and BG + N were similar across harvests in location 1. However, the location 2 May harvest had a greater "Other" component, likely due to the dry conditions stunting bermudagrass green-up. In location 1 for fall alfalfa treatments, the proportion of bermudagrass reached its highest contribution in June for FA (25%) and August for FA + CG (19%). Spring established alfalfa treatments had a greater bermudagrass component. A peak of 87% bermudagrass was recorded for SA in May and 96% in June for SA + CG. Location 2 recorded greater bermudagrass input across fall alfalfa treatments, with a greatest percentage in September (50%) for FA and 53% in July for FA + CG. Spring alfalfa and SA + CG in Location 2 had greatest bermudagrass contribution in the June harvest, with 99% and 90% bermudagrass, respectively. Ideal temperatures for bermudagrass are between 20°C and 35°C and it is more drought tolerant (Moore et at., 2004), thus the variations in bermudagrass proportion, specifically the greater bermudagrass proportion in location 2, follow as expected with reported temperatures and rainfall during growing seasons (Figure 1).

Whether or not crabgrass was intentionally planted, it was present across all treatments and both locations. The crabgrass component in FA for location 1, where crabgrass was not planted, was overall greater than in FA + CG. Peak crabgrass contribution was observed across July, August, and September harvests in FA (43%, 46%, and 45%, respectively), however FA + CG at those same harvests reported 31%, 36%, and 36% crabgrass, respectively. Both spring alfalfa treatments in location 1 also reported greatest crabgrass component in July, August, and September. Burt et al. (2022) reported similar findings in their "other" component, which included crabgrass, across the season in grazed bermudagrass + alfalfa. Location 2 had overall lower percentages of crabgrass across all treatments. This is contrary to results reported by Hendricks et al. (2020), where percentage of crabgrass and other drought tolerant weed species were greater in the establishment year of the alfalfa + bermudagrass mixture. The lesser crabgrass presence in location 2 is concurrent with lesser forage mass overall, due to lacking moisture.

Herbage Mass

Herbage mass (HM) data were analyzed by location within harvest and treatment to better isolate treatment differences (Table 2.1). There was a harvest x treatment interaction observed in both locations (P<0.0001).

In all location 1 harvests, except for May and September, both fall alfalfa treatments (FA and FA + CG) had greater HM than spring alfalfa treatments (SA and SA + CG) ($P < 0.0035$). There was no difference among SA, SA + CG, and CON in all harvests ($P \geq 0.19$). No difference was observed at the May harvest between FA and FA + CG ($P = 0.45$); however, FA + CG was greater than all other treatments ($P < 0.0032$), while no difference occurred among FA and CON, BG + N, SA, or SA + CG ($P \geq 0.61$). The bermudagrass + N treatment (BG + N) was no different than FA (ADD P VALUE) in the June harvest. This increase in HM is likely due to an increase in rainfall during the month of June in 2021. The bermudagrass + N treatment (BG + N) had the greatest HM in the August harvest ($P < 0.0001$), which is the result of N fertilization in late July. No difference was observed at the September harvest among BG + N, FA, and FA + CG ($P > 0.13$). Bermudagrass contribution lessens as fall progresses, thus the HM results for the October harvest follow as expected. Fall alfalfa treatments in the final harvest were greater than all other treatments ($P < 0.005$), with no difference observed among CON, BG +N, SA, and SA + CG ($P > 0.69$).

Location 2 HM values were decreased due to decreased rainfall in 2022 (Figure 1). No differences were observed among any treatments in location 2 for May ($P < 0.71$) or June harvests ($P < 0.11$). This is attributed to the lack of rainfall. Herbage mass was greatest for FA and FA + CG at the July harvest for location 2 ($P < 0.0001$). Meanwhile, SA and SA + CG were not different ($P = 0.81$); however. both treatments were greater than CON and BG + N ($P < 0.0491$), which were no different ($P = 0.93$). The August harvest for Location 2 followed the same trend as its counterpart in Location 1, with BG + N recording the greatest HM ($P < 0.02$), due to N fertilization in late July. Fall alfalfa (FA) and FA + CG were greater than the remaining treatments (SA, SA + CG, and CON; $P < 0.0001$), of which there was no difference ($P > 0.91$). The September harvest had fewer differences between treatments, in line with findings from the location 1 September harvest. No differences were observed between either fall alfalfa treatments and BG + N ($P < 0.16$), or between BG + N and both spring alfalfa treatments ($P < 0.09$). Bermudagrass + N, FA, and FA + CG were all greater than CON ($P > 0.005$). The October harvest in Location 2 only included treatments where alfalfa was planted. Plots with CON and BG + N treatments did not have enough forage material to sample, due to bermudagrass beginning dormancy. However, similar to previous harvests, FA and FA + CG were no different from each other ($P = 0.10$), while FA was greater than SA and SA + CG ($P < 0.04$). No difference was reported among FA + CG, SA and SA + CG ($P > 0.10$) for the final harvest in Location 2.

Fall established alfalfa treatments were always greater than spring established alfalfa treatments. Spring establishment causes alfalfa to compete with bermudagrass green-up shortly after planting. The more favorable establishment conditions of fall alfalfa planting allowed for better root development and less competition from other forage, which was evident in the reported greater HM. There was only one harvest between both locations that reported a difference between FA and FA+ CG or SA and SA + CG. The June harvest in Location 1 noted FA + CG being greatest among all treatments including alfalfa, likely due to contributions from all main components. Alfalfa was just hitting the beginning of "summer slump" but was still contributing, bermudagrass had come out of dormancy, and crabgrass had 4 weeks of growth. Overall, crabgrass inclusion in this alfalfa-bermudagrass system did not cause differences in herbage mass.

The observed forage mass in both alfalfa + bermudagrass mixture treatments and fertilized bermudagrass treatments in both locations was lesser than those reported by Hendricks et al. (2020) in the establishment year. Burt et al. (2022) reported greater forage mass in the fertilized nitrogen treatment than those in the present study. However, FA and FA + CG reported greater forage mass than the bermudagrass + alfalfa mixture, but the same fall established alfalfa – bermudagrass mixture reported by Burt et al. (2022) had greater forage mass than the spring established alfalfa + bermudagrass treatments in this study.

Forage Nutritive Value

Nutritive value parameters are reported by location and treatment within harvest (Tables 2.2 and 2.3). Across all harvests in Location 1, FA and FA + CG reported the greatest crude protein (CP) ($P < .0001$). This is expected, as fall established alfalfa plots consistently had the greatest percentage of alfalfa, thus greater protein concentration. The spring established alfalfa treatments were not different from BGN or CON in 5 of the 6 harvests for CP ($P > 0.14$), due to the low alfalfa contribution in spring established alfalfa treatments. Protein concentration was more variable among treatments within harvest in Location 2. Crude protein was still greatest for fall established treatments in 5 of the 6 harvests ($P < .01$). The outlier was the August harvest, in which BGN was no different than FA and FA + CG ($P > 0.83$), due to the fertilizer N application in late July on BGN plots. The May harvest in Location 2 reported greater CP for CON and BGN (154 g kg^{-1} and 164 g kg^{-1}, respectively) than for either spring established alfalfa treatment (SA, 106 g kg^{-1} and SA + CG, 115 g kg^{-1}; $P < .001$). In a grazing study by Rushing et al. (2022) comparing bermudagrass alone, bermudagrass fertilized with N, and fall established alfalfa + bermudagrass mixtures, CP was overall less across the season for the bermudagrass + alfalfa treatment than the fall established alfalfa treatments in the current study, but greater than SA and SA + CG. CP values reported by Beck et al. (2017) in continuously grazed, fall established alfalfa – bermudagrass treatments were lower than fall established alfalfa plots but greater than spring established alfalfa treatments in the current study.

Fiber factors followed as expected with botanical composition and alfalfa contribution. Acid detergent fiber (ADF) was lowest for FA and FA + CG in the May (289 g kg^{-1} and 307 g kg^{-1}, respectively; $P < .0001$) and October (266 g kg-1 and 275 g $kg^{-1,}$ for FA and FA + CG, respectively; $P < .003$) harvests for Location 1. Location 2 reported lowest ADF levels in FA and FA + CG during the May (252 g kg^{-1} and 258 g kg^{-1}, respectively; $P < .0001$), June (256 g kg^{-1} and 262 g kg^{-1} for FA and FA + CG, respectively; $P < .0001$), and October (234 g kg^{-1} and 231 g kg^{-1} for FA and FA + CG, respectively; $P < .0001$) harvests. Overall, NDF concentrations were least in FA anf FA + CG for both locations ($P \leq 0.04$). The only exceptions in term of lowest ADF was the September harvest in Location 1, in which FA + CG was not different than either spring established alfalfa treatment ($P > 0.10$) and the July harvest in Location 2, which observed no difference between FA and SA + CG ($P = 0.06$).

Results for in vitro true dry matter digestibility at 48 hours (IVTDM48) are expected with greater bermudagrass contribution in the summer months and lesser alfalfa percentage. The first two harvests in both Locations reported greatest digestibility in FA + CG. As the summer months progressed, less differences were observed between FA and FA+ CG and spring established alfalfa treatments or BG + N. This is due to the botanical composition of plots in warmer months as bermudagrass percentage increases, digestibility decreases. Fiber factors (ADF and NDF) and digestibility (IVTDM48) results reported in the establishment year of a spring planted alfalfa+bermudagrass baleage study by Hendricks et al. (2020) fall in line with spring established alfalfa treatment results in this study. BG + N treatments in the present study reported greater value for ADF and NDF, and lower digestibility than bermudagrass treatments fertilized with N observed by Hendricks et al. (2020).

Conclusions and Implications

The results from this study indicate that there is potential for cattle producers to save money on pre-emergent herbicide, allowing crabgrass and other annual "weeds" to persist in this system. Overall, crabgrass inclusion in the system did not cause differences in herbage accumulation or nutritive value, as crabgrass was present across all treatments and both locations, regardless of whether or not it was intentionally planted. Planting crabgrass in this mixture is not recommended, as it is likely to volunteer on its own. Future work should focus on comparing an alfalfa-bermudagrass pasture system that has utilized a pre-emergent herbicide to one that does not. Additionally, animal performance using the fall established alfalfa plus crabgrass inclusion restoration strategy should be evaluated. The present study also supports the current recommendation of fall establishment of alfalfa, with both locations, regardless of weather or crabgrass inclusion, reporting more favorable herbage accumulation and nutritive values for fall established alfalfa plots. Utilizing existing beneficial forages, like crabgrass, combine with fall establishment of overseeded alfalfa has potential to be a successful strategy to restore poor stands of bermudagrass pastures in the southeast.

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TABLES AND FIGURES

Table 2.1. Herbage accumulation (kg DM h^{-1}) of alfalfa-bermudagrass mixtures with and without intentional crabgrass inclusion and bermudagrass with and without N supplementation during the first respective first growing seasons in Tifton, GA: 2021 (Location 1) and 2022 (Location 2).

[a]CON (unfertilized bermudagrass control). BG + N (bermudagrass fertilized with 56 kg ha^{-1} of N). FA (fall established alfalfa overseeded onto bermudagrass). FA + CG (crabgrass and fall established alfalfa overseeded onto bermudagrass). SA (spring established bermudagrass overseeded onto bermudagrass). SA + CG (crabgrass and spring established alfalfa overseeded onto bermudagrass).

[b]Least square means within harvest and location not sharing a common letter differ according to Tukey-Kramer test ($P \leq 0.05$).

[c]SEM, standard error of the mean; *n* = 4 plots/treatment.

LOCATION 1 HARVESTS

TREATMENT[a]	May	June	July	Aug	Sept	Oct
			kg DM ha^{-1}			
BGN	674 b[b]	8521 ab	3909 b	10071 a	2350 abc	528 b
FA	1931 ab	7670 b	7284 a	6095 b	3683 a	2135 a
FA + CG	2352 a	9335 a	8016 a	6427 b	3197 ab	2603 a
SA	389 b	1896 c	2857 b	2185 c	1899 bc	478 b
SA + CG	481 b	1733 c	2898 b	2774 c	1711 bc	309 b
CON	449 b	1527 c	2498 b	2036 c	1471 c	358 b
SEM[c]	551.9	551.9	551.9	551.9	551.9	551.9

LOCATION 2 HARVESTS

TREATMENT[a]	May	June	July	Aug	Sept	Oct
			kg DM ha^{-1}			
BG + N	99	253	1198 c	6874 a	2425 ab	-
FA	560	1047	4979 a	5555 b	3211 a	1095 a
FA + CG	505	1132	4416 a	5846 b	2822 a	955 ab
SA	169	435	2574 b	1926 c	1554 bc	132 b
SA + CG	128	305	2170 b	2253 c	1767 bc	98 b
CON	99	293	1225 c	1963 c	1227 c	-
SE[c]	324.5	324.5	324.5	324.5	324.5	324.5

Table 2.2. Nutritive values (g kg^{-1}) of alfalfa-bermudagrass mixtures with and without intentional crabgrass inclusion and bermudagrass with and without N supplementation during the respective establishment growing season of Location 1 plots in Tifton, GA.

[a]BG + N, bermudagrass fertilized with 56 kg ha^{-1} of N; FA, fall established alfalfa overseeded onto bermudagrass; FA + CG, crabgrass and fall established alfalfa overseeded onto bermudagrass; SA, spring established bermudagrass overseeded onto bermudagrass; SA + CG, crabgrass and spring established alfalfa overseeded onto bermudagrass; CON, unfertilized bermudagrass control.

[b]Least square means within harvest not sharing a common letter differ according to Tukey-Kramer test ($P \leq 0.05$).

[c]SE, standard error.

Abbreviations: CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVTDMD, in vitro dry matter digestibility at 48 hrs.

LOCATION 1							
Item	**Treatment**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**
CP (g kg^{-1})	BG + N	128 b	137 b	125 b	116 b	127 b	152 bc
	FA	219 a	199 a	182 a	163 a	163 a	262 a
	FA + CG	226 a	195 a	189 a	160 a	159 a	258 a
	SA	113 b	142 b	130 b	124 b	122 b	159 b
	SA + CG	107 b	133 b	123 b	117 b	116 b	156 b
	CON	110 b	126 b	115 b	111 b	113 b	131 c
	SEM	8.3	8.3	8.3	8.3	8.3	8.3
NDF (g kg^{-1})	BG + N	653 bc	671 cd	644 b	705 c	677 c	643 c
	FA	390 a	549 a	506 a	594 a	543 a	392 a
	FA + CG	402 a	555 a	497 a	610 a	560 ab	393 a
	SA	598 b	613 b	609 b	632 ab	612 b	547 b
	SA + CG	621 b	634 bc	637 b	643 ab	609 b	545 b
	CON	692 c	698 d	650 b	677 bc	686 c	683 c
	SEM	19.5	19.5	19.5	19.5	19.5	19.5
ADF (g kg^{-1})	BG + N	372 b	361 a	357 ab	380 ab	346	318 b
	FA	289 a	390 ab	353 ab	387 ab	347	266 a
	FA + CG	307 a	394 b	341 a	403 b	360	275 a
	SA	378 b	376 ab	367 ab	374 ab	357	319 b
	SA + CG	391 b	384 ab	373 b	382 ab	359	318 b
	CON	388 b	367 ab	350 ab	361 a	353	333 b
	SEM	11.0	11.0	11.0	11.0	11.0	11.0
IVTDMD48 (g kg^{-1})	BG + N	624 b	713 b	715 cd	683 b	672 bc	708 b
	FA	790 a	748 ab	783 ab	726 a	728 a	808 a
	FA + CG	789 a	757 a	789 a	724 a	712 ab	793 a
	SA	624 b	726 ab	745 ab	719 ab	683 bc	713 b
	SA + CG	626 b	717 ab	732 cd	718 ab	685 bc	720 b
	CON	575 c	659 c	697 d	695 ab	645 c	656 c
	SEM	9.7	9.7	9.7	9.7	9.7	9.7

Table 2.3. Nutritive values (g kg^{-1}) of alfalfa-bermudagrass mixtures with and without intentional crabgrass inclusion and bermudagrass with and without N supplementation during the respective establishment growing season of Location 1 plots in Tifton, GA.

[a]BG + N, bermudagrass fertilized with 56 kg ha^{-1} of N; FA, fall established alfalfa overseeded onto bermudagrass; FA + CG, crabgrass and fall established alfalfa overseeded onto bermudagrass; SA, spring established bermudagrass overseeded onto bermudagrass; SA + CG, crabgrass and spring established alfalfa overseeded onto bermudagrass; CON, unfertilized bermudagrass control.

[b]Least square means within harvest not sharing a common letter differ according to Tukey-Kramer test ($P \leq 0.05$).

[c]SE, standard error.

Abbreviations: CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVTDMD, in vitro dry matter digestibility at 48 hrs.

LOCATION 2							
Item	**Treatment**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**
CP (g kg^{-1})	BG + N	164 b	148 b	132 b	188 a	112 b	-
	FA	229 a	212 a	165 a	193 a	165 a	255 a
	FA + CG	225 a	214 a	167 a	199 a	164 a	252 a
	SA	106 c	106 d	116 b	139 b	114 b	157 b
	SA + CG	115 c	119 cd	109 b	143 b	109 b	150 b
	CON	154 b	143 bc	131 b	151 b	112 b	-
	SEM	9.6	9.6	9.6	9.6	9.6	9.6
NDF (g kg^{-1})	BG + N	533 bc	553 b	658 c	617 b	652 b	-
	FA	323 a	352 a	572 ab	531 a	516 a	323 a
	FA + CG	328 a	359 a	545 a	529 a	516 a	320 a
	SA	628 d	619 c	636 c	608 b	609 b	542 b
	SA + CG	589 cd	594 bc	628 bc	589 b	603 b	544 b
	CON	525 b	562 bc	660 c	642 b	639 b	-
	SEM	19.8	19.8	19.8	19.8	19.8	19.8
ADF (g kg^{-1})	BG + N	368 b	329 b	369	324 a	336	-
	FA	252 a	256 a	386	353 ab	321	234 a
	FA + CG	258 a	262 a	369	358 b	321	231 a
	SA	393 b	340 b	375	353 ab	342	322 b
	SA + CG	369 b	326 b	375	349 ab	338	331 b
	CON	366 b	336 b	372	344 ab	330	-
	SEM	11.1	11.1	11.1	11.1	11.1	11.1
IVTDMD48 (g kg^{-1})	BG + N	671 b	675 b	628 b	766 a	668 b	-
	FA	823 a	811 a	688 a	764 a	742 a	832 a
	FA + CG	822 a	798 a	716 a	766 a	737 a	837 a
	SA	655 b	692 b	671 ab	734 ab	701 ab	698 b
	SA + CG	672 b	707 b	670 ab	749 a	704 ab	695 b
	CON	662 b	663 b	626 b	696 b	669 b	-
	SEM	12.2	12.2	12.2	12.2	12.2	12.2

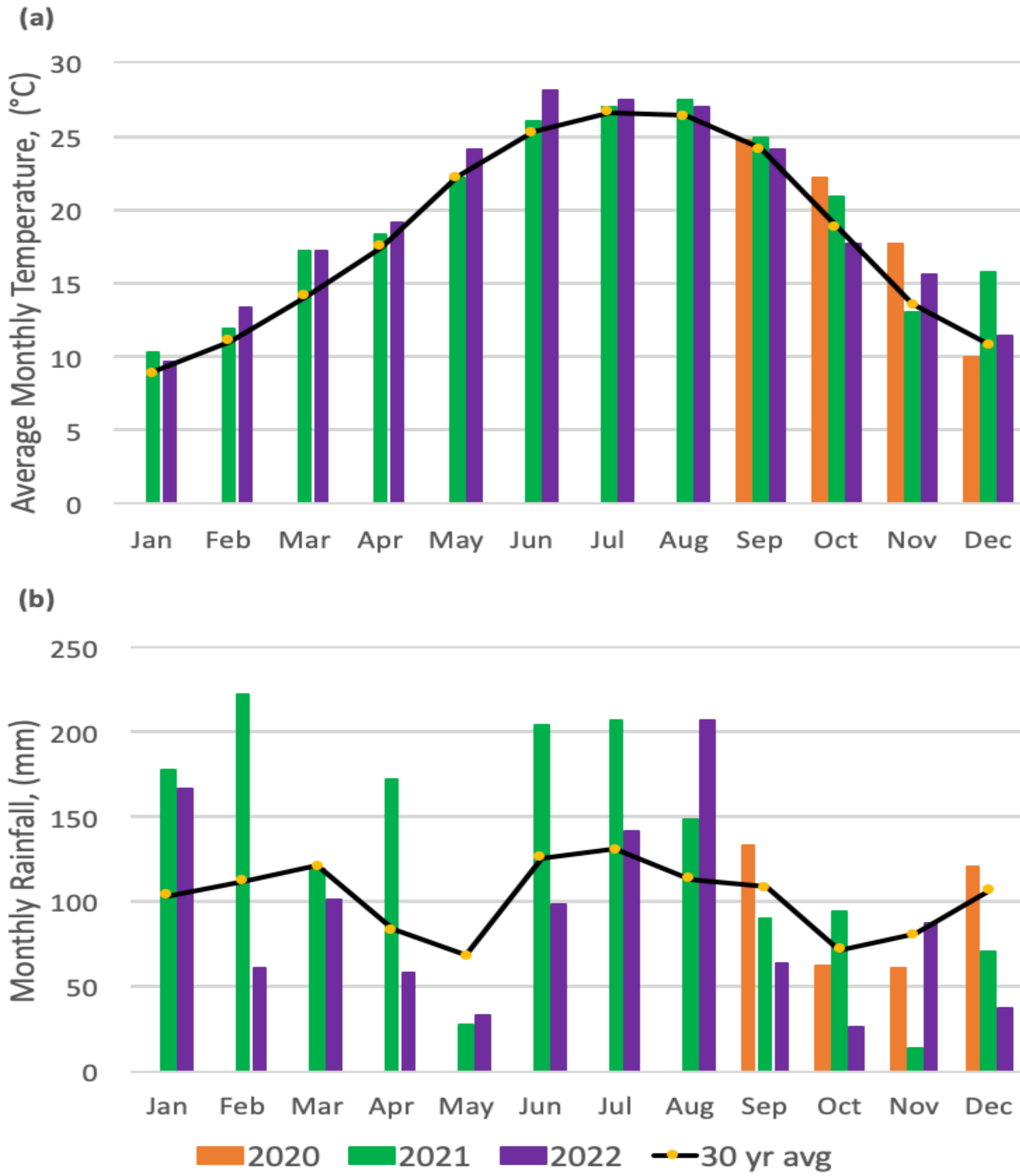

***Figure 2.1**.* (a) Average monthly temperature (°C) and (b) total monthly rainfall (mm) in 2020, 2021, 2022, and the 30-year average in Tifton, GA.
Data was collected from the UGA Automated Environmental Monitoring Network (UGA-AEMN, 2023) and NOAA (2023).

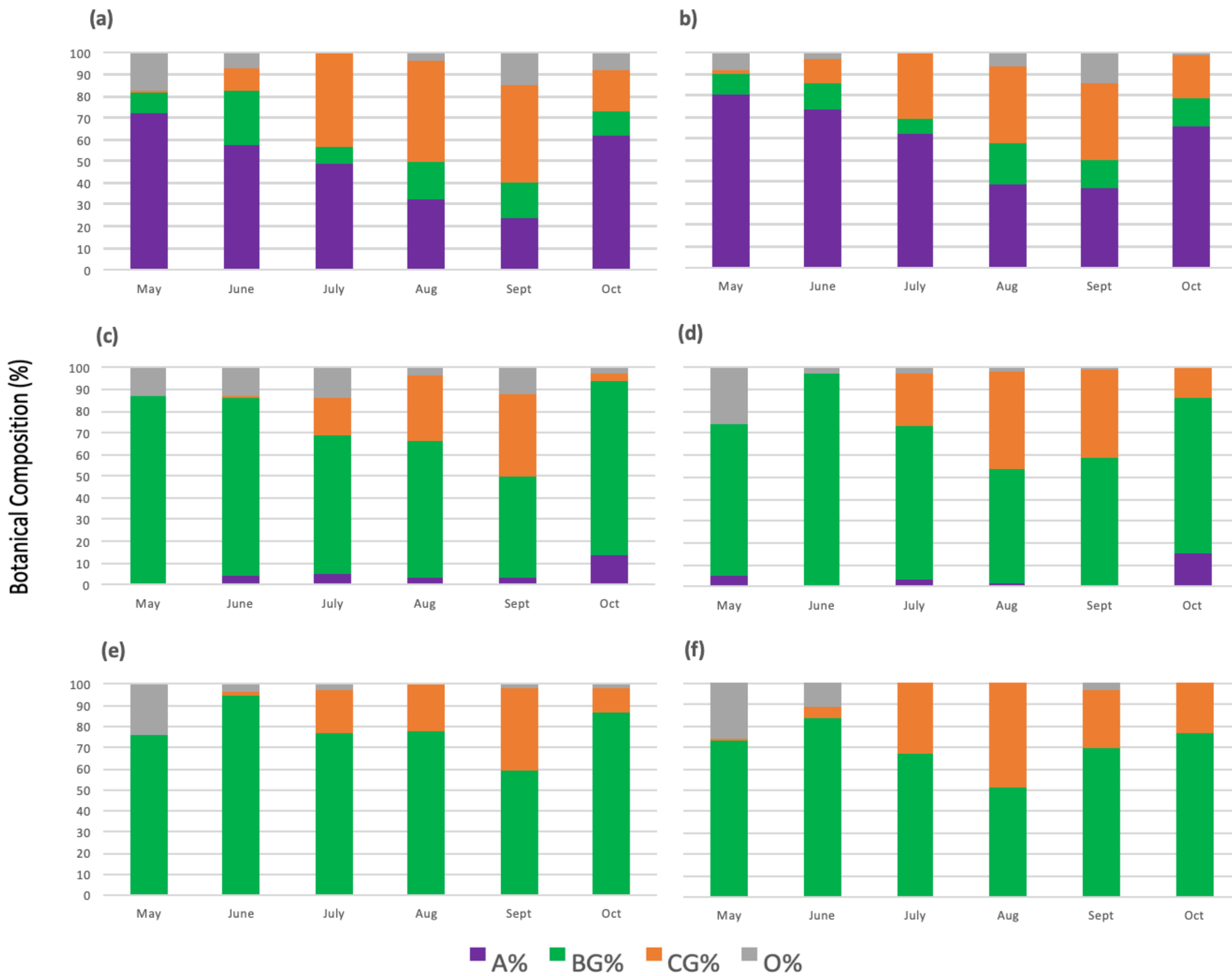

Figure 2.2. Botanical composition of alfalfa, bermudagrass, crabgrass, and 'other' components in Location 1 treatments: (a) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa (FA), (b) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa in October and MOJO crabgrass in June (FA + CG), (c) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa in February (SA), and (d) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa in February and MOJO crabgrass in June (SA + CG), (e) Unfertilized Control (CON), and (f) Tifton-85 bermudagrass supplemented with synthetic nitrogen (56 kg ha-1; BG + N) during the 2021 establishment growing season.
Harvests are expressed as months.

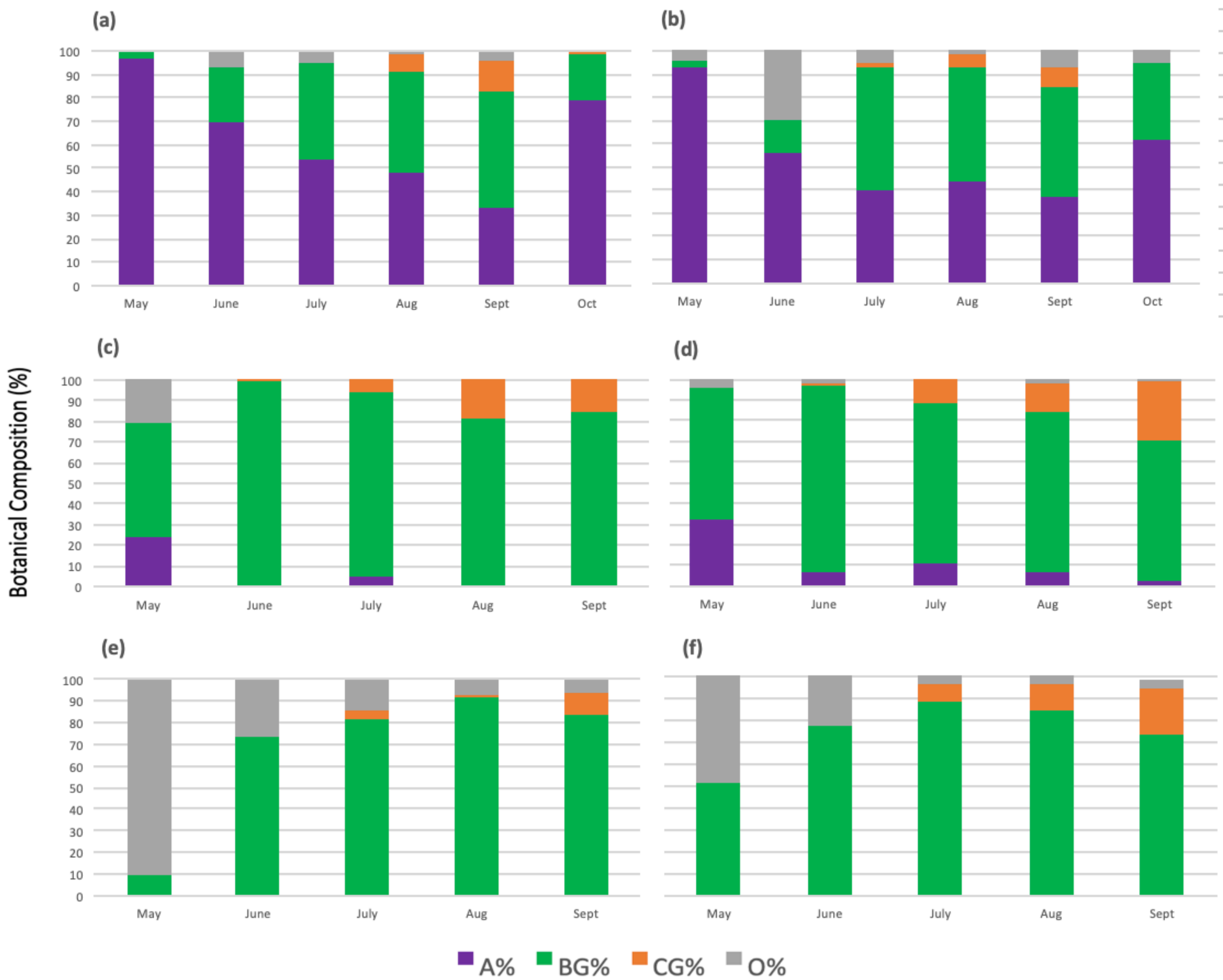

Figure 2.3. Botanical composition of alfalfa, bermudagrass, crabgrass, and 'other' components in Location 1 treatments: (a) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa (FA), (b) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa in October and MOJO crabgrass in June (FA + CG), (c) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa in February (SA), and (d) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa in February and MOJO crabgrass in June (SA + CG), (e) Unfertilized Control (CON), and (f) Tifton-85 bermudagrass supplemented with synthetic nitrogen (56 kg ha-1; BG + N) during the 2021 establishment growing season.
Harvests are expressed as months.

CHAPTER 3

EFFECT OF ALFALFA ESTABLISHMENT TIMING AND CRABGRASS INCLUSION IN SOUTHERN BERMUDAGRASS PASTURES ON HERBAGE ACCUMULATION, NUTRITIVE VALUE, AND BOTANICAL COMPOSITION

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Abstract

Inclusion of alfalfa (*Medicago sativa*) in bermudagrass *(Cynodon dactylon)* pastures improves nutritive value, increases grazing days, and reduces need for synthetic nitrogen fertilizer. Establishing alfalfa in the fall, versus spring, will allow for seed germination and growth with less bermudagrass competition, producing a stronger stand of alfalfa in subsequent years. Crabgrass (*Digitaria sanguinalis*) is a common weed in southeastern hayfields that requires pre-emergent herbicide technologies to control. However, in a grazing system, crabgrass could be a valuable inclusion, as it is a palatable warm-season annual grass with high nutritive value and prolific reseeding ability. The objective of this research is to evaluate the impact of alfalfa establishment timing, and the impact of crabgrass inclusion in alfalfa bermudagrass pastures on nutritive value, botanical composition, and forage accumulation. This two-year study conducted in Tifton, GA utilizes 4 replications of 6 treatments: Fall Alfalfa + Crabgrass, Fall Alfalfa, Spring Alfalfa + Crabgrass, Spring Alfalfa, Bermudagrass + Synthetic Nitrogen, and Untreated Bermudagrass Control. Data is collected on a 28 to 35-day interval to determine botanical composition, forage accumulation, and nutritive value. This research is ongoing. However, year two data on Location 1 reports increases for fall established alfalfa treatments, regardless of crabgrass inclusion, in herbage accumulation ($P < .0001$), CP ($P = .0003$), and IVTDM ($P < .0001$). Utilizing overseeded alfalfa into existing bermudagrass pastures, and allowing annual forages to persist in the system, could be a restoration strategy for poor pastures across the Southeastern United States.

Introduction

Bermudagrass (*Cynodon spp.*) is grown on approximately 8.1 million hectares in the Southeastern U.S., making it one of the most predominant warm-season perennial grasses. Though bermudagrass is known to provide high herbage accumulation, nutritive value is moderate at best and requires high nitrogen fertilizer input to reach production potential (Beck et al., 2017; Burton et al., 1963; Johnson et al., 2001; Osborne et al., 1999; Power, 1980; Stringer et al., 1994; Templeton and Taylor, 1975). This, in addition to overgrazing, has led to an abundance of poor bermudagrass stands (Rouquette, 2017). Even when managed properly, bermudagrass produce abundantly during the warmest months of the year, but production drops off during the transition into the fall months and won't pick back up again until late spring. The challenge in working toward year-round grazing is filling the forage gap during the fall months before winter forages become available in late fall (Blount 2017). Pasture renovation refers to the "renewing" of poor pasture by introducing desired species to the stand, often requiring partial destruction of existing sod, liming and fertilizing, controlling weeds, and seeding a legume or legume-grass mixture (Johnson, Rhykerd, & Hertel, 2003). If an adequate density of desirable forages is present, restoration by overseeding with another forage, improved grazing management, and addressing soil fertility with a soil test may be the most efficient option (Lemus, 2021).

Alfalfa (*Medicago sativa* L.) is a cool season perennial legume It is the fourth most widely grown crop in the United States, with 10.5 million hectares being cut for hay (ARS, 2020). Historically in the southeastern U.S., the humidity, higher temperatures and insect pressures, in addition to poor soil fertility and low soil pH common to this region were not conducive to alfalfa growth (Haby and Leonard, 2005; Terrill et al. 1996; Lacefield et al., 2009).

With the development of alfalfa varieties capable of withstanding the climatic challenges of the southeast, alfalfa production is increasing (Brown et al., 1990; Bouton and Gates, 2003; Haby and Leonard, 2005; Thinguldstad et al., 2020). Legumes like alfalfa have the ability to biologically fix nitrogen, making them a viable option to replace nitrogen fertilizer in mixtures with grasses (Biermacher et al., 2012; Rouquette & Smith, 2010), especially as producers are looking to save costs wherever possible. Additionally, alfalfa is known for its nutritive value. Lacefield et al. (2009) report that alfalfa in early bloom can provide 180-220 g kg^{-1} crude protein (CP), 420 – 500 g kg^{-1} neutral detergent fiber (NDF), 320 – 360 g kg^{-1} acid detergent fiber (ADF), and 610 – 640 g kg^{-1} total digestible nutrients (TDN).

Crabgrass (*Digitaria sanguinalis*) is a warm season annual grass, commonly considered a weed in southeastern hay pastures because it increases dry-down times (Dalrymple, 1999). Because of this, and that hay producers often have difficulty marketing hay with a high crabgrass component because of the color and texture (Andrae, 2002), many hay producers will choose to control crabgrass and other annual "weeds" with a pre-emergent herbicide like Pendimethalin. However, crabgrass has a prolific reseeding ability and is higher in nutritive value than warm-season perennial grasses. Dalrymple (1980) reported in a single replication demonstration, calves that grazed good to lush crabgrass gained an average of 0.94 kg per day and calves that grazed fully seeded mature stage crabgrass averaged up to 0.41 kg of average daily gain, noting that even poor crabgrass pasture produced gain. It has potential to be a value contribution in pasture settings.

Restoring bermudagrass pasture by use of cool season forages is not a novel concept. Inclusion of a cool-season perennial like alfalfa, however, can extend the grazing season, improve nutritive value of the forage base, and decrease the dependence on nitrogen fertilizer, while requiring similar soil fertility conditions and management recommendations (Tucker et al., 2021). Utilizing the nitrogen-fixing capabilities of cool-season legumes can have substantial monetary benefit for producers (Rouquette and Smith, 2010). The indirect effects of biological N fixation can reduce or eliminate the need to add supplemental N in alfalfa-bermudagrass mixtures (Heichel and Henjum, 1991; Stringer et al., 1994; Haby et al., 1999; Beck et al., 2017a). Establishing alfalfa into an existing stand of bermudagrass requires careful consideration of timing to ensure establishment success. Tucker et al. (2021) note that suppression of bermudagrass is key, therefore alfalfa should be planted in the fall when bermudagrass is dormant, when soil temperatures range from 65^{o} to 80^{o} F, and when plenty of soil moisture is present. This is further recommended by Ball et al. (2015), who note that September – October is the best time to plant in the Coastal Plains. Stringer et al. (1994) note that deeper rooting of alfalfa can prolong the growth advantage of alfalfa when moisture is lacking, thus the added time for establishment when planting in the fall would be of advantage to alfalfa persistence. Therefore, the objective of this research was to evaluate how different management strategies impact herbage accumulation and forage nutritive value of poor bermudagrass stands in need of restoration, including the addition of alfalfa, impacts alfalfa establishment timing, and crabgrass inclusion.

Materials and Methods

Experimental Location, Plot Establishment, and Maintenance

This study is ongoing and being conducted at the University of Georgia Better Grazing Program in Tifton, GA (31.49° N, -83.54° W; 104m elevation) on Tifton loamy sand type soils with 2 to 5% slopes (USDA, 2021). Two sets of identical plots were established in adjacent locations and consecutive years on existing 'Tifton-85' bermudagrass. A randomized complete block design was used, with six treatments and four replications per location. Bermudagrass was interseeded with 'Alfagraze 600RR' alfalfa and 'MOJO' crabgrass, depending on the treatment. Topsoil (0-15 cm) and subsoil (15-30 cm) samples were collected at the initiation of each season and all plots were fertilized with P, K, and micronutrients (B and Mo) according to University of Georgia soil test recommendations (Kissel and Sonon, 2008).

The six treatments are: Treatments evaluated were: bermudagrass fertilized with nitrogen (BG + N), bermudagrass overseeded with fall-established alfalfa (FA), bermudagrass overseeded with and fall-established alfalfa and crabgrass (FA + CG), bermudagrass overseeded with spring-established alfalfa (SA), bermudagrass overseeded with spring-established alfalfa and crabgrass (SA + CG), and an unfertilized bermudagrass control (CON). In both plot Locations (1 and 2), fall alfalfa treatments were planted in October of each year and spring established alfalfa was planted the following February. To prepare for alfalfa establishment, plots were mowed 7-day prior to planting and bermudagrass dormancy was induced following application of a suppression rate of glyphosate (Round-Up Power Max [N-(phosphonomethyl)glycine; Bayer] 9 ounces per acre of 5.5 lb. active ingredient formulation). After alfalfa emergence, 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 insect pests. Army worm and bermudagrass stem maggot pressure was addressed using Chlorantraniliprole (Prevathon, Corteva Agriscience) at a rate of 100 g a.i. ha^{-1} and zeta-cypermethrin (Mustang Maxx, FMX Corporation) at a rate of 28 g a.i. ha^{-1} at four points during the summer. Crabgrass was planted in assigned plots in June of each year at a rate of 9 kg seed ha^{-1}, on a 35.5 cm row spacing off-set from alfalfa rows. Calcium Ammonium Nitrate was applied to BG + N treatments (n=4 per location) at a rate of 56 kg ha^{-1} in July of each year. Fertilizer N was only applied once per growing season to more closely simulate a pasture situation in the coastal plains, where one application of fertilizer, if any, is utilized. Pre-emergent herbicide was not used in this evaluation to observe efficacy of pasture restoration management techniques without the use of pre-emergent herbicide technology.

Data Collection

Location 1 second year data was collected during the growing season of 2022 on a 28-to-35-day interval beginning when alfalfa reached 25% bloom stage, with data collection occurring from April through October. Second year data for Location 2 is being collected during the summer of 2023. A 0.1 m^2 quadrat was randomly placed at three points in each plot were destructively harvested and the material separated by species and used to measure botanical composition. Separation of samples was split into four categories: alfalfa, bermudagrass, crabgrass, and other forage components (all other forage species and weeds). Samples were then forced-air dried at 55°C for four days to correct for moisture content, after which dried weights were used to determine species component contribution. A 3.25 m^2 strip was mowed from each plot to a 7.6 cm stubble height to determine herbage accumulation by taring and weighing the mower bag using a hanging scale. Samples were pulled from the bag to determine dry matter and nutritive value. These samples were forced air dried at 55°C for four days before grinding through a Wiley Mill (Thomas Scientific, Philadelphia, PA) 1-mm screen. After grinding, samples were split using a sample splitter. One subsample was analyzed through a Foss CT-293 Cyclotec Cyclone Mill (Foss Analytics, Eden Prairie, MN) 1-mm screen (McIntosh et al., 2022) for nutritive value analysis via near infrared spectroscopy (NIRS) and the second subsample was analyzed via wet chemistry.

The 2022 Mixed Hay and Grass Hay calibration equations, as provided by the NIRS Forage and Feed Testing Consortium (NIRSC, Berea, KY), were used to analyze 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). Sample analysis was conducted using a Foss DS2500 near infrared spectrometer (NIRS; Foss Analytical, Eden Prairie, MN) that was standardized to the NIRSC master instrument to ensure prediction accuracy. Moisture content was assessed initially for forage sample sets to ensure consistent scanning and results across all samples on a NIRS (McIntosh et al., 2022). Nutritive value data were reported with predictions fitting the allowable global $H < 3.0$ statistical comparison with the overall calibration population (Murray and Cowe, 2004). A subset of samples (18%) was randomly selected from each harvest for validation of nutritive value parameters through the University of Georgia Tifton Animal and Dairy Science Laboratory. The wet chemistry technique for CP (AOAC, 1990) and digestibility (Pomerleau-Lacasse et al., 2018) were used for validation of NIRS results. Total monthly rainfall and average maximum and minimum temperatures for the experimental period were collected from University of Georgia weather station records (UGA-AEMN, 2023) and historical weather data (30-year average) were collected from the NOAA (NOAA 2023) and are presented in Figure 1.

Statistical Analysis

Data were analyzed in SAS 9.4 (SAS Institute) by restricted maximum likelihood using PROC MIXED (Littell et al., 2006) and PROC PLM. 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). 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. Fixed effects were harvest, treatment, and their interactions. Block was considered a random effect. The subject of the repeated measure was plot. Differences in herbage accumulation, nutritive value, and botanical composition were examined within harvest and location. Means were compared using the LSMEANS procedure with Tukey–Kramer adjustment ($P \leq 0.05$). Data were sliced by harvest and adjustments were made with Tukey slices. Differences were considered significant at $P \leq 0.05$.

Results and Discussion

Weather

Monthly rainfall and average monthly temperature compared to the 30-yr average is presented in Figure 1 (NOAA, 2023; UGA-AEMN, 2023). The 2022 growing season (May – October 2022) for location 1 began dry, reporting 32.2 mm of rainfall in the month of May, compared to the 30-yr average of 67.8 mm (NOAA, 2023). June also lacked moisture compared to the 30-year average of 126 mm of rainfall, reporting 99 mm. A significant rain event was not recorded until August, where the monthly rainfall rose to 207 mm. The average monthly temperatures were similar to or slightly greater than the 30-year average through the growing season.

Botanical Composition

Botanical Composition is reported across harvest (April, May, June, July, August, September, and October) for all treatments in Figure 2. Alfalfa percentage in treatments fluctuated as expected across harvests. Fall established alfalfa treatments reported a higher alfalfa contribution than spring established treatments. Highest alfalfa percentages in FA and FA+ CG were observed at the May (FA, 99%; FA + CG, 95%) and June (FA, 92%; FA + CG, 91%) harvests. As opposed to spring established alfalfa treatments, which reported maximum contribution at the April (SA, 65%; SA + CG, 52%) and October harvests (SA, 65%; SA + CG, 71%). Fall planting allows for less bermudagrass competition as alfalfa is germinating and growing (Haby et al., 1997). The more favorable establishment conditions of fall alfalfa planting allowed for better root development and less competition from other forage, as evidenced in the higher alfalfa contribution in alfalfa treatments. As alfalfa experiences its "summer slump" as the days become warmer, bermudagrass percentage increases. Particularly in July, August, and September in FA (14%, 25%, and 19%, respectively) and FA + CG (34%, 28%, and 29%, respectively). Alfalfa percentage was 32% or greater in all harvests and treatments, except for the SA + CG treatment at the September harvest. A legume component of 30% of greater in a grass-legume mixture can provide up to 50% of the N required by the grass (Collins et al., 2018; Heichel & Henjum, 1991). These fluctuations in alfalfa and bermudagrass contributions in an ebb and flow relationship are also reported by Burt et al (2022), Hendricks et al. (2020), and Rushing et al. (2022). Crabgrass contribution is overall lower than observed levels in establishment data for the current study. However, whether or not the crabgrass was intentionally planted, it was present among all treatments, particularly from July to September. "Other" percentage was greatest in BG + N and CON treatments, especially in the April (both 100%) and May (70% and 77%, respectively) harvests, before bermudagrass green-up.

Herbage Mass

Herbage mass (HM) is presented by harvest in Table 1. Herbage mass was suppressed in April, May and June harvests, likely due to dry conditions. Reported HM values were greatest in the July and August harvests, specifically in fall established alfalfa treatments. This may be in part due to the first significant rain event of the summer occurring in August. FA + CG was greatest in most harvests ($P < 0.005$), except for the October harvest, where no differences were reported ($P > 0.306$). Even after fertilization with nitrogen in late July, the BG + N treatment at the August harvest reported lower HM than FA + CG ($P < 0.006$) and was no different than FA ($P = 0.062$). Herbage mass is generally as great or greater in a grass-legume mixture than pure stands of either component alone (Carter and Scholl, 1962; Sprague and Garber, 1950; Washko and Pennington, 1956). Herbage mass of spring -established alfalfa-bermudagrass values in April, May and June in year two of the study reported by Hendricks et al. (2020) were lower than fall established alfalfa treatments but greater than spring established alfalfa treatments in the present study. July, August, and September values of HM in all alfalfa-bermudagrass treatments in the present study are greater than the spring-established alfalfa-bermudagrass mixture reported by Hendricks et al. (2020) in the second year of the study. Forage mass of fall established alfalfa-bermudagrass reported in a grazing study by Beck et al. (2017) was lower in year two of the study in both rotational and continuous grazing treatments than FA or FA + CG, and comparable to SA and SA + CG in the April, May, and June data collections. Further, HM in SA and SA + CG were greater for the July, August, and September harvests than HM values reported by Beck et al. (2017).

Nutritive Value

Nutritive values were affected by treatment and harvest (Table 2). FA and FA + CG crude protein (CP) values were greater than all other treatments in the June ($P < 0.03$) and

October (P <0.02) harvests, following the high alfalfa contribution in these harvests. Alfalfa contribution was also higher in April and May; however, the "other" component was made of predominantly annual ryegrass (*Lolium multiflorum*), a nutritious forage present in other treatments. This is likely the cause of the rise in SA and SA + CG for the April harvest, as no difference was reported between spring established alfalfa treatments and fall established alfalfa treatments, regardless of crabgrass inclusion. The BG + N treatment was never different from CON in any harvest (P >0.068).

Neutral detergent fiber (NDF) reported lowest in the May (P < .0001), June (P < .0005), and October (P < .0002) harvests for FA and FA + CG. Spring alfalfa (SA) and SA + CG were generally intermediate or no different than BG + N or CON. This is likely due to the higher bermudagrass component in spring established alfalfa treatments. Acid detergent fiber (ADF) values for spring established treatments and fall established treatments were not different in April (P > 0.785), June (P > 0.085), August (P > 0.920). No differences were detected among any treatments in the July (P > 0.426) and September (P > 0.993) harvests. Few differences were observed in the August harvest. This could be in part due to the more diverse species mix seen among treatments in botanical composition results. Although not statistically different from FA, SA, SA + CG, or CON, lowest ADF levels were reported for BG + N in the August harvest. Leite et al. (2021) report that N fertilization increased soluble fractions of cell content concentrations in palisadegrass and changed the sugar composition and associated bonds between them and the cell wall. Thus, N fertilization and consequential reduction in total carbohydrate concentrations, resulted in decreased ADF. The reported reduction in ADF in the present study at the August harvest could be a result of nitrogen fertilization in BG + N treatments in July, as increasing N levels decreases fibrous compounds of forages because of stimulation of new tissue growth (Leite et al., 2021). IVTDMD48 followed the inverse of fiber factors, reporting highest values when alfalfa contribution was greatest. Fall alfalfa (FA) and FA + CG were greater than all treatments at the May ($P < .0009$) and October ($P < .002$) harvests. In April ($P > 0.083$), June ($P > 0.098$), July ($P > 0.953$), August ($P > 0.723$), and September ($P > 0.217$), no difference was observed between fall and spring established alfalfa treatments, regardless of crabgrass inclusion. Although it is expected that bermudagrass would have higher fiber fractions (ADF and NDF), the type of linkages observed in Tifton 85 bermudagrass allows for greater digestibility (Mandebvu et al., 1999). This supports observations made in the current study, where fewer differences were reported among ADF, NDF, and IVTDMD48 results.

Conclusions and Implications

In the preliminary second year data for this study, alfalfa-bermudagrass improved the forage nutritive value and increased herbage accumulation compared to bermudagrass alone. These data also support the current recommendation of fall establishment of alfalfa, as opposed to spring establishment, in the Coastal Plains. Further, crabgrass inclusion didn't cause differences in herbage accumulation or nutritive value, and persisted across the system, regardless of whether or not it was intentionally planted. There is potential to save time and cost from application of pre-emergent herbicide technology and allow winter annual "weeds" like crabgrass to persist in a grazing scenario. The first set of second year data in this study concludes that overseeding alfalfa into existing bermudagrass and allowing crabgrass and utilizing the volunteer annual forages that emerge is a viable option for restoring southern pastures.

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TABLES AND FIGURES

Table 3.1. Herbage accumulation (kg DM h^{-1}) of alfalfa-bermudagrass mixtures with and without intentional crabgrass inclusion and bermudagrass with and without N supplementation during the second growing season (2022) of Location 1 plots in Tifton, GA.

[a]BG + N (bermudagrass fertilized with 56 kg ha^{-1} of N). FA (fall established alfalfa overseeded onto bermudagrass). FA + CG (crabgrass and fall established alfalfa overseeded onto bermudagrass). SA (spring established bermudagrass overseeded onto bermudagrass). SA + CG (crabgrass and spring established alfalfa overseeded onto bermudagrass. CON (unfertilized bermudagrass control).

[b]Least square means within harvest not sharing a common letter differ according to Tukey-Kramer test ($P \leq 0.05$).

[C]SEM, standard error of the mean.

TREATMENT[a]	April	May	June	July	Aug	Sept	Oct
				kg DM ha^{-1}			
BGN	697 b[b]	216 c	1,331 c	4,992 c	9,768 bc	3,054 cd	-
FA	4,512 a	3,297 ab	3,308 ab	10,192 a	11,658 ab	6,204 ab	1,906
FA + CG	4,799 a	3,497 a	3,658 a	11,176 a	12,199 a	6,991 a	2,396
SA	2,321 b	1,522 bc	1,688 bc	7,697 b	8,928 cd	4,292 bc	1,344
SA + CG	1,942 b	1,065 c	1,391 bc	5,786 bc	7,379 d	3,679 cd	1,005
CON	450 b	83 c	159 c	2,208 d	3.418 e	1,831 d	-
SEM[c]	668.8	668.8	668.8	668.8	668.8	668.8	668.8

Table 3.2. Nutritive values (g kg^{-1}) of alfalfa-bermudagrass mixtures with and without intentional crabgrass inclusion and bermudagrass with and without N supplementation during the second growing season (2022) of Location 1 plots in Tifton, GA.
[a]BG + N, bermudagrass fertilized with 56 kg ha^{-1} of fertilizer nitrogen; FA, fall established alfalfa overseeded onto bermudagrass; FA + CG, fall established alfalfa and summer crabgrass overseeded onto bermudagrass; SA, spring established alfalfa overseeded onto bermudagrass; SA + CG, spring established alfalfa and summer crabgrass overseeded onto bermudagrass; and CON, Unfertilized bermudagrass control.
[b]Least square means within harvest not sharing a common letter differ according to Tukey-Kramer test ($P \leq 0.05$).
[c]SEM, standard error of the mean.
Abbreviations: CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; IVTDMD, in vitro dry matter digestibility at 48 hours.

Item	Location	Treatment[a]	April	May	June	July	August	September	October
CP (g kg^{-1})	1	BG + N	117 bc[b]	209 ab	153 b	123 b	184	125 c	-
		FA	173 ab	245 a	220 a	185 a	203	188 a	265 a
		FA + CG	170 abc	243 a	220 a	187 a	205	184 ab	268 a
		SA	205 a	181 b	165 b	143 ab	160	140 abc	211 b
		SA + CG	192 a	178 b	167 b	138 ab	159	133 c	202 b
		CON	109 c	160 b	145 b	130 b	153	120 c	-
		SEM[c]	25.5	18.1	18.1	18.1	18.1	18.1	18.1
NDF (g kg^{-1})	1	BG + N	527 b	508 b	573 bc	674 b	631 bc	643 b	-
		FA	444 ab	338 a	375 a	565 a	541 a	501 a	330 a
		FA + CG	459 ab	335 a	374 a	554 a	551 ab	503 a	327 a
		SA	408 a	479 b	505 bc	605 ab	600 abc	567 ab	448 b
		SA + CG	424 ab	471 b	496 b	618 ab	593 abc	570 ab	453 b
		CON	527 b	521 b	584 c	665 b	647 c	641 b	-
		SEM[c]	40.2	28.5	28.5	28.5	28.5	28.5	28.5
ADF (g kg^{-1})	1	BG + N	383 b	324 b	334 b	369	338 a	326	-
		FA	342 ab	262 a	296 ab	395	367 ab	325	241
		FA + CG	345 ab	262 a	276 a	389	381 b	323	239
		SA	323 a	326 b	274 a	382	374 ab	334	288
		SA + CG	335 a	323 b	311 ab	385	370 ab	332	296
		CON	392 b	358 b	334 b	372	355 ab	330	-
		SEM[c]	19.8	14.0	14.0	14.0	14.0	14.0	14.0
IVTDMD (g kg^{-1})	1	BG + N	646 b	747 b	701 bc	642 bc	750 ab	689 b	-
		FA	747 a	827 a	795 a	693 ab	762 a	760 a	834 a
		FA + CG	741 a	828 a	787 a	700 a	764 a	762 a	841 a
		SA	771 a	745 b	747 ab	683 abc	736 ab	725 ab	762 b
		SA + CG	757 a	745 b	744 ab	688 abc	739 ab	717 ab	753 b
		CON	635 b	682 c	659 c	631 c	693 b	674 b	-
		SEM[c]	27.8	19.7	19.7	19.7	19.7	19.7	19.7

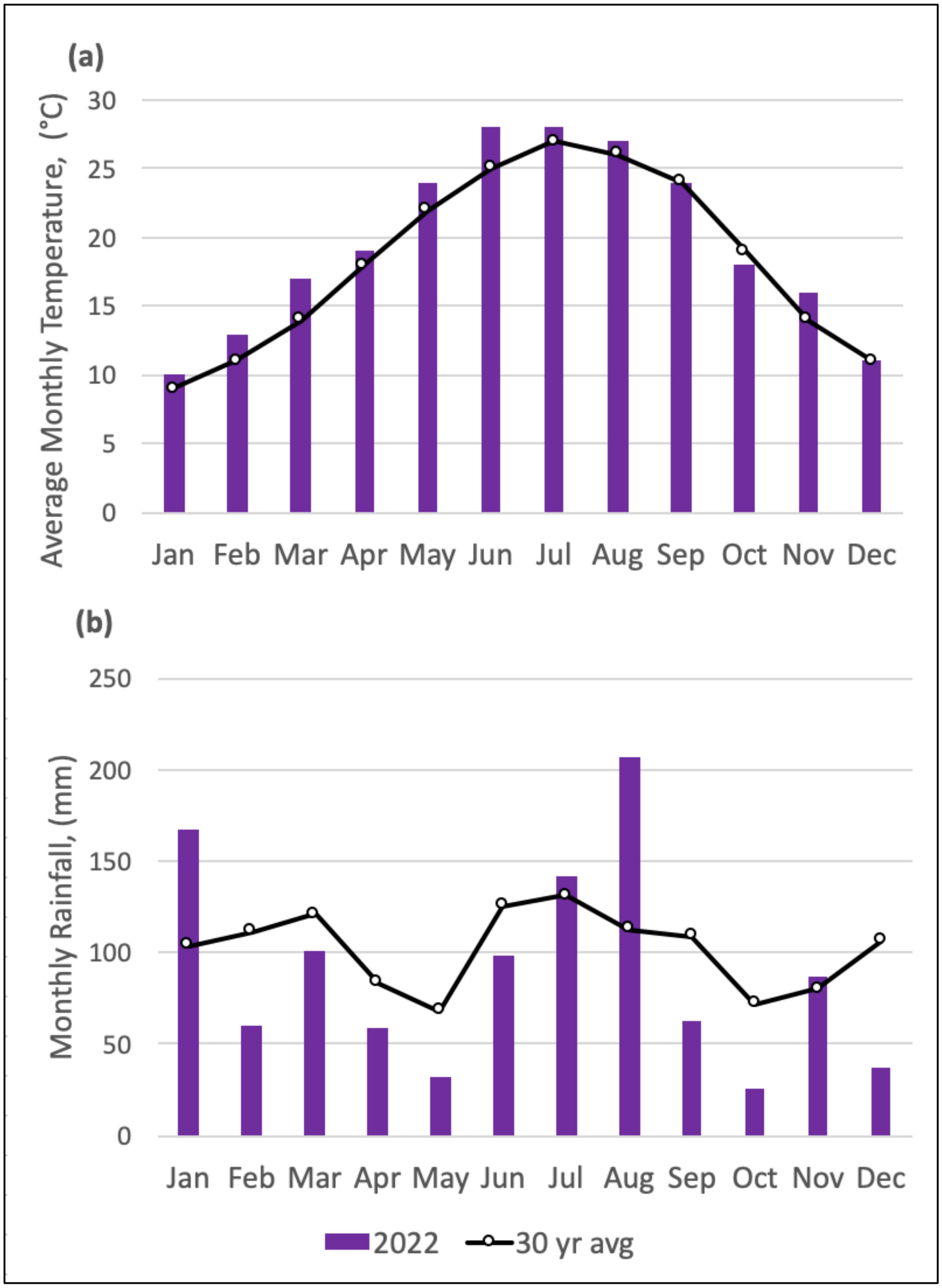

Figure 3.1. (a) Average monthly temperature (°C) and (b) total monthly rainfall (mm) and the 30-yr average in Tifton, GA in the second growing season of Location 1 plots in 2022. Weather data were collected from the University of Georgia Automated Environmental Monitoring Network (UGA-AEMN, 2023). 30-year average data were collected from the National Oceanic and Atmospheric U.S. Climate at a Glance (NOAA, 2023).

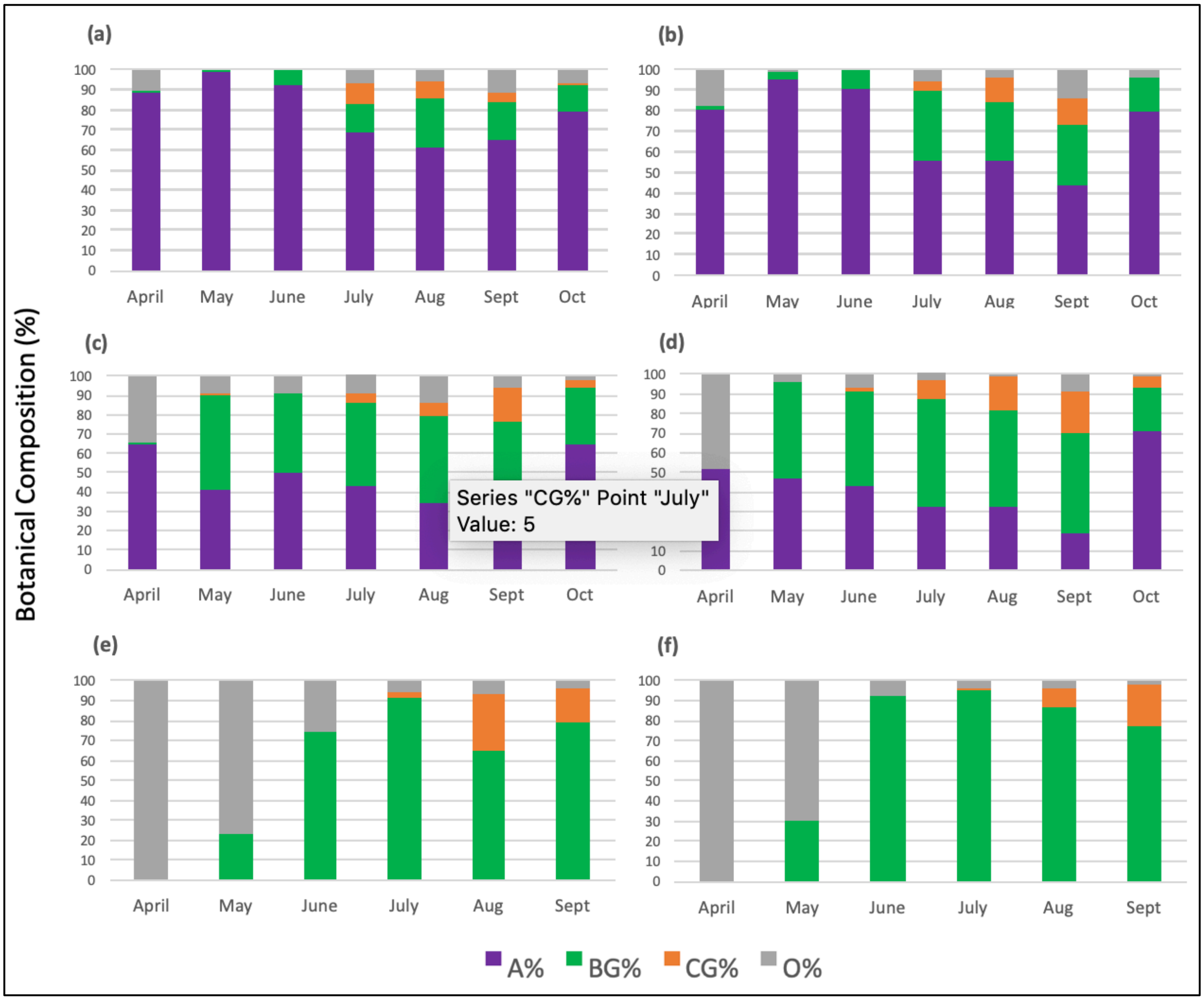

Figure 3.2. Botanical composition of alfalfa, bermudagrass, crabgrass, and 'other' components in Location 1 treatments: (a) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa (FA), (b) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa in October and MOJO crabgrass in June (FA + CG), (c) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa in February (SA), and (d) Tifton 85 bermudagrass overseeded with Alfagraze 600 RR alfalfa in February and MOJO crabgrass in June (SA + CG), (e) Unfertilized Control (CON), and (f) Tifton-85 bermudagrass supplemented with synthetic nitrogen (56 kg ha-1; BG + N) during the second growing season (2022) of Location 1 plots.

CHAPTER 4

CONCLUSIONS AND IMPLICATIONS

Poor bermudagrass pastures are abundant across the southeastern United States, as lack of adherence to higher maintenance requirements and overgrazing cause thinning stands. Overseeding grass pastures with cool season legumes is a viable option for pasture restoration (Lemus, 2021). Alfalfa-bermudagrass mixtures used for grazing have been reported to extend the grazing season and help reduce cost of feeding stored forage (hay or baleage) as the cool-season legumes can carry grazing further into the winter months (Beck et al., 2017a; Bouton et al., 1998; Cassida et al., 2006). Establishing alfalfa into an existing stand of bermudagrass requires careful consideration of timing to ensure establishment success. Tucker et al. (2021) note that suppression of bermudagrass is key, therefore alfalfa should be planted in the fall when bermudagrass is dormant, when soil temperatures range from 65° to 80° F, and when plenty of soil moisture is present. This is further recommended by Ball et al. (2015), who note that September – October is the best time to plant in the Coastal Plains. Stringer et al. (1994) note that deeper rooting of alfalfa can prolong the growth advantage of alfalfa when moisture is lacking, thus the added time for establishment when planting in the fall would be of advantage to alfalfa persistence. This information led to the current recommendation of fall establishment of alfalfa in the Coastal Plains.

This research set out to assess that recommendation, evaluating fall and spring establishment timing. Results indicate that fall established alfalfa treatments reported higher percentages of alfalfa in establishment years in both locations, which resulted in more favorable nutritive values. Fall established alfalfa treatments also reported higher herbage accumulation and extended the data collection period one month further than bermudagrass monoculture treatments. These findings are supported by preliminary second year data in Location 1, which reported generally higher nutritive values and herbage accumulation for fall established alfalfa treatments.

A second objective of the current research was to evaluate crabgrass inclusion and competition in alfalfa-bermudagrass mixtures. Crabgrass is a common pest that requires pre-emergent herbicide technologies to control in southeastern hayfields. However, in a grazing system, utilizing beneficial annual species with higher nutritive value, like crabgrass, could save producers time and money on herbicide while not negatively impacting the system. Crabgrass was present across all treatments and both locations, regardless of whether or not it was intentionally planted. Further, crabgrass inclusion didn't cause differences in herbage accumulation or nutritive value. There is potential to save time and cost from application of pre-emergent herbicide technology and allow winter annual "weeds" like crabgrass to persist in a grazing scenario.

In conclusion, results from this research indicate that fall establishment of alfalfa in the Coastal Plains is recommended. Additionally, allowing annual "weeds" like crabgrass to persist in the system could be of benefit to both the forage base and the economics of the operation. Utilizing fall established alfalfa can be a useful strategy for restoring poor stands of bermudagrass in the Southeastern United States.

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