Chemical dormancy and cool-season annual forage establishment method effects on overseeded bahiagrass

by

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Abstract

Warm-season perennial pastures are the base of livestock production systems in lower Alabama. To overcome the shortage in forage production during the late fall and winter months, during bahiagrass (*Paspalum notatum*) dormancy, overseeding pastures with cool-season annuals can be used as an option for providing forage. Diverse forage mixtures of multiple forage species along with effective establishment methods could help increase production in this system, but few evaluations have been conducted in overseeded sods. The first objective of these studies was to evaluate forage mass and nutritive value of different cool-season forage mixtures overseeded in bahiagrass. The second objective was to evaluate cool-season annual production using different planting methods to overseeding bahiagrass sod treated with different herbicides to induce a chemical dormancy. For the first objective, six 0.40-ha paddocks were overseeded with one of three cool-season forage mixtures (n = 2 paddocks/treatment): 1) oat (*Avena sativa*) + wheat (*Triticum aestivum*) + Balansa clover (*Trifolium michelianum*), red clover (*Trifolium pratense*), and white clover (*Trifolium repens)*; 2) oat + cereal rye (*Secale cereale)* + clovers; and 3) cereal rye + annual ryegrass (*Lolium multiflorum)* + clovers. For the second objective, herbicide treatments consisted of two different rates of two nonselective herbicides (paraquat or glyphosate) and a control treatment (no herbicide) replicated (n = 4 herbicide treatments per planting method) in two different planting methods (no-till drilled or broadcasted). In the first objective, there was an effect of treatment (*P* = 0.02) and harvest (*P* = 0.03) on forage biomass in year one, but this was not observed in year two. There was a treatment effect (*P* = 0.0009) and harvest effect (*P* = 0.02) on forage nutritive value (i.e. CP, NDF, ADF) for year one but not in year two. There was no effect of treatment on forage botanical composition for either year (*P* = 0.24). In the second project, there was no effect of treatment (*P* = 0.62) for any of the cool-season harvests between planting method, herbicide, or herbicide rate. In addition, cool-season botanical composition was not affected by herbicide treatment or planting method ($P = 0.32$). However, there was an effect of herbicide treatment ($P < 0.0001$) in the warm season harvest in which the glyphosate treatment suppressed bahiagrass production. Also, herbicide treatment affected warm-season botanical composition in which glyphosate treated plots experienced increased weed presence ($P < 0.0001$). There was no effect of herbicide treatment ($P = 0.07$) on forage CP, NDF, or ADF for the cool-season harvests. However, there was an effect of harvest date for all cool-season annual forage nutritive value parameters ($P < 0.0001$). These results indicate that consideration may need to be given to using nonselective herbicides for chemical dormancy. However, this study demonstrates overseeding bahiagrass sods with cool-season annuals can be an effective cool-season forage system for southeastern producers.

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ORC	oats/cereal rye/clover
OWC	oats/wheat/clover
RRC	cereal rye/ryegrass/clover
CP	crude protein
NDF	neutral detergent fiber
ADF	acid detergent fiber
DM	dry matter
ae	acid equivalent
ai	active ingredient
ha	hectare
cm	centimeter
mm	millimeter
N	nitrogen
°C	degrees Celsius

I. Literature Review

Introduction

Bahiagrass ((*Paspalum notatum* Flueggé) is a widely grown and utilized warm season perennial forage in the Deep South U.S. because of its hardiness and adaptability to many sites. It is grown for both grazing and hay production, providing continuous forage from late spring through mid-fall in most of its range (Gates et al., 2001). However, it becomes less productive in late fall and can become dormant when photoperiod and temperatures decrease starting with the fall-summer transition period. Seasonal dormancy is the state where a plant becomes physiologically inactive, and its growth is reduced or suspended for a certain time period (Adhikari, 2017). Once bahiagrass is no longer productive for grazing, producers must find alternative grazing sources or use feed supplements (Gates et al., 2001). With the rise of input and supplement costs, it may be more economical to plant cool-season forages to graze during the time that bahiagrass is dormant than to provide feed supplements or hay (Benson, 2010). To better utilize dormant bahiagrass stands, producers can overseed or sodseed these fields in the fall with cool-season annual forages to provide grazing during the winter and spring months. Cool-season annual forages can complement perennial warm-season grass pastures by providing an additional 60 to 120 d of grazing during the year (Rouquette, 2017). Timing of planting is crucial. The earlier in the fall planting occurs, the better cold hardiness and overall forage production (Myer et al., 2008). However, bahiagrass growth may still be active in the fall and early winter depending on environmental conditions, which can hinder planting and establishment of cool-season annuals (Gates et al., 2001). Bahiagrass grows as a dense sod and will generally outcompete other species. To achieve earlier fall planting and to reduce the chance of competition for establishing cool-season annual forages, herbicides can be sprayed on bahiagrass at low rates to induce an early dormancy in the bahiagrass without killing the forage. After the induced dormancy is achieved, planting of the cool-season annuals can take place using either a no-till drill or with light tillage and broadcast methods (Evers, 2005).

Southeastern Beef Cattle and Forage Systems

The beef cattle industry plays a significant role in the agricultural economy of the Southeast United States and the state of Alabama. As of January 1st, 2024, Alabama ranks 8th in the number of beef cattle farms and has the 17th largest beef herd in the country according to the USDA inventory report. Cow-calf operations are the predominant production type in both Alabama and the Southeast with 97% of operations having brood cows (Asem-Hiablie et. al., 2018). The cow-calf industry in the Southern U.S. accounts for approximately 50% of all mature beef cows in the nation and generates $7 billion annually in total farm income (NASS, U., 2020). In these operations, herds of brood cows are managed to birth calves who are then weaned after reaching a production stage deemed fit to enter pre-conditioning systems or feed-lot systems. Most of these weaned calves are shipped to the Midwest regions of the United States but some pre-conditioning operations also exist within the Southeast and Alabama. Both cow-calf and pre-conditioning systems in Alabama rely on a base diet of forages to meet animal nutrition requirements (Forte et al., 2017). The Southeast states (AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, and VA) in the six southern-most USDA plant hardiness zones have diverse climatic conditions with tropical to temperate summers and the region offers various opportunities and challenges for beef production, particularly in terms of forage management. Forages constitute the backbone of beef cattle production systems in the Southeast, with the majority of these systems using perennial forages as the base for grazing or hay production. Currently, it is estimated that the southeast has approximately 24 million hectares of perennial pasture (Ball et al., 2015). A perennial forage is defined as a forage that is productive for more than one growing season. In the northern portions of the region cool season perennial forages such as Tall Fescue (*Schedonorus arundinaceus*) are more widespread, whereas warm-season perennial grasses such as bermudagrass (*Cynodon dactylon*) and bahiagrass (*Paspalum notatum*) dominate the more southern regions (Hoveland, 1986).

Adaptation of Warm-Season Perennial Forages in the Southeast

Warm-season perennial grasses are widely utilized due to their adaptation to hot and humid climate conditions in the region. These forages are C4 grasses that are more metabolically efficient than temperate forages (C3) in relation to their photosynthetic pathways. C3 plants fix energy into 3-carbon units which allows them to only be able to utilize 25 - 50% of sunlight that reaches its leaves for photosynthesis. In contrast, C4 plants fix energy into 4-carbon units allowing them to utilize more sunlight raising its photosynthetic efficiency (Ball et al., 2015). In C4 plants Rubisco is saturated with CO_2 which eliminates photorespiration under most conditions producing higher rates of CO_2 fixation than C3 plants. As a result, net CO_2 assimilation rates are usually higher in C4 than in C3 plants making nitrogen-use efficiency (NUE) greater. (Long, 1999). The absence of photorespiration in C4 plants allows them fully utilize the energy captured during photosynthesis, while the presence of it in C3 causes them to waste up to 40% of the energy produced from photosynthesis (Ball et al., 2015). C4 plants also have a higher water use efficiency (WUE) which results from CO_2 uptake in the C_4 pathway being catalyzed by a coupled system of carbonic anhydrase (CA) and PEP-carboxylase (PEPc), which has a higher affinity for CO_2 and a greater maximum velocity than Rubisco (Ehleringer & Monson, 1993). This helps in making C4 plants drought tolerant while also being adapted to different sites of higher temperatures and lower atmospheric $CO_{2.}$ (Sollenberger et al., 2020).

Operations use warm-season perennial forages for grazing as a primary source to meet animal nutritional needs. As input costs continue to rise, feed costs have been found to be the single greatest expense of livestock production at 63% of the variation in total cow costs (Miller et al., 2001). For this reason, much emphasis has been put on forage production and grazing management to help lower feed input costs. For cow-calf operations in South Alabama the majority of supplemental feeding occurs in the cool season when the warm season perennial forages are dormant. It has been estimated that hay is fed for over 130 d/yr in southeastern United States to fill the gap during perennial forage dormancy (Troxel et al., 2014). This forage gap then represents a large portion of producer input costs as compared to when grazing is available. Thus, reducing this gap by providing more grazable forage will decrease the input and feed costs and in turn benefit producer profit margins (Beck et al., 2017).

In South Alabama, one option for decreasing the fall-winter time gap grazing days is to implement the practice of planting cool-season annual forages (Mullenix and Rouquette, 2017). These forages are normally planted in the fall and grow throughout the winter and into spring. The growing season for cool-season annuals fits relatively well with the growing season of warm-season perennials. As the warm-season forages are slowing down production and going into dormancy, cool-season forages are being planted and become productive. In addition, as cool-season forages are ending their lifecycle and decreasing in production, warm-season forages are coming out of dormancy and begin their growth for the spring-summer months.

Warm Season Perennial Forages

Bermudagrass

Bermudagrass is a warm-season perennial forage utilized in Alabama for grazing and hay production. Bermudagrass is a perennial, warm-season forage originating from southeastern Africa, that can be established by rhizomes, stolons or seeds and spreads by stolons. It is drought tolerant and well adapted to sandy, well-drained soils (Ball et al., 2015). Bermudagrass is often associated with high forage production and good animal performance per unit of land area (Rouquette, 2011). Hill et al. (1993) found that beef steers grazing fertilized Tifton-85 bermudagrass had an average daily gain of 0.67 kg/d with a gain per hectare of 1,156.4 kg/ha. Yield can range from 3600 kg to 6300 kg of dry matter per hectare with a range of 47 to 60% digestibility and a crude protein (CP) range of 12 to 16% (Wallau et al., 2020). Bermudagrass is very responsive to nitrogen fertilization. Prine et al. (1956) found that increasing nitrogen application from 0 kg/ha to 112 kg/ha increased yield from 4349 kg/ha to 12778 kg/ha. Also, bermudagrass is a luxury consumer of potassium, which may lead to nutrient deficiencies when split applications of fertilizer are not practiced. Inadequate potassium fertilization is one of the leading causes for stand declines in bermudagrass systems (Ball et al., 2015). Bertucci et al. (2020) found that increasing potassium fertilization rates did not significantly increase yield but did increase foliar potassium concentrations. This contributed to an increase in potassium removal in harvested hay and decreased season-total forage recovery. Most bermudagrass varieties are tolerant of different soil conditions, moderate to heavy grazing pressure, variable rainfall distribution and differing defoliation management. Most varieties are used in dual-purpose systems for grazing and hay production (Hill et al., 2001). Bermudagrass initiates growth 30 to 45 days after the last frost in the spring, so the grazing period for actively growing bermudagrass can range from May through October (Rouquette, 2011).

In recent years bermudagrass production has become more challenging with rising input costs and new pests. One of the most notable being the introduction of the bermudagrass stem maggot (*Atherigona reversura*). First discovered in the Southeast in 2010 in Georgia, bermudagrass stem maggot has become a prevalent pest management issue for forage producers in the region (Baxter et al., 2014). Bermudagrass stem maggot damage can lead to loss in forage quality and a yield loss of up to 6,700 kg/ha. For an untreated field, this could equate to a $1,500/ha loss in production (Baxter et al., 2019). This increase of insect pressure combined with rising fertilizer prices has lead to an increase in the cost of bermudagrass production as compared to bahiagrass. Bahiagrass establishment can cost $30 to $200 per hectare less than hybrid bermudagrass and annual maintenance expenses for bahiagrass can be $50 to $150 less per hectare because of lower fertility requirements along with less disease and insect pressure (Hancock et al., 2010).

Bahiagrass

Bahiagrass is a widely used warm-season perennial forage primarily adapted to temperate zone A and the lower portion of temperate zone B as described in Ball et al. (2015). It occupies approximately 400,000 hectares in Alabama and is an important pasture and hay resource (Griffen et al., 2023). It originates from South America and can be established by seeds. It grows prostrate from shallow, horizontal rhizomes that form a deep-rooted, aggressive, and dense sod that allows it to be very competitive with other species. Bahiagrass grows on a wide range of soils but is best adapted to sandy loam soils (Wallau et al., 2019). It is very hardy, drought-tolerant, and can also withstand poor drainage. Also, bahiagrass is tolerant of low fertility and soil acidity which makes it ideal for the poorer soils of the southern coastal plain region of the United States (Gates et al., 2004). Bahiagrass cultivars can be characterized into two ploidy types, diploid and tetraploid, respectively. Naturally occurring tetraploid cultivars only reproduce by apomixis and produce less seeds than diploids (Acuña et al., 2007). Selections have only been made from naturally occurring types and therefore, breeding and cultivar development has not been as extensive (Gates et al., 2001). 'Argentine' is the most widely grown tetraploid cultivar in the U.S. which was introduced in 1944 from Argentina (Zilli et al., 2018). Forage production starts later in spring and is more concentrated in late summer and early fall and has wider, darker leaves as compared to diploids. It also has similar forage quality and yield as improved diploid cultivars but less cold tolerance (Dore 2006). Diploid cultivars have been the most widely bred and planted of the bahiagrass cultivars and extensive research has been conducted to improve these cultivars. Common bahiagrass is the most common phenotype of *P.notatum* in that it is broadleaved, strong-rooted, and spreads slowly by stout rhizomes with short internodes. 'Pensacola' bahiagrass belongs to *P.notatum var. saurae,* and when compared to common bahiagrass, it is taller, spreads faster, has longer and narrower leaves, smaller spikelets, and can have more racemes per inflorescence. Pensacola bahiagrass was first discovered growing near the docks in Pensacola, FL, and its seed probably arrived on a ship from Argentina prior to 1926 (Finlayson, 1941; Burton, 1967). In 1938, Finlayson (1941) began collecting seed from the grass, and shortly thereafter, he started distributing the seed and promoted the grass for pasture and conservation purposes. The diploid Pensacola is more cold tolerant than the tetraploids; therefore, it is more widely distributed. The grass grows throughout the southern USA, from Texas to North Carolina, extending into Arkansas and Tennessee (Watson and Burson, 1985).

Compared with the tetraploid types, Pensacola bahiagrass is taller; spreads faster; has longer, narrower leaves; is more frost resistant and winter hardy; is more resistant to ergot (*Claviceps paspali*); has smaller seeds that germinate more readily without scarification but shatter much worse (Burton and Hanna, 1986). 'Tifton-9' is an improved cultivar developed from Pensacola through a bahiagrass breeding program in Tifton, GA by Dr. Glen Burton (Burton, 1989). Compared with the Pensacola cultivar, Tifton 9 has much greater vigor in the seedling stage and develops longer leaves. It is 30 percent higher yielding than Pensacola, but quality is the same (Chambliss and Sollenberger, 1991). To achieve greater seedling vigor and less hard seed with faster stand formation the cultivar 'TifQuik' was developed from Tifton 9 and released from the University of Georgia-Tifton campus along with the USDA-ARS in 2008. It has similar yields and quality as compared to Tifton 9 with earlier spring growth (Anderson et al., 2011) The most cold tolerant diploid cultivar is 'AU Sand Mountain' which was selected from certain Pensacola stands and developed by Auburn University (Hancock et al., 2010). This selection for cold tolerance has allowed for more northern spread of bahiagrass production in the southeast (Blount et al., 2003). The cultivar 'UF-Riata' was developed and released in 2007 by the University of Florida from selections of certain Pensacola stands that exhibited a lower sensitivity to daylength allowing for earlier spring and later fall growth. UF-Riata has the longest overall growing season of bahiagrass cultivars but lacks a consistent peak of production (Wallau et al., 2019).

Bahiagrass production starts with increasing temperature and photoperiod in mid to late spring with the height of production in the summer. Onset of dormancy begins in the mid to late fall when temperatures and photoperiod decrease triggering the plant to store nonstructural carbohydrates in the stem bases and rhizomes for overwintering (Thorton et al., 2000). Forage quality is highest in the spring and early summer and lowest in the fall when nutrients are being diverted to root stores. Yield is highest in the summer months and lowest in the spring and fall. It can be utilized for grazing and hay production and is very tolerant of close grazing (Sollenberger et al., 2020). Bahiagrass can produce 40,000 to 60,000 of dry matter per acre which is very similar to bermudagrass with total digestible nutrients (TDN) ranging from 40 to 60% and CP levels ranging from 7-15% (Wallau et al., 2019). However, digestibility and quality are strongly associated with plant maturity and decreases in quality are rapid as the plant ages (Baxter et al., 2023). Moore et al. (1971) showed a decline in concentration of in vitro digestible organic matter (IVDOM) from 599 to 432 g/kg DM in bahiagrass hay when age at cutting increased from 6 to 14 wk. Nitrogen concentration also declined between the two ages from 12.2 to 10.1g/kg DM; whereas, acid detergent fiber (ADF) and lignin concentrations increased from 409 to 453 g/kg DM and from 37 to 54 g/kg DM, respectively.

Bahiagrass is mainly used for grazing and is highly touted for its persistence under stress and frequent defoliation. Combining its tolerance of close grazing and the need to keep the plant maturity in the vegetative stage make it ideal for pasture because higher grazing frequency and intensity contribute to higher forage quality in bahiagrass (Stewart et al., 2007). Lower animal performance when grazing bahiagrass compared with bermudagrass has attributed to its low use for growing weaned calves without supplementation (Utley et al., 1974). The quality of bahiagrass forage is adequate for mature beef cattle, but weaned calves or stocker yearlings make relatively low average daily gains, especially in July and August due to the low quality of the grass at that time (Chambliss et al., 1991). Utley et al. (1974) found that beef steers gained 0.43 kg/d of average daily gain on fertilized Pensacola bahiagrass over a four-year grazing trial. In addition, Sollenberger et al. (1989) found that beef steers average 0.38 kg/d of average daily gain over three grazing seasons when grazed on fertilized Pensacola bahiagrass.

Bahiagrass has been successfully utilized in a sod-based rotation following the conventional and conservation tillage of row crops in the Southeast. It has been observed that with traditional crop rotations and tillage methods used in the Southeast crop yields became stagnant and soil properties such as organic matter and structure diminished over time (Reeves 1997). For this reason, planting bahiagrass in rotation with popular Southeastern crops has become a growing practice. Wright et al. (2004) found soil organic matter and structure improved along with an increase in yield for both cotton and peanuts when in rotation with bahiagrass. Also, bahiagrass nutrient utilization and water retention improved in the following cash crop. Because of its deep fibrous root system, bahiagrass is able to break though sub-soil compaction and better utilize nutrients that would otherwise leach from the soil profile. This high root density and nutrient storage ability in rhizomes allow it to remove substantial amounts of nutrients, especially nitrogen. This is especially important in the Coastal Plain region of the Southeast where sandy base soils allow more leaching of nutrients (Acuña et al., 2008). To reduce economic loss of not growing a cash crop when utilizing bahiagrass in the rotation, cattle are grazed on bahiagrass and profits from animal sales are used as income (Gamble et al., 2014). This has contributed to an increased use and awareness of bahiagrass across farming systems in the Southeast.

Overseeding

Overseeding is a term used to describe the agricultural practice of planting forage crops into perennial grass hay or pasture without permanently killing the existing perennial sod. These forages can be established during the fall via no-till seeding or broadcast seeding on warm-season perennial grass pastures such as bermudagrass and bahiagrass (Dillard et al., 2018). This method has been used throughout the Southeast for many years to help extend the grazing season and increase high quality forages in the animal diet. One of the first overseeding experiments was conducted by Dudley and Wise (1953). In this study, oats (*Avena sativa)* and annual ryegrass (*Lolium multiflorum)* were overseeded using no-till and conventional seed bed practices into existing bermudagrass, dallisgrass (*Paspalum dilatatum)*, and white clover (*Trifolium repens* L.) sods. It was concluded that seeding cool-season annual forages into existing dormant sod using a grain drill can be a successful alternative to conventional seedbed preparation and could reduce the acreage requirements per animal unit by essentially providing two grazing seasons on the same area of land. In south Alabama, cool-season annual grasses or legumes are commonly planted into dormant bermudagrass and bahiagrass sods. Dormant warm-season perennials are not productive and offer little forage value. Herbage accumulation of these forages is concentrated during summer and only 14% of forage production occurs from October through March (Mislevy and Everett, 1981). This is primarily due to photoperiod sensitivity in which the plant begins storing nonstructural carbohydrates in shoot bases and rhizomes to sustain it overwinter (Sinclair et al. 2003; Thorton et al., 2000). By incorporating cool-season annuals into the dormant sod, forage can be provided in a space and time when forage is usually limited, and supplemental feeding is at its highest. Coats (1957) found that crops drilled into permanent pastures offer an excellent opportunity for extending the grazing season and for producing hay or grain from pastureland that would otherwise be left idle during the winter months.

The most common cool-season annual grasses adapted to the Southeast utilized in overseeding are annual ryegrass and small grains such as cereal rye (*Secale cereale*), wheat (*Triticum aestivum*), triticale (*Triticosecale*), and oats. The largest concentration of production of these cool-season grasses occurs from November to April after seeding in late September to early October (Ball et al., 2015). Distribution of forage growth can vary among these species and is important in planning grazing systems. Oats are generally more cold-sensitive than cereal rye and do not produce as well early in the winter grazing season. Cereal rye is generally available earlier in the season but matures and loses quality earlier and faster than oats. Bruckner and Raymer (1990) noted that differences in forage growth distribution among species were greatest during January and February when cereal rye produced greater forage yields than wheat, triticale and oats. Cereal rye yields were 27, 33 and 78% greater than forage yields of triticale, wheat and oats during the 3-yr trial. Coffey et al. (2002) evaluated forage quality and animal performance of stocker calves grazing sod-seeded winter-annual mixtures. Over a 112-d grazing season, concentration of CP was 20.3% and 21.4% for cereal rye + annual ryegrass and wheat + ryegrass, respectively. Percentage IVDMD of wheat + annual ryegrass averaged 73.9% and was similar to that of cereal rye + annual ryegrass. Seasonal distribution of DM yield was evident over the grazing season. In year 1 at the beginning of the grazing trial in mid-December, average DM availability for cereal rye + annual ryegrass and wheat + annual ryegrass was 1,682 kg DM/ha. Forage availability decreased to 495 kg DM/ha by day 84 of the trial for the cereal rye and annual ryegrass mixture but increased to 1,358 kg DM/ha by day 112. The wheat and annual ryegrass mixture availability decreased to around 700 kg DM/ha on day 28 but increased to 1,347 kg DM/ha during the next period.

Mixtures of small grains generally produce more uniform and greater distribution of yield than monocultures of individual small grain crops, resulting in improved animal performance (Dillard et al., 2018). Inclusion of annual ryegrass in mixtures with small grains interseeded into bermudagrass pastures increased animal grazing-d/ha from 546 grazing-d/ha to 600 grazing-d/ha, a 10% increase compared with a small grain monoculture (Beck et al., 2007). Beck et al. (2007) also found the addition of annual ryegrass did not affect animal performance during the fall and winter, but ADG was increased in the spring by 15% (1.06 vs. 1.22 kg, respectively).

Adding annual ryegrass to the mixture increased BW gain per ha by 45% over rye alone (514 vs. 354 kg/ha) and net returns were improved by $143/ha.

In addition, cool-season legumes, particularly clovers, can be utilized in overseeding and are often used in mixtures with cool-season annual grasses to improve forage quality and add organic nitrogen to the system. DeRhouen et al. (1991) reported the advantages of supplemental grazing of cool-season annual grasses mixed with clovers on animal productivity and decreasing inputs over winter. The mixtures were sodseeded on perennial Argentine bahiagrass pasture and cow-calf productivity was measured. Five hundred forty-seven reproductive and calving records obtained over eight years from purebred Angus cows (*Bos taurus*) were used to evaluate two pasture systems (PS). Stocking rates of 1 cow/0.81 hectares were maintained for each PS. The two PS consisted of: (1) bahiagrass and (2) bahiagrass and bahiagrass sodseeded with cool-season annuals [cereal rye or wheat with crimson clover (*Trifolium incarnatum*) and arrowleaf clover (*Trifolium vesiculosum*)]. They found that cows supplemented with cool-season annuals consumed 30% less hay and 22% less protein supplement than cows on bahiagrass pasture only. Reproductive performance was not affected by the pasture systems but weaning and 205-d weights of calves from PS 2 were 6 to 7% heavier ($P < 0.07$) than those from calves in PS 1. Cows in PS 2 were 22 kg heavier ($P < 0.07$) at the time of weaning and produced 6 kg more ($P < 0.07$) calf per 454 kg of cow weight. In addition, Neto et al. (2024) was able to demonstrate the ability of incorporating legumes into cool-season annual mixtures overseeded into Argentine bahiagrass pasture to add organic nitrogen to that system. Pastures were overseeded with a mixture of annual ryegrass (89.6 kg/ha; cv. Prine) and oats (16.8 kg/ha; cv. RAM) fertilized with 112 kg N/ha with 34 kg N/ha applied in fall four weeks after seeding and 78 kg N/ha applied February of the same growing season. The treatment Grass + Clover consisted of bahiagrass that was overseeded in the fall with annual ryegrass-oat-clover mixture, consisting of crimson clover

(16.8 kg/ha; cv. Dixie), red clover (*Trifolium pratense* L. [6.7 kg/ha; cv. Southern Belle]), and ball clover (3.4 kg/ha). This treatment received an N-fertilizer application (34 kg N/ha) only in the Fall four weeks after seeding. Average daily gain, gain per area, and stocking rate in the winter did not differ across treatments. It was shown that the clover incorporation added 32.5 kg N/ha to the system via atmospheric nitrogen fixation. The nutritive value of grass and legumes across all treatments did not differ indicating that incorporating clover with annual cool season grasses can partially replace the N fertilizer. Hoveland et al. (1978) also showed the value of adding clover to overseeding mixtures in a three-year grazing study. Beef cows and calves were grazed on four Coastal bermudagrass sod treatments: (a) not overseeded + 112 kg/ha N; (b) overseeded 'Gulf' ryegrass + 168 kg/ha N; (c) overseeded 'Wrens Abruzzi' cereal rye, 'Yu-chi' arrowleaf clover (*Trifolium vesiculosum*), and ‘Autauga' crimson clover + 112 kg/ha N; and (d) overseeded arrowleaf and crimson clovers with no N fertilizer. Calf annual average daily gain of 0.89 kg was higher ($P < 0.05$) on rye-clover or clover than on annual ryegrass or non-overseeded Coastal bermudagrass. During the study, cow gain per ha and ADG were also increased by overseeding with clover. Overseeding sod with rye and clover resulted in nearly double the calf gain per head extended the grazing season three months longer than that of Coastal bermudagrass alone. Overseeding clovers alone with no N fertilizer resulted in calf gains equal to those for annual ryegrass overseeded on Coastal bermudagrass and fertilized with 168 kg/ha N.

Planting Method

Overseeding warm season perennial sods can be accomplished using light tillage or no tillage using either grain drills or broadcast applications. No-till planting can either be done using a no-till grain drill or simply by broadcasting seed directly onto the sod surface if using small-seeded forages. If the sod is dense, then light tillage may be deemed necessary to ensure adequate seed to soil contact (Evers, 2005). Mooso et al. (1990) conducted a two-yr study evaluating the effect of sodseeding method and ryegrass-clover mixtures on forage production, animal performance, and economics of sodseeded winter pastures for growing beef animals was conducted. Forage mixtures of either annual ryegrass-white clover (*Trifolium repens*) (R-W) or annual ryegrass-white clover-crimson clover (R-W-C) were sodseeded into common bermudagrass pastures in the fall by (i) drilling into the sod using a conventional grain drill equipped with a small seed attachment (Drill), or (ii) lightly disking (less than 2.5 cm. deep) before broadcast seeding followed by lightly disking and harrowing (Broadcast). Pastures were grazed with weanling calves beginning in late November in Year 1 and late December in Year 2 through May. Sodseeding method had no effect on monthly forage production except for January, when the broadcast pastures produced more forage ($P < 0.05$) than drilled pastures. Total forage production during the grazing season was similar for both planting methods, averaging 7611 kg/ha. Neither sodseeding method nor mixture affected average daily gains, days on test, or total beef produced/ha.

Chemical Dormancy

Challenges associated with overseeding perennial warm season sods center around competition between species seeded and the existing sod at planting in fall. Bermudagrass is dormant during winter, following freezing temperatures. However, bahiagrass, particularly improved Pensacola cultivars, can remain green, especially at winter temperatures > 0°C and thus compete with seeded cool season annuals for water and nutrient resources. (Gates et al. 2001). To ensure better establishment of cool season annuals, herbicides can be used to transition the warm season perennial sods into an early dormancy or at least suppress sods long enough to overseed until temperatures are low enough to ensure natural dormancy.

Hoveland et al. (1981) conducted a three-year study evaluating two different herbicides for perennial warm season grass suppression to aid in establishment of winter annual forages when overseeding in bermudagrass and bahiagrass in Alabama. Established sods of Pensacola bahiagrass and Coastal bermudagrass were closely clipped and residue removed before planting in mid-September. The systemic non-selective herbicide glyphosate (*N*-(phosphonomethyl) glycine) was applied at 0.28 kg ae, 0.56 kg ae and 1.12 kg ae per hectare and applied in 13 cm bands 25 cm apart to the sod. In addition, the non-systemic non-selective herbicide paraquat (1, 1' dimethyl-4, 4' bipyridinium dichloride) was applied at 0.56 kg per hectare in 13 cm bands 25 cm apart to the sod. 'Wrens Abruzzi' cereal rye was seeded with a grain drill at 56 kg/ha, 'Gulf' ryegrass was broadcast at 17 kg/ha, and 'Yuchi' arrowleaf clover was broadcast at 6 kg/ha. Cool season annual species were planted on both herbicide treated and untreated sod with control plots left with unseeded and untreated sod. It was observed that paraquat gave rapid top kill of the bahiagrass and bermudagrass aboveground plant canopy. After several weeks, however, new growth of bahiagrass began and continued until frost, competing with new seedlings for soil water. Top kill from glyphosate was slower, but longer lasting than from paraquat. However, summer (May to October) bahiagrass forage growth was reduced approximately 1100 to 1700 kg DM/ha where glyphosate had been applied but paraquat had no effect on summer production. Sod-seeding of rye increased December-April forage production by about 1360 kg DM/ha vs. unseeded sod. However, there was little difference in forage production of herbicide treatments and untreated sod in overall cool season production, but glyphosate treated plots had significantly greater forage production earlier in the cool season from November to February. This was attributed to greater bahiagrass control in the fall.

In another study Kalmbacher et al. (1980) conducted a two-year study on overseeding planting methods of three different legumes along with chemical suppression of bahiagrass sod. The objective of this investigation was to compare several methods of establishing three temperate legumes in a semi-dormant bahiagrass sward. This was accomplished by studying the performance of alfalfa, red, and ladino type white clover seeded with a Midland Zip® sod-seeding drill or a disk and broadcast seeding method in bahiagrass treated with herbicides designed to provide a wide range of sod suppression. At the Ona Agricultural Research Center in south Florida, red clover and ladino clover were seeded in 1976, and red and ladino clover and alfalfa (*Medicago sativa*) were seeded in 1977 by a Midland Zip® sod-seeder or a disk and broadcast method (D+B). The following herbicides (active ingredient rates kg/ha): 0.56 paraquat, (1, 1' dimethyl-4, 4' bipyridinium dichloride) 2 days before seeding, with sod burned at seeding (1976); 0.28 paraquat desiccation and burn (1977); 0.14 paraquat desiccation and burn (1977); 0.56 paraquat at seeding (1976); 0.28 paraquat at seeding (1976 and 1977); 2.49 dalapon (2, 2·dichloropropionicacid) (1976); 1.66 dalapon (1977); 2.49 dalapon, 13 days before seeding with 0.2B paraquat at seeding (1976); and no herbicide (1976 and 1977) were used to control sod growth. The two-year average number of legume seedlings per m^2 was 103 in the D+B seeding method vs. 49 in the Zip-seeded plots. Paraquat-burn treated plots averaged 131 seedlings/m^2 while all other herbicide treatments averaged 64. Legume dry matter yield was 6,130 kg/ha in the D+B plots vs. 4,500 kg/ha in sod-seeded plots. Yields averaged 6,740 kg/ha in paraquat-burn plots vs. 4,630 kg/ha in all other herbicide treatments. Crude protein and IVOMD in the D+B plots averaged 15.2 and 62.5%, respectively, vs. 14.0 and 60.6%, in Zip-seeded plots. Paraquat-burn treated plots averaged 15.2 and 63.2% crude protein and JVOMD, respectively, vs. 14.4 and 60.8% in other herbicide treatments. Disking bahiagrass sod and broadcasting seed (D+B) without herbicides generally resulted in better legume stands and legume yields than sod-seeding with a Zipseeder. Suppression of bahiagrass with herbicides resulted in little further increase in yield in the D+B method. When the Zip seeder was used, spraying sod with paraquat 2 to 3 days before seeding with the desiccated sod burned at seeding, resulted in better stands of legumes and higher yields of dry matter, and percent crude protein and IVOMD than other herbicide treatments.

Summary

Extending the grazing season with cool-season annuals is an important option which can help producers maintain profitability. As bahiagrass acreage has grown in Alabama and the Southeast, the importance of the forage to beef cattle systems has grown as well. Overseeding bahiagrass with cool-season annuals can also increase sustainability by increasing land utilization. While overseeding warm-season perennials grasses is not a new management technique, establishment methods are still not optimized for the greatest yield and season long production efficiency particularly in bahiagrass. Competition for water and nutrient resources with the established warm-season perennial grass usually results in later fall plantings of cool-season annuals. This in turn can result in lower forage production and a shorter cool-season grazing window. Herbicide and mechanical methods can be used to improve establishment for earlier fall planting. However, these findings have been inconclusive at times and results have shown a decrease in bahiagrass production the following warm season. Also, cool-season annual species used in establishment have also affected the production and quality of the stand. The objectives of this study were to evaluate different cool season annuals mixtures for production and nutritive value, in addition to the evaluation of chemical dormancy and establishment methods to help extend the grazing season.

II. Evaluation of cool season annual mixtures for overseeding bahiagrass

Introduction

The Southeast U.S. relies predominantly on perennial pasture systems to meet the nutritional requirements of the cow-calf sector. Therefore, the challenge becomes providing adequate nutrition to lactating and growing animals when warm-season perennial pastures become limiting in the fall. Additionally, because the cost of stored forages (e.g., labor, equipment, and time) is the greatest cost for livestock producers, grazing becomes the most cost-effective way to maximize beef production throughout the year, but particularly during the winter months (Ball et al., 2015). To overcome the shortage in forage production during the late fall and winter months during bahiagrass dormancy, overseeding pastures with cool-season annuals can be used as an option for providing forage during this time. Using mixtures of different forage species allows for a more uniform distribution of available forage throughout the entire cool season by matching specific growth patterns of the different species (Mullenix et al., 2012). The concept behind planting mixtures of cool-season annual species has been that of extending the supply of high-quality forage over a longer period when an early-maturing species is grown in combination with one that is later maturing (Mullenix et al., 2018). An example would be combining small grains (early-mid maturing) with annual ryegrass and clovers (late maturing). Diverse forage mixtures of multiple species and functional groups have gained popularity in use among forage-livestock producers for its potential to lengthen the grazing season, but few evaluations have been conducted in overseeded sods (Dubeux Jr, J. C. et al., 2016). The objective of the study was to evaluate forage mass and nutritive value of different cool-season forage mixtures overseeded into bahiagrass sods as a way to extend forage availability in the cool season.

Materials and Methods

Research Site

This experiment was conducted at the Wiregrass Research and Extension Center (WREC) in Headland, AL, U.S. (31˚21’25.5” N 85˚19’23.1”W) during the cool season of 2021 – 2022 (Year one) and 2022 – 2023 (Year two). Soil type was classified as a Dothan fine, sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with a pH of 5.8. Weather data from growth months during each cool season (October - March) were collected and provided via the Auburn University WeatherLink database (https://www.weatherlink.com/; Figures 1 and 2). Ten-year average weather data were collected and provided by the National Weather Service database (https://www.weather.gov/; Figure 3).

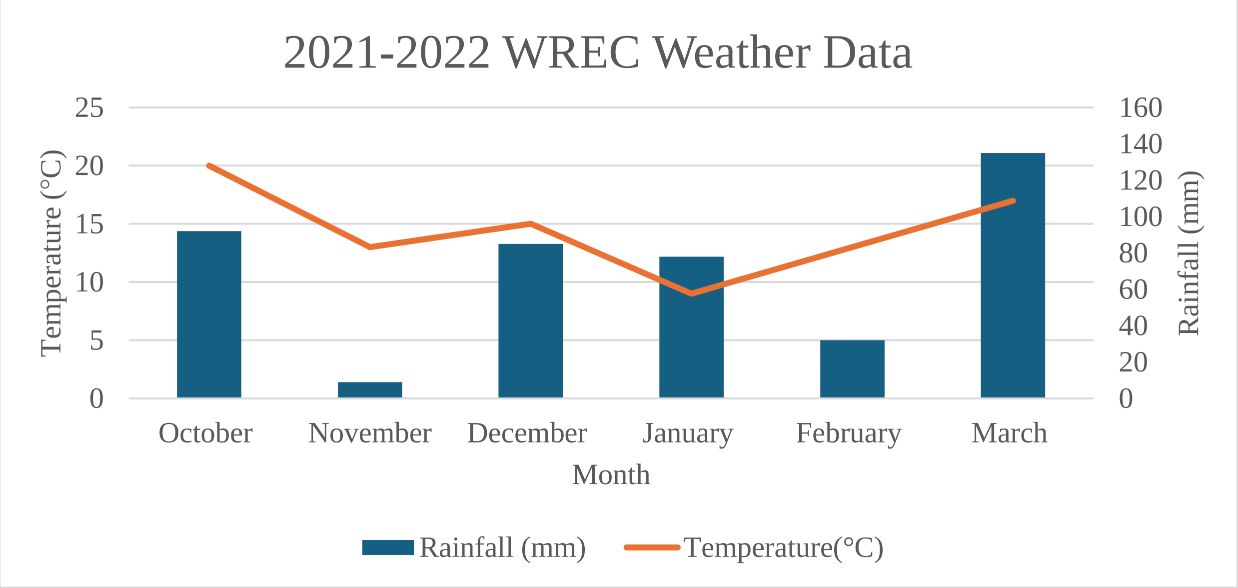


Figure 1. Monthly average temperature (˚C) and total monthly precipitation (mm) for October 2021 - March 2022 at the Wiregrass Research and Extension Center in Headland, AL.

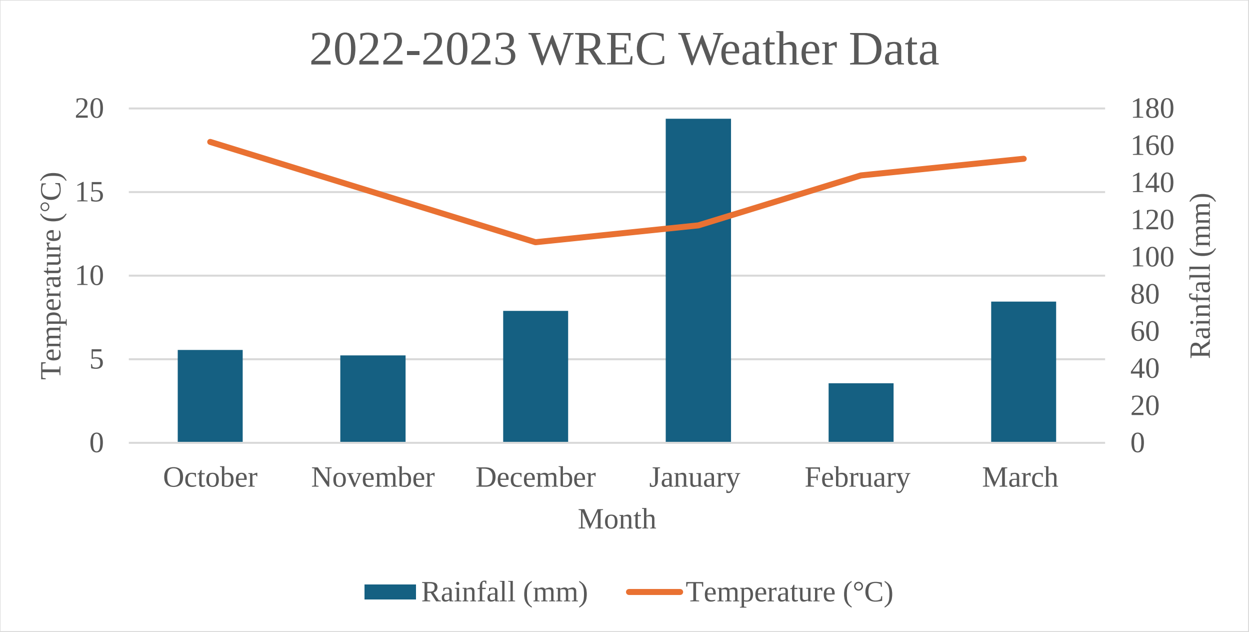


Figure 2. Monthly average temperature (˚C) and total monthly precipitation (mm) for October-March 2022 - 2023 at the Wiregrass Research and Extension Center in Headland, AL.

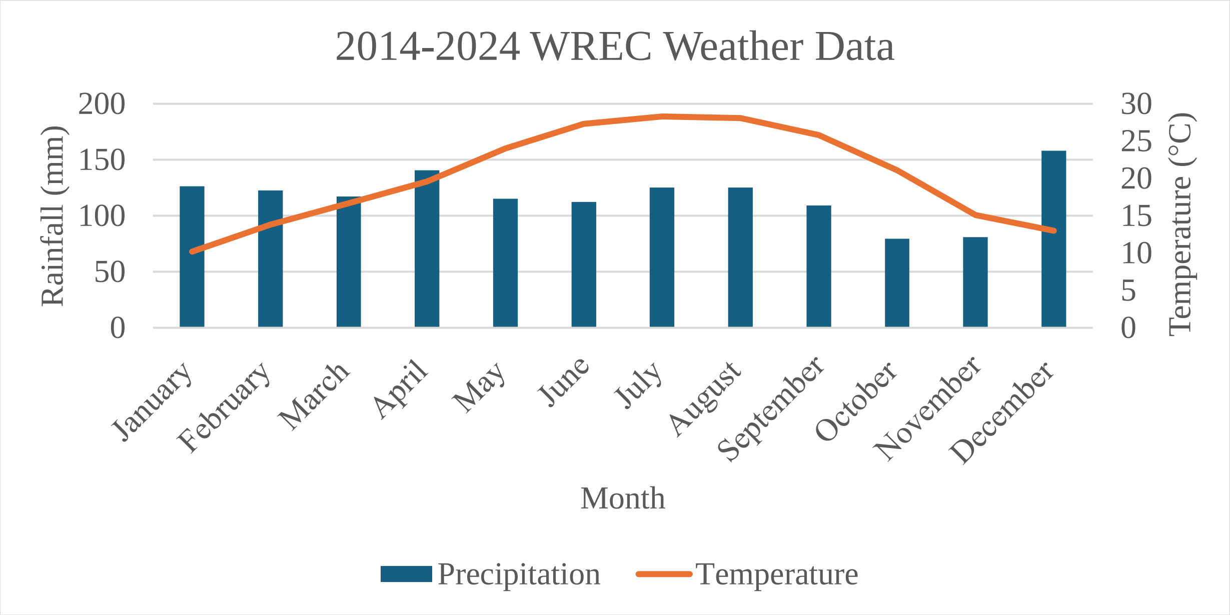


Figure 3. Ten-year monthly average temperature (°C) and mean monthly precipitation (mm) at the Wiregrass Research and Extension Center in Headland, AL.

In both year one and year two, average and total precipitation for the 6-month period in which the study was conducted were below the average and total for the same months in the 10-year average. Average precipitation in the six-month study period was 72 mm in year one of the study (2021-2022) and 75 mm in year two (2022-23) as compared to 114 mm in the 10-year average for those months. Total rainfall in the 6-month period study period was 431 mm in year one and 451 mm in year two as compared to 685 mm in the 10-year average for those months.

Experimental Design and Establishment

This experiment was a randomized complete block design (n = 2 blocks) with three treatments replicated twice. Experimental unit was the paddock and individual paddock size was 0.34 hectare each. Paddocks were seperated using temporary electric fencing. Treatments consisted of different cool-season annual mixtures overseeded into a six-year old existing 'Tifton 9' bahiagrass stand. Paddocks one and five treatment mixture consisted of: 'Coker 227' oats (62 kg pure live seed (PLS)/ha) + 'Horizon 201' wheat (62 kg PLS/ha) + clovers ('Fixation' balansa (*Trifolium michelianum*; 7 kg PLS/ha), 'CW9901' red (*Trifolium pratense*; 7kg PLS/ha) and 'REGALGRAZE' white (2.2 PLS/ha) clover. Paddocks two and four treatment mixture consisted of: 'FL 401' rye (62 kg PLS/ha) + 'Jumbo' ryegrass (17.8 kg PLS/ha) + clovers. Paddocks three and six treatment mixture consisted of: 'Coker 227' oats + 'FL 401' rye + clovers. The control treatment was no overseeding and had no replicate. Paddocks were seeded on 12 November 2021 for year one and 18 November 2022 for year two using a no-till drill (Great Plains, Salinas, KS). The bahiagrass stand used for the experiment was mowed to a two-inch stubble height to reduce thatch and allow the no-till drill to make better seed-to-soil contact. In addition, to induce a chemical dormancy intended to suppress bahiagrass competition, a light rate of glyphosate herbicide (1.8 kg active ingredient) was applied, after mowing and before seeding cool season annuals, at a rate of 0.84 kg/hectare to all experiment paddocks on 4 October 2021. This herbicide application resulted in the loss of the bahiagrass stand in the following season and thus planting in year two of the experiment was drilled into the remnants of the previous bahiagrass paddocks. Paddocks were fertilized according to soil test for annual phosphorus and potassium requirements. Nitrogen requirements were initially supplied by 14 kg/ha of synthetic urea (46-0-0) at planting. All other N requirements for the rest of the cool season were intended to be supplied by legume N-fixation from the clover portion of forage mixture. However, after poor stands in both years, 45 kg/hectare of synthetic N (46-0-0) was split applied after the initial N fertilization at planting. In year 1, N (46-0-0) was applied at 27 kg/hectare on 4 January 2022 before grazing and again on 14 February after first grazing event. In year 2, N (46-0-0) was applied at 27 kg/hectare on 12 January 2023 before grazing and again on 20 February 2023 after first grazing event.

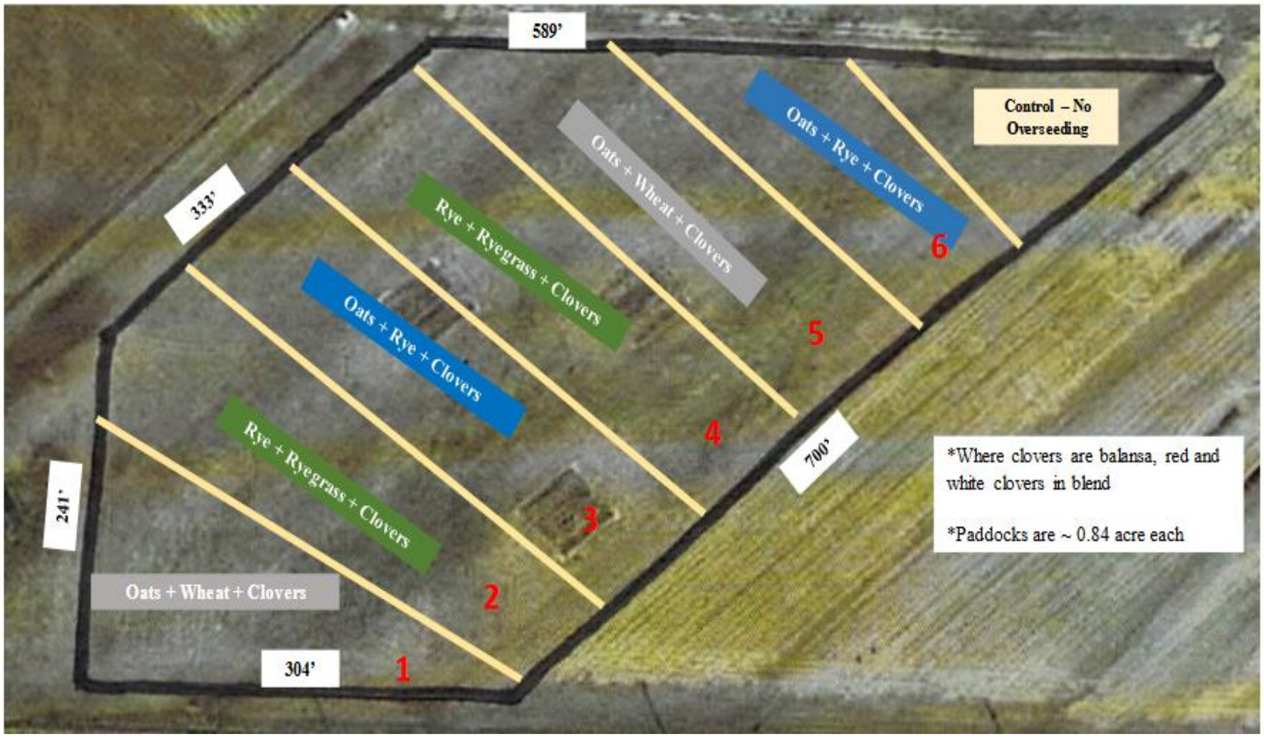


Figure 4. Experimental plot design and layout for 2021-22 and 2022-23 at the Wiregrass Research and Extension Center in Headland, AL.

Forage and Grazing Management

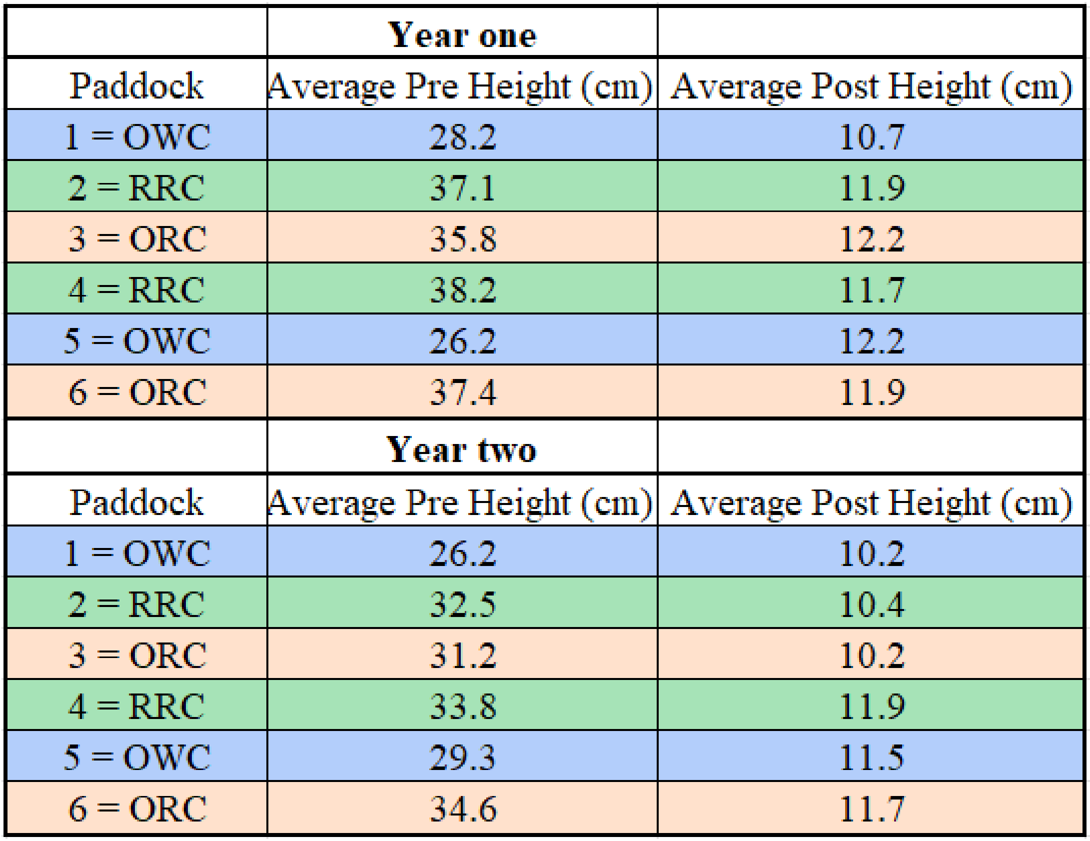
Grazing events were initiated when the cool season stand height reached an average of 25 to 38 cm. Paddocks were grazed using a flash mob grazing technique using 20 cow/calf pairs. Pairs were assigned to paddocks and remained until the average stubble height of the stand reached approximately 8 to 12 cm. Grazing events lasted approximately 3-4 hours and only one paddock was grazed per day. Paddocks were grazed in order of stand height starting with the tallest average stand height and rotating to the shortest. In year 1 paddocks 2, 3, 4, and 6 were initially measured for height, mass, and botanical composition on 2 February 2022 and this was considered 'early harvest'. In addition, paddock 2 was grazed at this time. Paddock 4 was grazed on 3 February 2022 and paddock 3 on 7 February 2022. Paddock 6 was grazed on 8 February 2022 and paddocks 1 and 5 were measured for initial height, mass, and botanical composition and this was considered 'early harvest'. Paddocks 1 and 5 were then grazed on 9 and 10 February 2022 respectively. Paddocks were then allowed to regrow until the target 25 to 38 cm stand height was achieved and then all paddocks were sampled for height, mass, and botanical composition on 8 March 2022, and this was considered 'late harvest'. Paddocks were grazed in the same order starting on 8 March 2022 and ending on 17 March 2022. In year 2, initial height, mass, and botanical composition measurements were taken on 6 February 2023 for paddocks 2, 3, 4, and 6, and was considered 'early harvest'. Grazing was initiated in the same order as year 1 for these paddocks on 8 February 2023 and ended on 11 February 2023. Initial forage height, mass, and botanical composition measurements were taken on 13 February 2023 for paddocks 1 and 5, which was considered 'early harvest'. These paddocks were grazed starting on 14 February 2023 and ending on 15 February 2023. Paddocks were then allowed to regrow until the target 25 to 30 cm stand height was achieved. Paddocks 2,3,4,6 were sampled for height, mass, and botanical composition on 7 March 2023 and this was considered 'late harvest'. Grazing was also initiated at this time in the same order and ended on 10 March 2023 for these paddocks. Paddocks 1 and 5 were sampled for height, mass, and botanical composition on 13 March 2023 and this was considered 'late harvest'. These paddocks were also grazed at this time and all grazing was completed on 16 March 2023.

Response Variables and Laboratory Procedures

Forage canopy height was used as a determining factor for when to initiate or terminate grazing in paddocks. Twenty height measurements were taken and recorded on pre- and post-graze condition using a grazing stick/pasture ruler in each treatment paddock. To determine herbage mass (kg DM/ha) samples were collected at five random locations throughout each paddock before grazing using 0.1-m^2 quadrats. These samples were collected before each grazing event. Each herbage mass sample was then botanically separated by hand into grass, legume, and weed components. Samples were transported to the Auburn University Ruminant Nutrition Laboratory in Auburn, AL and were dried at 55˚C for 72 h until a stable dry weight was achieved then weighed for dry matter (DM) determination. Total seasonal forage biomass was calculated using the sum of the mean herbage mass for each forage mixture and harvest. Botanical composition components were composited and processed by grinding them through a 1 mm screen on a Wiley Mill (Thomas Scientific, Philadelphia, PA). Samples were analyzed for concentrations of neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein

(CP) to determine forage nutritive value. Analyses performed by Cumberland Valley Analytical Services, INC. (Zullinger, PA) utilizing near infrared reflectance spectroscopy (NIR ; FOSS™ NIRS™ DS3 F; Fisher Scientific, Hampton, NH). Nutritive value was determined using prediction equations provided by the National Forage Testing Association (NIRSC, 2016). To validate NIR values, 10% of samples were randomly selected each year to undergo wet chemistry analysis. Samples randomly selected for wet chemistry analysis were evaluated for DM, CP, NDF and ADF. Laboratory DM was determined according to AOAC (1995) at 108˚C for 12 h. Crude protein was determined utilizing the Kjeldahl procedure (AOAC, 1995) using a Kjeltech System (Foss™ Tecator Kjeltech™ 8100, Fisher Scientific, Hampton, NH) for N determination. Crude protein was then calculated as N × 6.25. Neutral detergent fiber and ADF were evaluated via the Van Soest et al. (1991) method using ANKOM 2000® Fiber Analyzer (Ankom Technology Corporation, Fairport, NY).

Table 1. Average paddock forage height within year. Pre-height = before grazing was initiated; Post-height = after grazing was terminated; OWC = oats + wheat + clovers; RRC = cereal rye + annual ryegrass + clovers; ORC = oats + cereal rye + clover



	Year one	
Paddock	Average Pre Height (cm)	Average Post Height (cm)
1 = OWC	28.2	10.7
2 = RRC	37.1	11.9
3 = ORC	35.8	12.2
4 = RRC	38.2	11.7
5 = OWC	26.2	12.2
6 = ORC	37.4	11.9
	Year two	
Paddock	Average Pre Height (cm)	Average Post Height (cm)
1 = OWC	26.2	10.2
2 = RRC	32.5	10.4
3 = ORC	31.2	10.2
4 = RRC	33.8	11.9
5 = OWC	29.3	11.5
6 = ORC	34.6	11.7

Statistical Analysis

Data were analyzed using SAS v. 9.4 (SAS Institute, Cary, NC) for a randomized complete block design. Data were analyzed using the generalized linear mixed model procedure (PROC GLIMMIX). Year was considered a fixed effect because of different establishment conditions from year 1 and year 2 of study. Pasture was the experimental unit. The independent variable was the forage mixture treatment, and the dependent variables were harvest date and nutritive value parameters. For all response variables, mean separations were performed based on F-protected t-tests using the LINES options in the LSMEANS statement of PROC GLIMMIX and were adjusted for Tukey's test ($P < 0.05$). Differences were considered significant at $P < 0.05$. Significant interactions, when $P < \alpha$, were discussed in addition to significant main effects.

Results

Forage Biomass

In year one, there was an effect of treatment ($P = 0.03$) on forage biomass between the OWC (oats + wheat + clovers) mixture and the RRC (cereal rye + annual ryegrass + clovers) mixture. The RRC (1,790 kg DM/ha) mixture produced 500 kg DM/ha more than the OWC mixture (1,290 kg DM/ha; Figure 4). The ORC (oats + cereal rye + clovers) mixture (1,655 kg DM/ha) did not differ from the other treatments in year one. There was no treatment effect in year two with the OWC mixture producing the most (1,700 kg DM/ha) followed by the RRC mixture (1,610 kg DM/ha) and the ORC mixture (1,425 kg DM/ha).

There was a harvest effect ($P = 0.02$) in year one in which the late harvest (1,903 kg DM/ha) produced 650 kg DM/ha more than the early harvest (1,253 kg DM/ha; Figure 5). There was no effect of harvest in year two with the early harvest (1,590 kg DM/ha) producing only 24 kg DM/ha more than the late harvest (1,567 kg DM/ha).

Total seasonal biomass was calculated using the sum of the mean herbage mass for each forage mixture and harvest. In year one, there was an effect of forage treatment ($P = 0.02$) on total seasonal forage biomass in which the RRC (3,580 kg DM/ha) mixture produced 1,000 kg DM/ha more than the OWC (2,580 kg DM/ha) mixture (Figure 6). The ORC (3310 kg DM/ha) mixture did not differ from the other treatments in year one. There were no differences in total seasonal forage biomass among forage mixtures in year two.

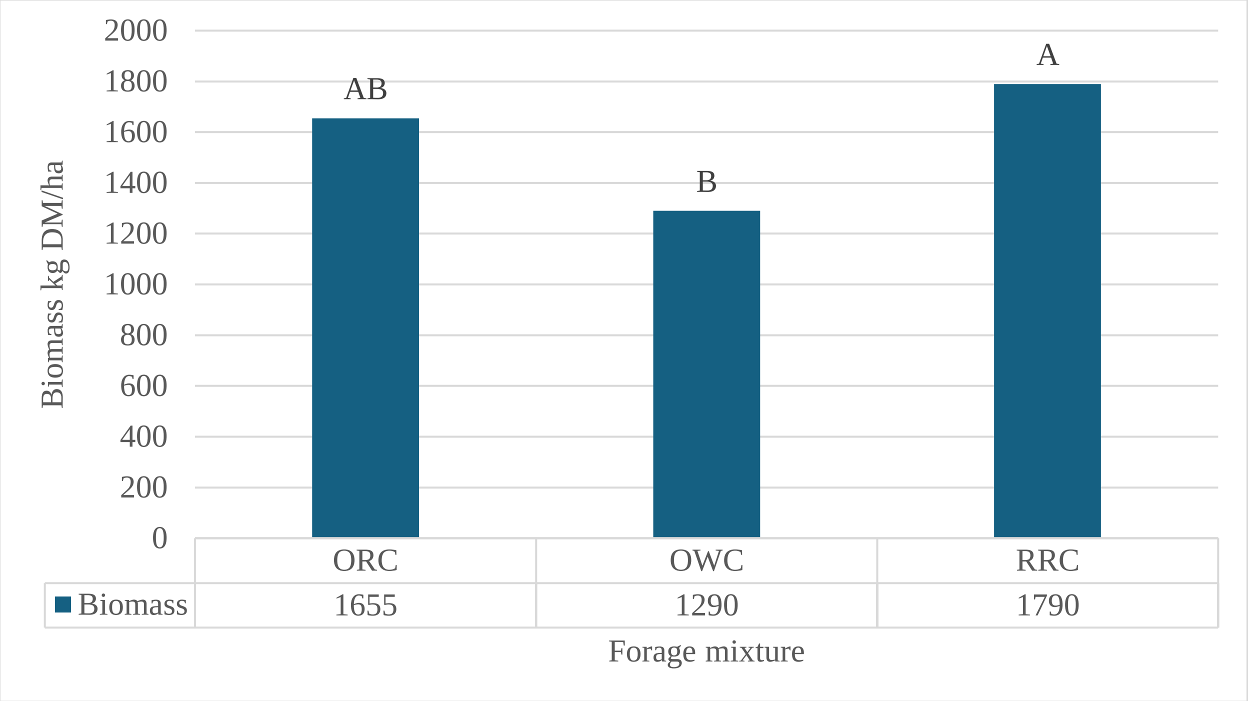


Figure 5. Mean forage biomass (kg DM/ha) of cool season forage mixtures at the Wiregrass Research and Extension Center, Headland, AL. ^{ABC}Means without a common letter are significantly different ($P = 0.03$). OWC = oats + wheat + clovers; RRC = cereal rye + annual ryegrass + clovers; ORC = oats + cereal rye + clovers.

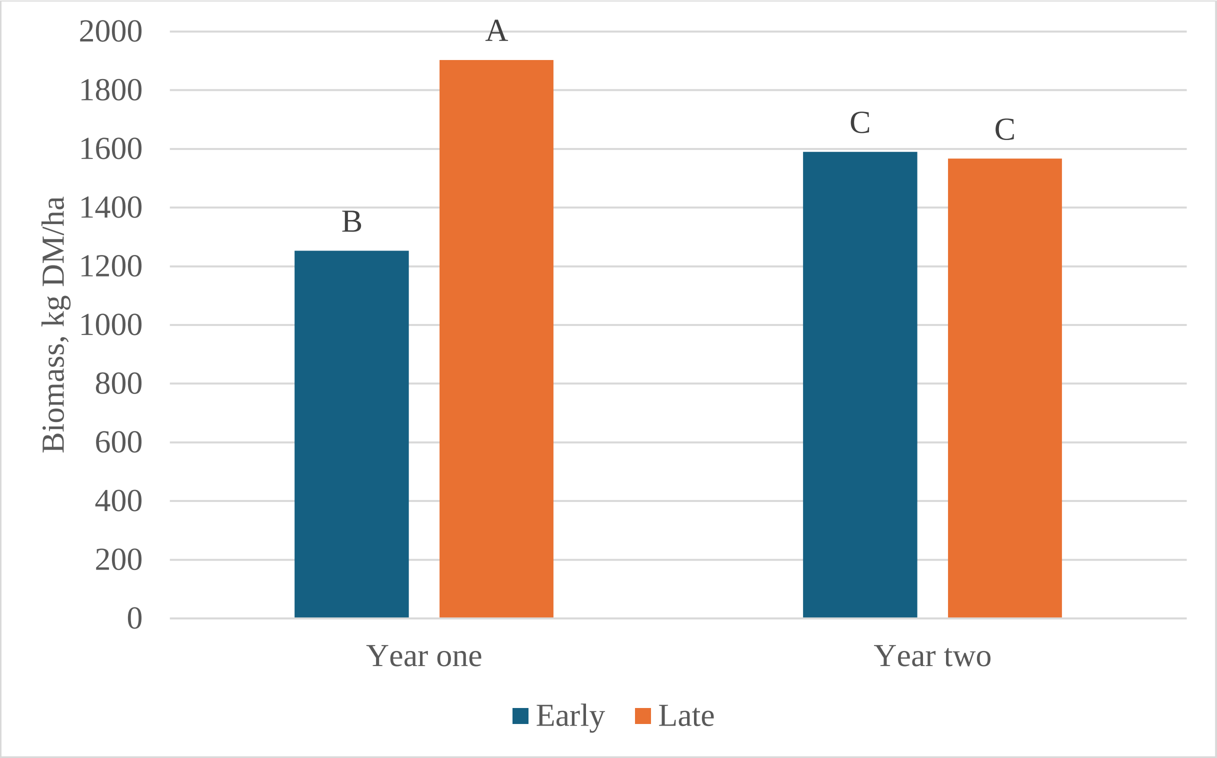


Figure 6. Mean forage biomass (kg DM/ha) of cool season forage mixtures by year and harvest date at the Wiregrass Research and Extension Center, Headland, AL. ^{ABC}Means without a common letter are significantly different ($P = 0.02$). Early = early harvest (early February; Late = late harvest (early March).

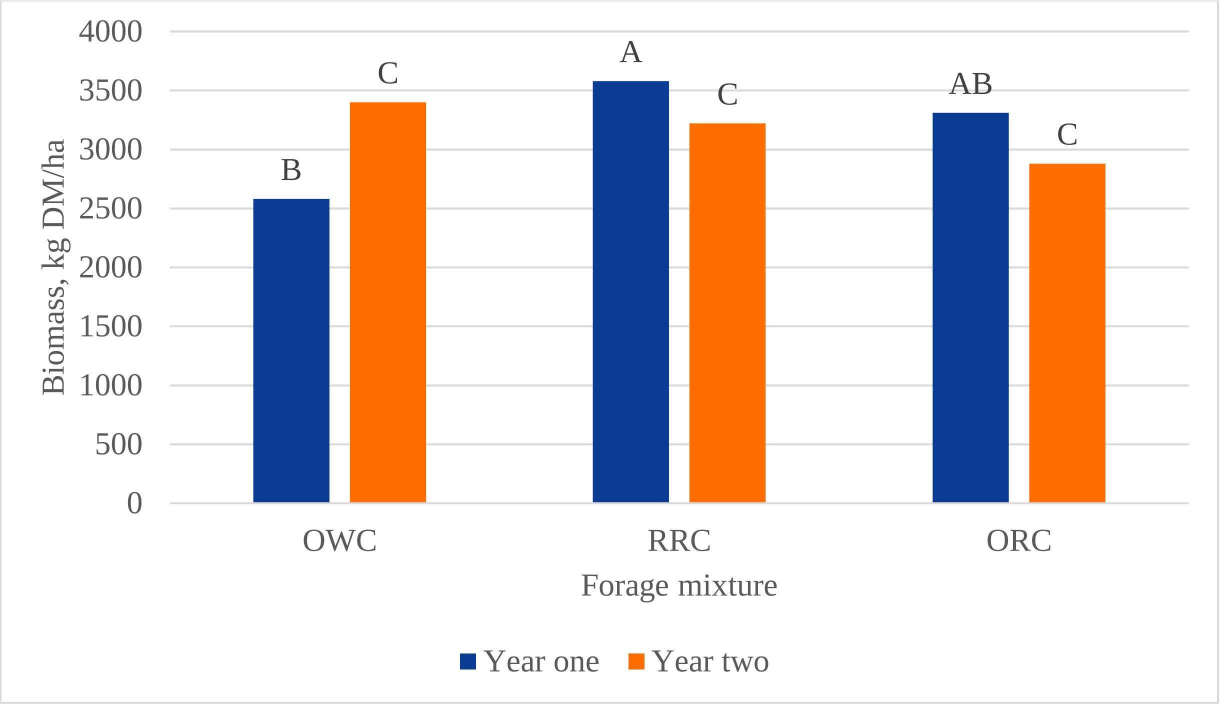


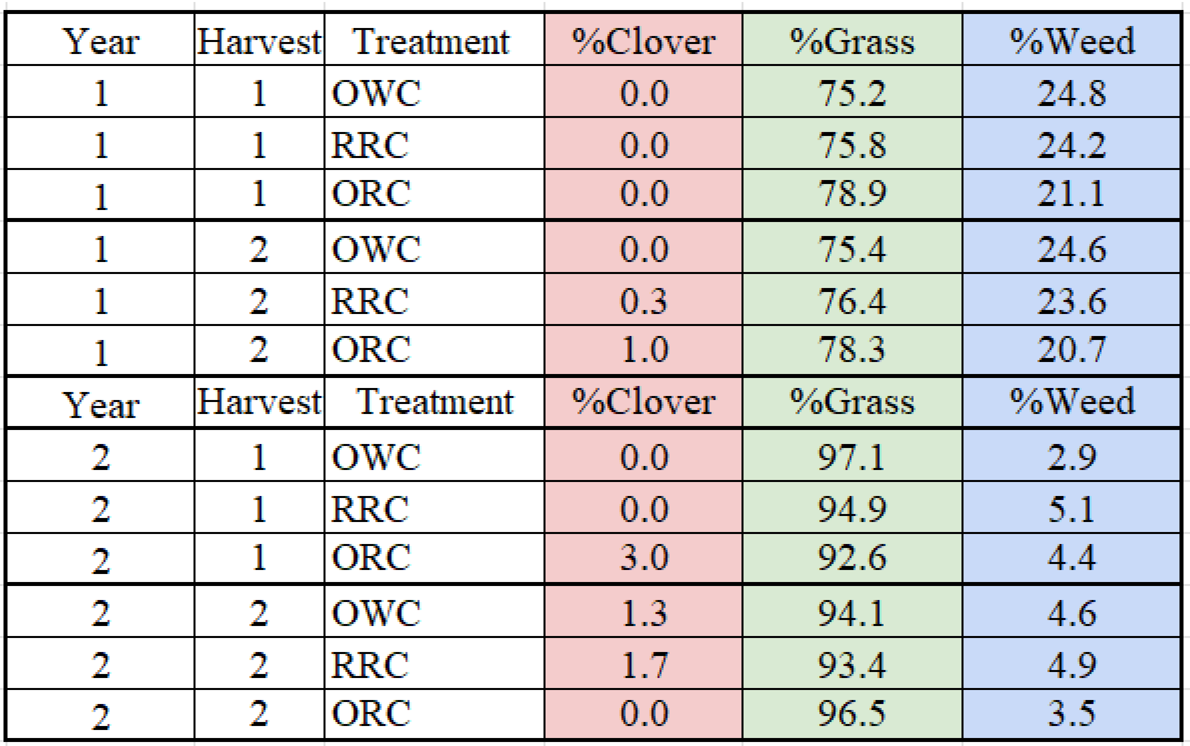
Figure 7. Total seasonal forage biomass (kg DM/ha) by forage mixture and year at the Wiregrass Research and Extension Center, Headland, AL. ^{ABC}Means without a common letter are significantly different ($P < 0.05$). OWC = oats + wheat + clovers; RRC = cereal rye + annual ryegrass + clovers; ORC = oats + cereal rye + clovers. Totals from early and late harvests (early February and March, respectively).

Botanical Composition and Forage Height

Forage cool season grasses dominated the botanical composition of each stand. There was no difference in species composition across forage mixtures in either year of the study ($P = 0.24$), nor was there a difference in composition between harvests ($P = 0.08$). Cool season grass composition made up no less than 75% of the composition in year one and no less than 93% of the composition in year two for any harvest or mixture. Weed prevalence was greater in year one with an average of 18% n as compared to only 4 % composition average in year two ($P =$

0.0006). However, weed composition was similar within year between harvest dates. Clover composition of the stands was minimal making up no more than 3% of forage composition in any mixture, harvest, or year (Table 2).

Table 2. Botanical composition of cool season forage mixtures within harvest and year at the Wiregrass Research and Extension Center, Headland, AL. OWC = oats + wheat + clovers; RRC = cereal rye + annual ryegrass + clovers; ORC = oats + cereal rye + clovers. Harvest 1 = early harvest (early February); Harvest 2 = late harvest (early March).



Year	Harvest	Treatment	%Clover	%Grass	%Weed
1	1	OWC	0.0	75.2	24.8
1	1	RRC	0.0	75.8	24.2
1	1	ORC	0.0	78.9	21.1
1	2	OWC	0.0	75.4	24.6
1	2	RRC	0.3	76.4	23.6
1	2	ORC	1.0	78.3	20.7
Year	Harvest	Treatment	%Clover	%Grass	%Weed
2	1	OWC	0.0	97.1	2.9
2	1	RRC	0.0	94.9	5.1
2	1	ORC	3.0	92.6	4.4
2	2	OWC	1.3	94.1	4.6
2	2	RRC	1.7	93.4	4.9
2	2	ORC	0.0	96.5	3.5

Forage Nutritive Value

In year one, there was an effect of treatment ($P = 0.0009$) on forage CP (Figure 6). The OWC mixture had the greatest CP (18.3%) and was followed by the ORC mixture (16.1%) and the RRC mixture (14.3%). There was no significant difference between treatments in forage CP in year two with the RRC mixture (22.4%) having the highest CP followed by the ORC mixture (21.9%) and the OWC mixture (21.0%). There was an effect of harvest ($P = 0.02$) on forage CP in year two. The early harvest had greater CP (22.8%) than the late harvest (20.8%). There was no harvest effect in year one with the early harvest having slightly higher CP (16.5%) than the late harvest (16.1%).

Figure 8. Mean crude protein (CP) percentage (DM basis) by year and forage mixture at the Wiregrass Research and Extension Center, Headland, AL. ^{ABC}Means without a common letter are

significantly different ($P < 0.05$). ORC = oats + cereal rye + clovers; OWC = oats + wheat + clovers; RRC = cereal rye + annual ryegrass + clovers.

There was an effect of treatment ($P = 0.05$) in year one on forage NDF between the OWC mixture (39.8%) and the ORC mixture (45.7%) along with the RRC mixture (46.1%). There was no difference in NDF between treatments in year two with the ORC mixture (44.6%) having a slightly greater NDF than the OWC mixture (43.9%) and the RRC mixture (43.6%). There was a harvest effect ($P = 0.001$) on forage NDF across both years with the early harvest (38.5%) having a lower NDF than the late harvest (49.4%). There was also a harvest by treatment effect ($P = 0.02$) across years. In the early harvest, the RRC mixture (36.6%) had the lowest NDF followed by the ORC mixture (38.8%) and the OWC mixture (40.3%). In the late harvest, the OWC mixture (43.5%) had the lowest NDF followed by the ORC mixture (51.6%) and the RRC mixture (53.1%).

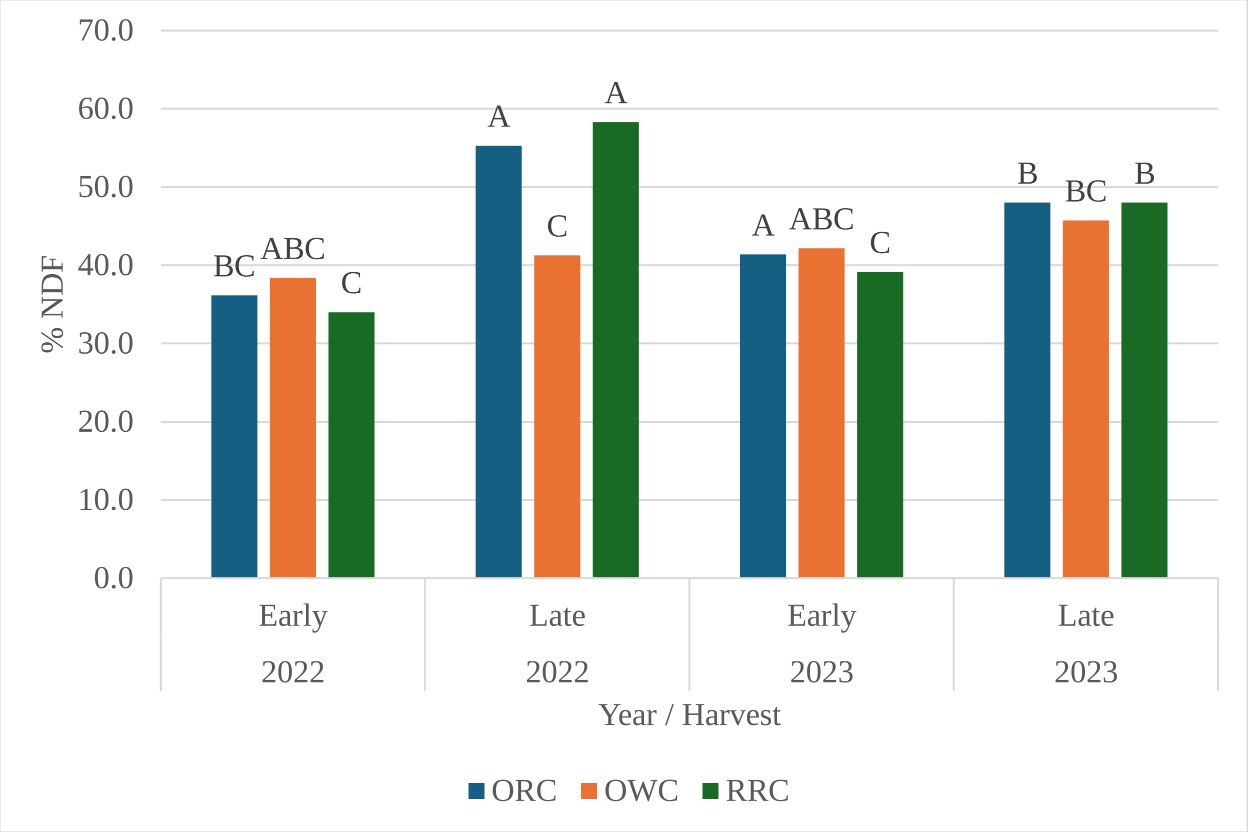


Figure 9. Mean neutral detergent fiber (NDF) percentage (DM basis) by year, harvest, and forage mixture at the Wiregrass Research and Extension Center, Headland, AL. ^{ABC}Means without a common letter are significantly different ($P < 0.05$). Early = early harvest (early February; Late = late harvest (early March); ORC = oats/cereal rye/clover; OWC = oats/wheat/clover; RRC = cereal rye/ryegrass/clover.

In year one, there was an effect of treatment on forage ADF ($P < 0.0001$). The OWC mixture (18.6%) had the lowest ADF followed by the ORC mixture (21.0%) and the RRC mixture (22.2%). There was no significant difference in ADF between treatments in year 2 with the RRC mixture (25.1%) having the lowest ADF followed by the ORC mixture (25.7%) and the OWC mixture (26.5%). There was a harvest effect ($P < 0.0001$) on forage ADF across both years with the early harvest (20.1%) having a lower ADF than the late harvest (26.3%). In addition, there was a harvest by treatment effect ($P = 0.01$) across years. In the early harvest, the RRC mixture (18.9%) had the lowest ADF followed by the ORC mixture (19.9%) and the OWC mixture (21.5%). In the late harvest, the OWC mixture (23.6%) had the lowest ADF followed by the ORC mixture (26.8%) and the RRC mixture (28.4%).

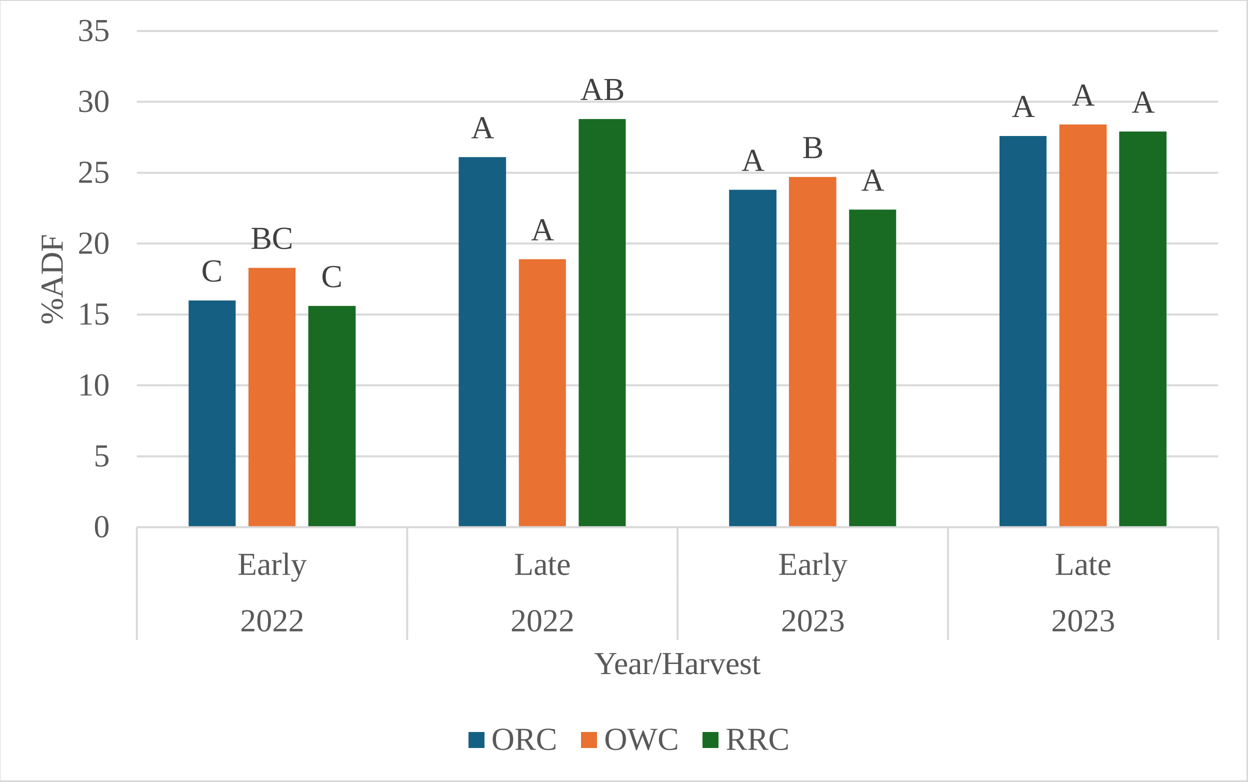


Figure 10. Mean acid detergent fiber percentage (ADF; DM Basis) by year, harvest, and forage mixture at the Wiregrass Research and Extension Center, Headland, AL. ^{ABC}Means without a common letter are significantly different ($P < 0.05$). Early = early harvest (early February; Late = late harvest (early March); ORC = oats/cereal rye/clover; OWC = oats/wheat/clover; RRC = cereal rye/ryegrass/clover.

Discussion

Forage Biomass

Overall, average forage biomass production was similar in both year one (1,578 kg DM/ha) and year two (1,583 kg DM/ha) of this study. This was similar production to a study in Alabama by Mason et al. (2020) in which cool season annuals grazed by cow/calf pairs produced an average of 1,604 kg DM/ha per harvest or grazing event. In year one of our study, forage treatment and harvest effects were observed for forage mass. Mixtures containing cereal rye generally produced more biomass than other treatments. This could be due to relative maturity differences in small grain forages, where cereal rye tends to mature and accumulate both earlier and total biomass than oats and wheat in the cool season (Bruckner & Raymer, 1990). This might also be partially explained by the colder January temperatures in year one than in year two, which could have reduced oat and wheat yields as compared to cereal rye. In comparison, cereal rye has a greater cold tolerance than other small grains (Ball et al., 2015). This was similar findings to Dubeux et al. (2016) in which 'FL 401' cereal rye in a mixture with annual ryegrass tended to produce greater early spring yields than mixtures of oats and annual ryegrass and triticale and annual ryegrass in Florida. Our study, however, did not report a significant difference in biomass between forage treatment mixtures, as was observed in this study in year two. This was consistent with findings from Beck et al. (2007) in which treatments evaluating yield of various small grain species along with ryegrass did not produce a significant difference in average overall yield between treatments in either year one (2,025 kg DM/ha) or year two (2,114 kg DM/ha) over the two-year study in Arkansas. An effect of harvest was observed in year one in which late harvest produced more biomass than the early harvest. This possibly occurred due to more favorable weather conditions, warmer and longer days with more frequent rainfall, after the early harvest when animals were removed, and regrowth of stand was allowed before the late harvest. In addition, increased relative maturity of forages is associated with increased biomass which could explain higher yield in the late harvest as forages matured (Moore et al., 2020). Again, these findings were similar to Dubeux et al. (2016) in which small grains mixed with ryegrass tended to accumulate more biomass after grazing as the cool season progressed into spring. This interaction was not observed between in year two of this study and Dubeux et al. (2016), which could be explained by the milder winter temperatures which could have resulted in more consistent production between species.

Botanical Composition

Species botanical composition (grass, legumes, or weeds) did not differ among cool-season mixtures overseeded within year (between early and late harvests). However, weed prevalence was lower in year two than year one which may have been attributed to the difference in site preparation before planting. Year one seed was drilled into existing bahiagrass sod but year two seed was drilled into a tilled field after loss of sod. In addition, legume establishment was poor for all treatments and years possibly due to adverse effects from planting depth or competition with other stand components (Evers, 2005). In ideal conditions small grains would have been expected to dominate the stand earlier with the clovers and ryegrass becoming more prevalent later in spring (Mullenix & Rouquette, 2018).

Forage Nutritive Value

There was an effect of treatment on forage CP, NDF, and ADF for year one. The oats/wheat/clover mixtures had a greater CP than oats/rye/clover and the rye/ryegrass/clover mixtures. However, this was not observed in year two. Mason et al. (2020) reported a mean CP value of 21.7% on DM basis in a study in Alabama where cool-season annuals were grazed by cow/calf pairs. This was similar mean CP values in year two (21.8%) of our study but was greater than year one (16.3%). The difference in CP, NDF, and ADF between forage mixtures in year one could be explained in part by the relative maturity of the species and the greater production and presence of cereal rye in the mixtures that contained it. Rye tends to mature earlier than other small grain species and as a result tended to have more stem and reproductive components when harvested which could have reduced the forage quality (Bruckner & Raymer, 1990). If plants are fully developed and stems have already elongated, forage quality will likely decline because of loss of cell soluble compounds, greater cell wall content, and reduced protein concentration (Coleman et al., 2004). This was consistent with Dubeux et al. (2016) where they observed 'FL 401' cereal rye having an earlier fall growth and rapid maturity in the spring, thus lowering its quality and digestibility. In addition, there was an effect of harvest across all forage nutritive value parameters. This could also be explained by forage maturity in which the late harvest was comprised of more mature forages than the early harvest. In this case the forages in the late harvest would start to express reproductive physiological traits such as longer stems, reduced leaf:stem ratio, and seed heads which would indicate a shift from the vegetative stage lowering forage quality (Moore et al., 2020). In addition, a study in Alabama by Mullenix et al. (2012) evaluating mixtures of oat, cereal rye, and annuals ryegrass reported that mixtures containing cereal rye tended to have lower NDF and ADF values as compared to mixtures with only oats and ryegrass. This was also attributed to the earlier maturation of cereal rye as compared to other small grains and ryegrass.

Conclusion

Results of this study suggest that overseeding bahiagrass with cool-season mixtures of small grains, ryegrass and clovers can provide approximately 1,500 kg of dry matter per hectare of grazable forage per grazing event, with an average of **** across the season. The extended grazing season provided by the cool-season mixtures overseeded into bahiagrass may reduce feeding costs during the shortage in forage production (Benson, 2010). Forage mixtures evaluated in this study would provide a high-quality forage option for beef cow-calf pairs grazing during the cool season. With similar forage mass among all treatments, the decision on which cool-season mixtures overseeded into dormant bahiagrass may be made based on the nutritive value of those mixtures and the stage of production of the grazing animal. Brood cows in the first months of pregnancy (requirements: 7% CP and 48% TDN) and those in mid-lactation (requirements: 9% CP and 54% TDN) can have their nutritional needs met by grazing any of the three mixtures used in this study (NRC, 2016). Similarly, cows in peak lactation (60 to 80 days after calving; requirements: 12% CP and 60% TDN) can also have their nutritional needs met by any of the mixtures evaluated (NRC, 2016). In conclusion, overseeding pastures with mixtures of cool-season grasses and legumes may support winter and spring grazing in beef cattle operations. Number of species in the mixture and seasonality of forage species growth is important in optimizing growing season length. Additional work to improve establishment methods of diverse, cool-season mixtures is needed to target an earlier grazing window in this system.

III. Evaluation of chemical dormancy and planting methods effects on bahiagrass overseeded with cool season annuals.

Introduction

Earlier fall planting of cool-season annuals results in better cold hardiness and overall biomass production (Meyer et al., 2008). However, bahiagrass growth may still be active in the fall and early winter depending on environmental conditions, which can hinder planting and establishment of cool-season annuals (Gates et al., 2004). To achieve earlier fall planting and to reduce the chance of competition for establishing cool-season annual forages, chemical herbicides can be applied to bahiagrass at low rates to induce an early dormancy in the bahiagrass without killing the forage. After the induced dormancy is achieved, planting of the cool-season annuals can take place using either a no-till drill or with light tillage and broadcast methods (Evers, 2005). However, when using these methods stand results and damage to bahiagrass sods have been inconsistent. In this experiment we evaluated the effect of using a non-systemic herbicide or systemic herbicide, along with different planting methods, on establishment and production characteristics of cool-season annuals and bahiagrass in the following warm season.

Materials and Methods

Research Site

This experiment was conducted at the Wiregrass Research and Extension Center (WREC) in Headland, AL, U.S. (31˚21’25.5” N 85˚19’23.1” W) during the cool season (October

– April) and the warm season (May-September) of 2023-2024. The results are from the first year of a two-year evaluation reported herein. Soil type was classified as a Lucy loamy sand (loamy, kaolinitic, thermic Arenic Kandiudults) with an initial pH of 4.8. Weather data from the beginning and end of year 1 of study (September 2023-August 2024) were collected and provided via the Auburn University WeatherLink database (https://www.weatherlink.com/; Figure 8). Ten-year average weather data were collected and provided by the National Weather Service database (https://www.weather.gov/; Figure 9).

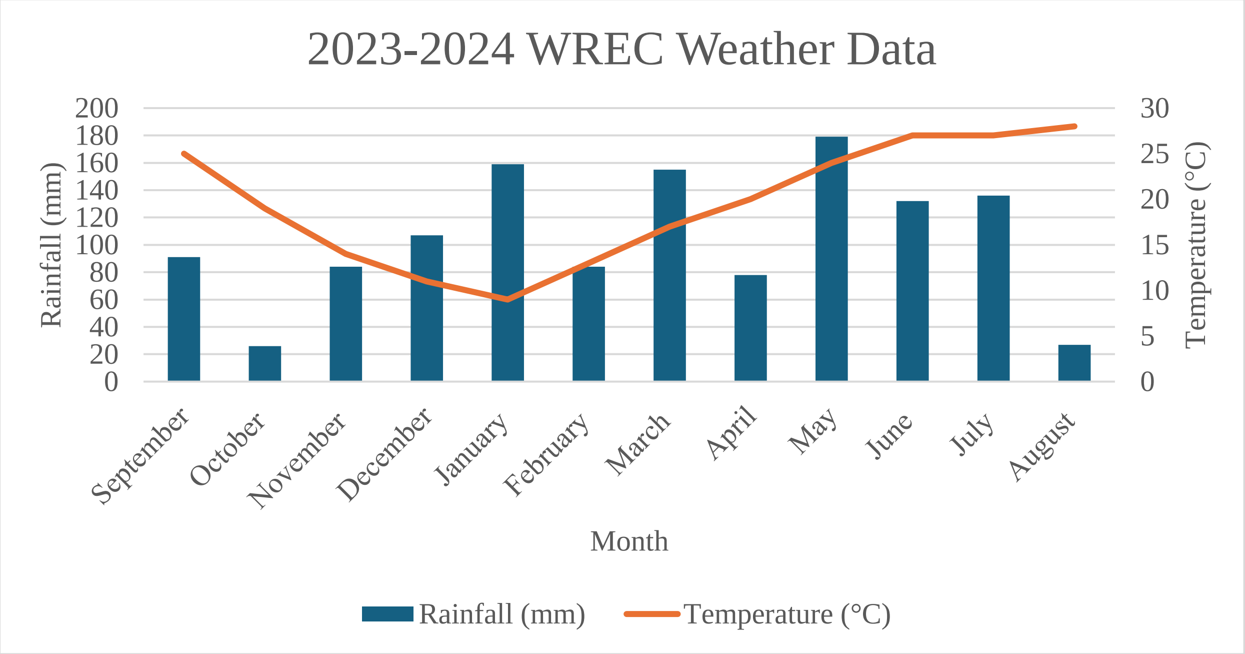


Figure 11. Monthly average temperature (˚C) and total monthly precipitation (mm) for September-August 2023 - 2024 at the Wiregrass Research and Extension Center in Headland, AL.

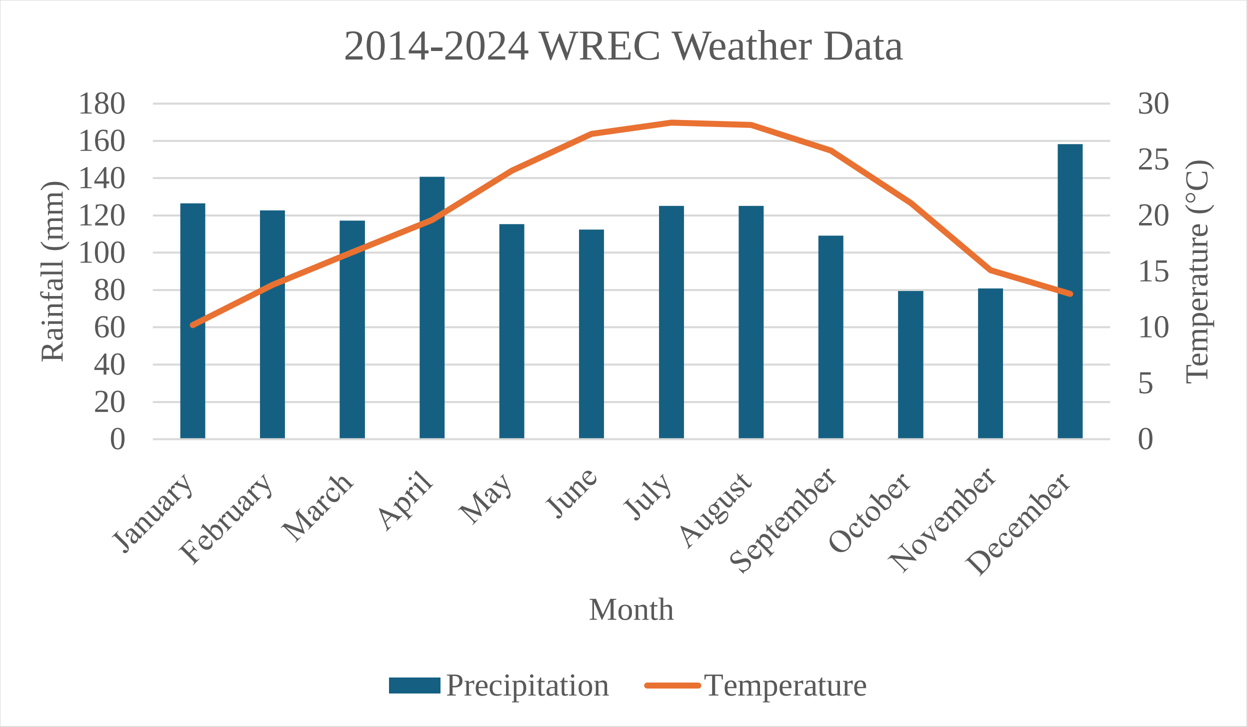


Figure 12. Ten-year monthly average temperature (°C) and mean monthly precipitation (mm) at the Wiregrass Research and Extension Center in Headland, AL.

Precipitation during cool season stand establishment in the month of October 2023 was well below the 10-year average precipitation totals for the month (26 mm and 80 mm, respectively). This contributed to poor stand formation and the decision to irrigate the study area. In addition, the 12-month period, spanning both the cool (October – April) and warm (May – September) seasons of the study, experienced less total precipitation than the 10-year average yearly total (1,258 mm and 1,413 mm, respectively).

Experimental Design and Establishment

This experiment was a 2 x 2 + 1 factorial design. The treatment area was measured and layed out in an exsiting six year-old 'Tifton 9' bahiagrass field utilized for hay production measuring

(30 m x 60 m). Treatments consisted of two herbicides 1.) paraquat (1,1′-dimethyl-4,4′-dipyridinium salt) + nonionic surfactant (Helmquat® 3SL, HELM Agro US Inc.) + Alligare 90, Alligare, LLC) or 2.) glyphosate (*N*-(phosphonomethyl)glycine) (Cornstone® Plus, WinField Solutions, LLC), and a control (no herbicide). Each herbicide treatment (Factor A) was replicated four times, randomized within each block, for a total of twelve 5 x 9 m plots per planting method. Each herbicide treatment was applied at two different rates (Factor B), 'low' and 'high', keeping each rate on the same side of the plot throughout the treatment area. Paraquat (0.91 kg ai) was applied at a low rate of 1.12 kg ai ha and a high rate of 2.24 kg ai ha. Glyphosate (1.81 kg ae) was applied at a low rate of 0.42 kg ae ha and a high rate of 0.84 kg ae ha. All herbicide treatments were applied using CO_2 pressurized backpack sprayer on 3 October 2023 at an output of 140 L ha using a hand held 2 m spray boom equipped with four TeeJet AIXR11002 flat-fan nozzles (Spraying Systems Co, Wheaton, IL). This 2 x 2 + 1 factorial design was replicated and re-randomized across two planting methods (no-till drilled vs. broadcast).

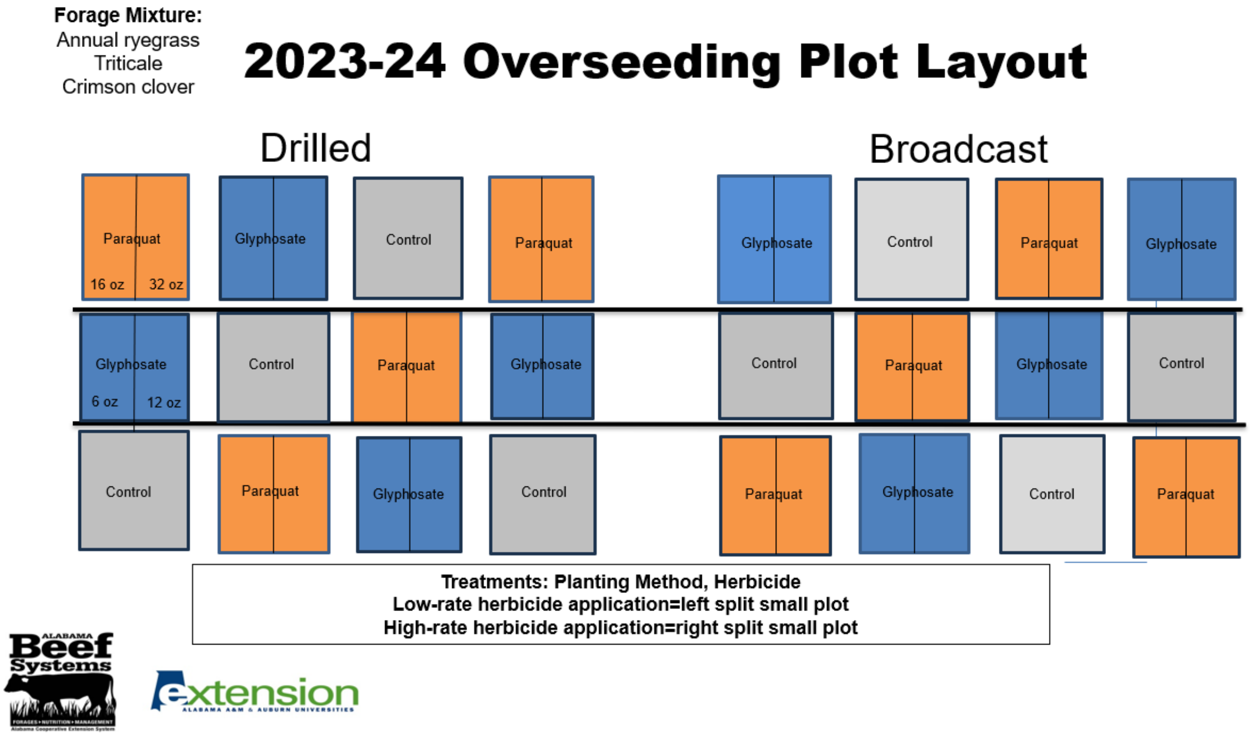


Figure 13. Experimental plot design and layout for 2023-24 overseeding methods study at the Wiregrass Research and Extension Center, Headland, AL.

Forage Establisment and Management

A cool season forage mixture was overseeded across all treatments on 18 October 2023 and consisted of 'Fria' annual ryegrass (34 kg/ha PLS broadcasted; 23 kg/ha PLS drilled), 'Surge' triticale (84 kg/ha PLS broadcasted; 56 kg/ha PLS drilled), and 'Dixie' crimson clover (*Trifolium incarnatum*) (34 kg/ha broadcasted; 23 kg/ha drilled). The no-till treatment was seeded directly into the sod using a no-till drill (Great Plains, Salinas, KS) and the broadcast treatment was seeded using a spinning hand-held bag seeder onto the lightly tilled sod Case 475 disc harrow (Case IH, Racine Wisconsin) with pitched 46 cm disc pans. One light tillage pass was made prior to seeding and one after broadcasting seed to ensure seed to soil contact. Plots were fertilized with potassium (0-0-60) according to soil test at planting and were also limed according to soil test to raise pH to 6.0. Initial soil pH was 4.8 and was raised to 5.4 at the time of planting. Urea nitrogen fertilizer (46-0-0) was applied at 168 kg/ha split into three applications of 56 kg/ha 8 November 2024, 8 Febuary 2024, and 5 March 2024. Due to the lack of precipitation leading up to and after planting the decision was made to irrigate the study area for establishment purposes. The 0.10 hectare study area was irrigated with 26,498 liters a week split into two 13,249 liter applications per week. The plots were irrigated from 24 October 2024 through 8 November 2024 until the occurnace of adequate natural precipiation. After stand establishment, all treatment plots were harvested on 8 February 2024 (Harvest one), 21 March 2024 (Harvest two), and 17 April 2024 (Harvest three) for cool season herbage mass, botanical compostion, and nutritive value. After each harvest plots were cut to a 10 cm stubble height using a flail mower and biomass was removed. Following the final cool-season harvest the plots were left for regowth of bahiagrass sod. Plots were mowed every 30 days for hay production after final cool-season harvest. On 11 July 2024 plots were fertilized with 56 kg/ha of both urea nitrogen (46-0-0) and potassium (0-0-60) and 7 August 2024 all plots were harvested for evaluation of bahiagrass herbage mass and botanical composition. This harvest time was chosen later in the warm season to allow for adequate regrowth potential to be expressed of any herbicide damaged bahiagrass plots.

Response Variables and Laboratory Procedures

All samples harvested were analyzed for herbage mass, botanical composition, and nutritive value. To determine herbage mass (kg DM/ha) samples were collected at three random locations in each high and low herbicide treatment and within each control treatment using 0.1-m^2 quadrats. Herbage mass sample were then botanically separated into grass, legume, and weed components for the cool season harvests. Samples for the warm season harvest were separated into bahiagrass, bermudagrass, and weed components. Samples were transported to the Auburn University Ruminant Nutrition Laboratory in Auburn, AL and were dried at 55˚C for 72 h until a stable dry weight was achieved then weighed for dry matter (DM) determination. Botanical composition components were then composited and processed by grinding them through a 1 mm screen on a Wiley Mill (Thomas Scientific, Philadelphia, PA). These samples were then analyzed for concentrations of neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP) to determine forage nutritive value. The analyzation was performed utilizing near infrared reflectance spectroscopy (NIR) (FOSS™ NIRS™ DS3 F; Fisher Scientific, Hampton, NH). Nutritive value was determined using prediction equations provided by the National Forage Testing Association (NIRSC, 2016). To validate NIR values, 10% of samples were randomly selected to undergo wet chemistry analysis. Samples randomly selected for wet chemistry analysis were evaluated for DM, CP, NDF and ADF. Laboratory DM was determined according to AOAC (1995) at 108˚C for 12 h. Crude protein was determined utilizing the Kjeldahl procedure (AOAC, 1995) using a Kjeltech System (Foss™ Tecator Kjeltech™ 8100, Fisher Scientific, Hampton, NH) for N determination. Crude protein was calculated as N × 6.25. Neutral detergent fiber and ADF were evaluated via the Van Soest et al. (1991) method using ANKOM 2000® Fiber Analyzer (Ankom Technology Corporation, Fairport, NY).

Statistical Analysis

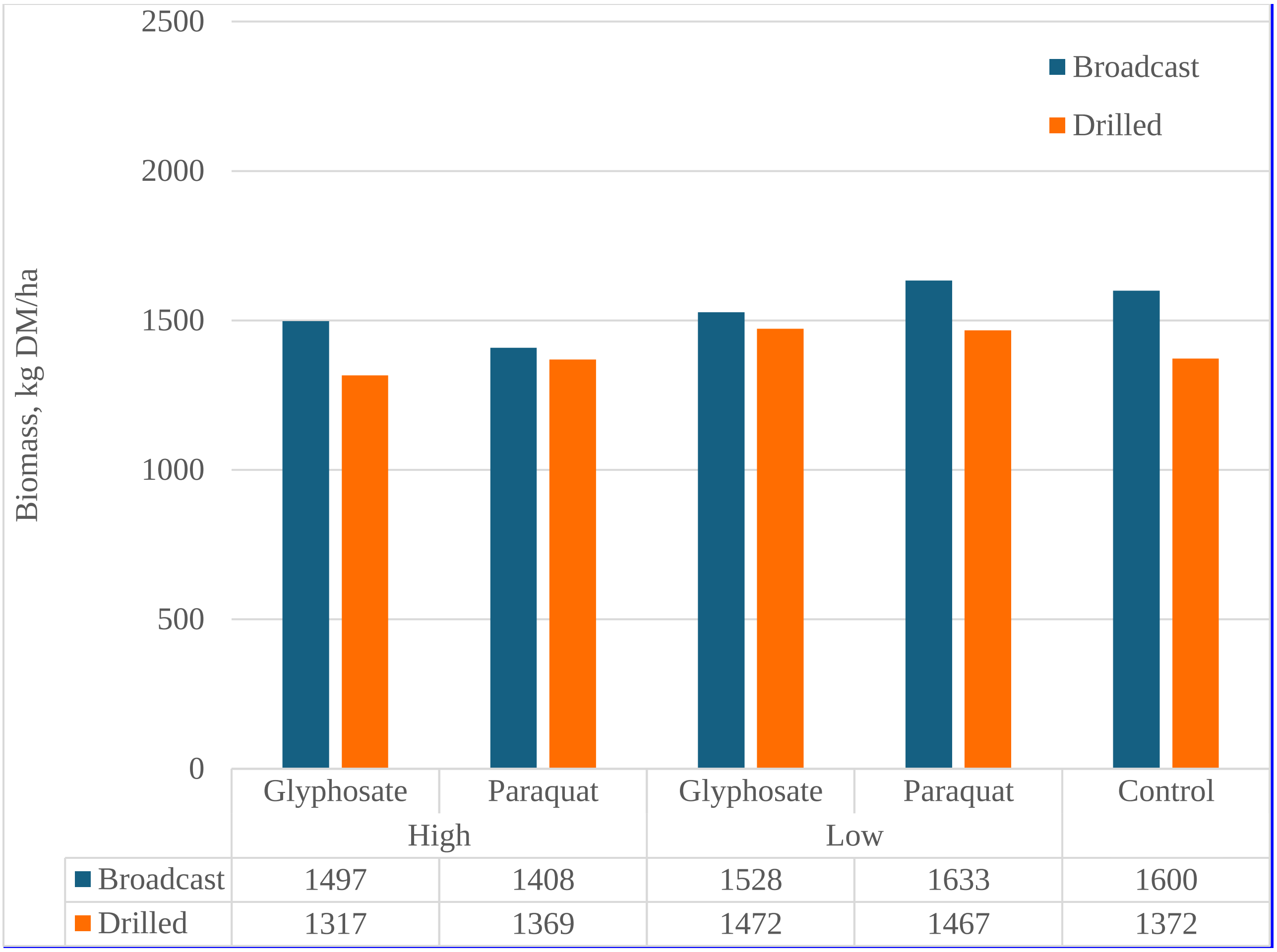
Data was analyzed using SAS v. 9.4 (SAS Institute, Cary, NC) for a 2 x 2 +1 factorial. Data were analyzed using the generalized linear mixed model procedure (PROC GLIMMIX). Herbicide treatment and harvest were considered fixed effects. For all response variables, mean separations were performed based on F-protected t tests using the LINES options in the

LSMEANS statement of PROC GLIMMIX and were adjusted for Tukey's test ($P < 0.05$). The repeated measures procedure was used for variables with measurements having consecutive cycles. Differences were considered significant at $P < 0.05$. Significant interactions, when $P < \alpha$, were discussed in addition to significant main effects.

Results

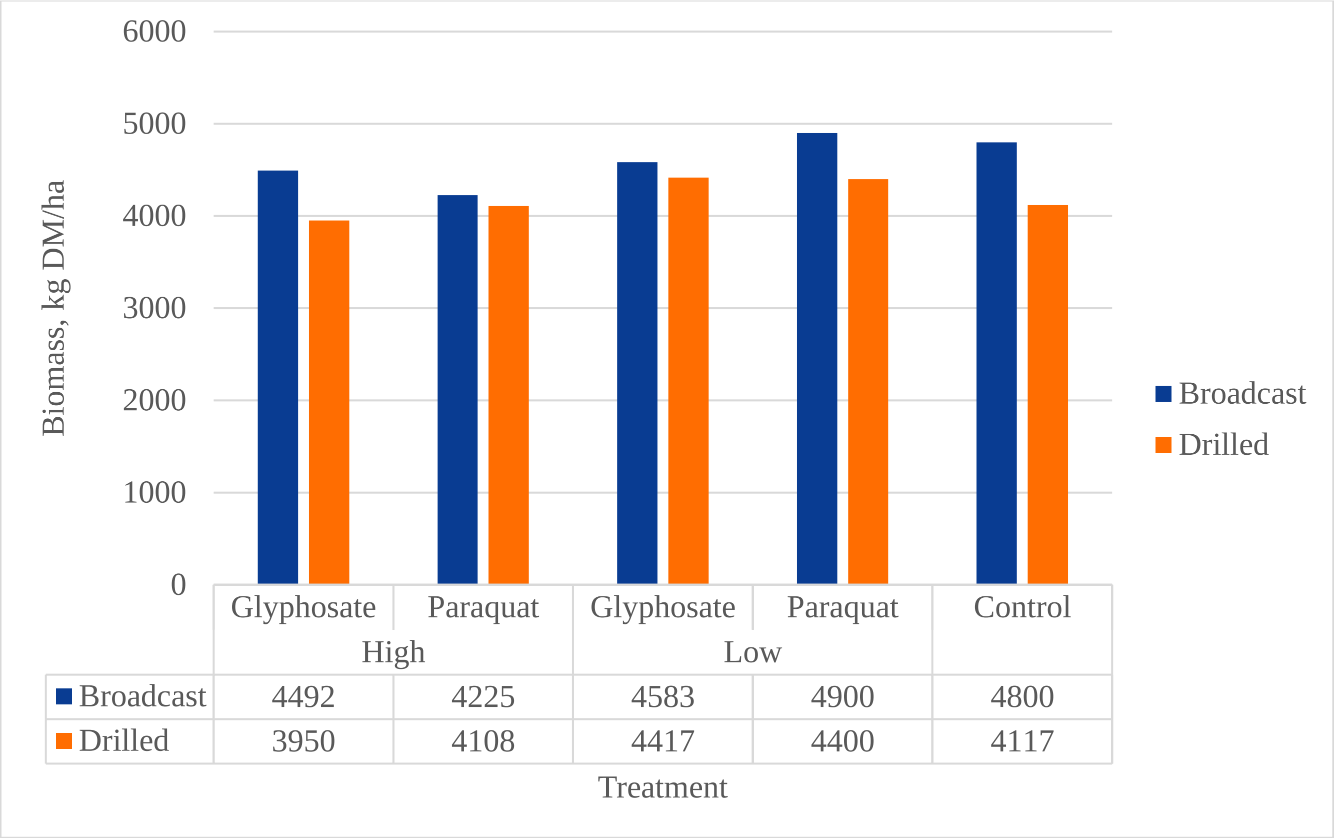
Forage Biomass

There was no effect of treatment ($P = 0.62$) for any of the cool season harvests when evaluating herbicide, or herbicide rate. However, there was an effect of treatment ($P < 0.0001$) in the warm-season harvest in which the glyphosate treatment suppressed bahiagrass production. In the broadcast planting method, bahiagrass yield significantly decreased in the 'low rate' glyphosate treatment (250 kg DM/ha) by 87% as compared to the control treatment (1,983 kg DM/ha). In the 'high rate' glyphosate treatment (8 kg DM/ha) of the broadcast planting method bahiagrass yield significantly decreased by 99.5% as compared to the control treatment (1,983 kg DM/ha). In the no-till drilled planting method bahiagrass yield decreased in the 'low rate' glyphosate treatment (2,242 kg DM/ha) by 30% as compared to the control treatment (3,225 kg DM/ha). In the 'high rate' glyphosate treatment (1,983 kg DM/ha) of the no-till drilled planting method bahiagrass yield decreased by 39% as compared to the control treatment (3,225 kg DM/ha). In addition, there was an effect of harvest ($P < 0.0001$) for the cool season harvests in which harvest two produced the greatest biomass (2,217 kg DM/ha) followed by harvest one (1,388 kg DM/ha) and harvest three (794 kg DM/ha).



	Glyphosate High	Paraquat High	Glyphosate Low	Paraquat Low	Control
■ Broadcast	1497	1408	1528	1633	1600
■ Drilled	1317	1369	1472	1467	1372

Figure 14. Mean cool-season annual biomass (kg DM/ha) by planting method and herbicide treatment (*P* = 0.62) at the Wiregrass Research and Extension Center in Headland, AL. Herbicide rate = glyphosate: 0.42 kg ae ha (low) / 0.84 kg ae ha (high); paraquat: 1.12 kg ai ha (low) / 2.24 kg ai ha (high).



	Glyphosate	Paraquat	Glyphosate	Paraquat	Control
	High		Low		
■ Broadcast	4492	4225	4583	4900	4800
■ Drilled	3950	4108	4417	4400	4117

Figure 15. Total seasonal forage biomass by herbicide treatment and planting method. (*P* = 0.62). in 2023-2024 at the Wiregrass Research and Extension Center in Headland, AL. Herbicide rate = glyphosate: 0.42 kg ae ha (low) / 0.84 kg ae ha (high); paraquat: 1.12 kg ai ha (low) / 2.24 kg ai ha (high). All treatment plots were harvested on 8 February 2024 (Harvest one), 21 March 2024 (Harvest two), and 17 April 2024 (Harvest three).

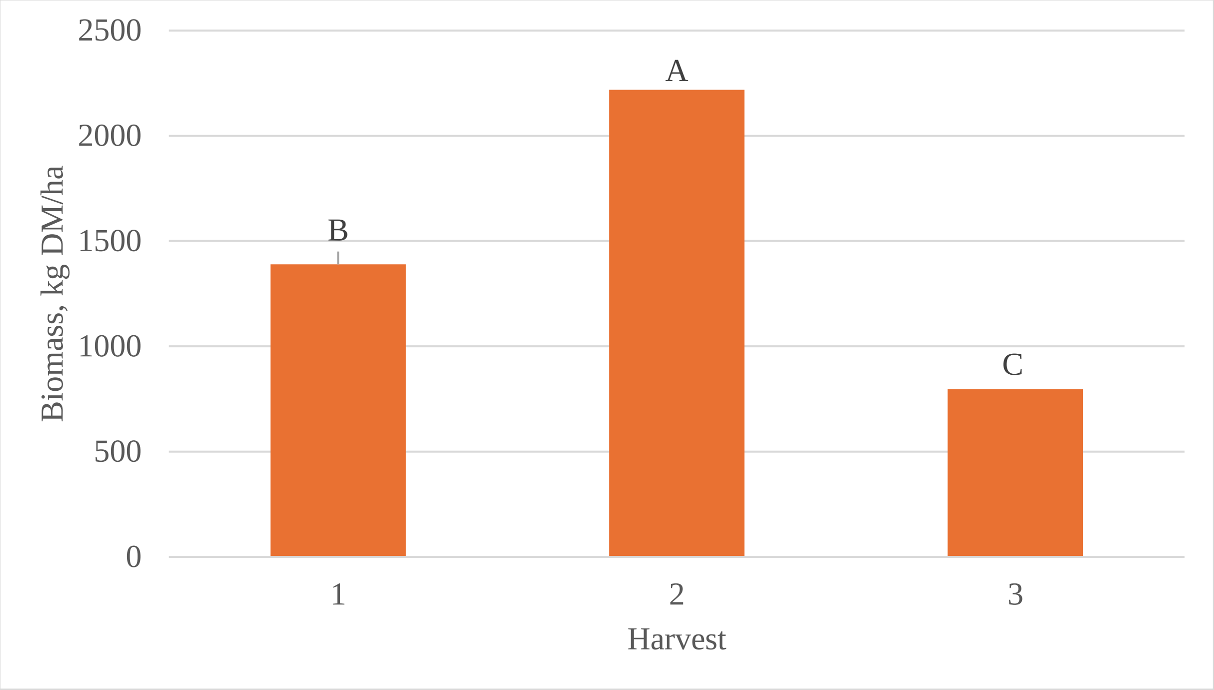
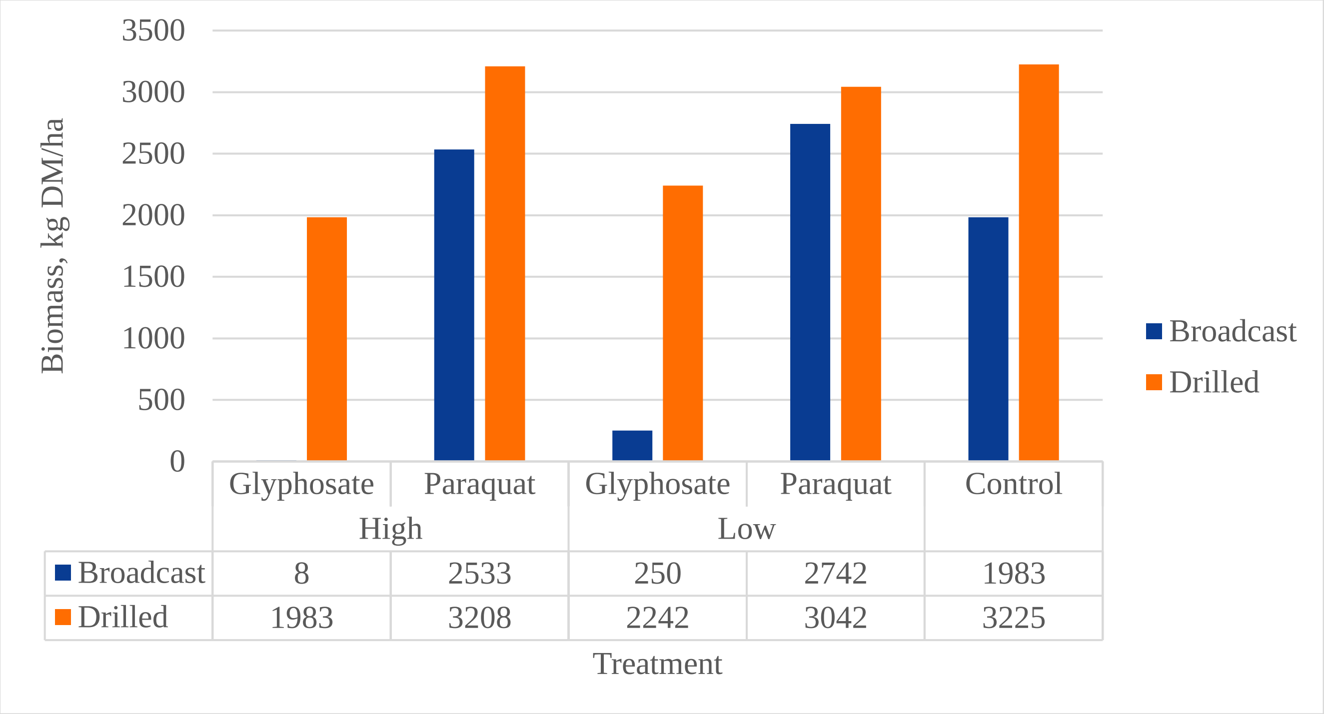


Figure 16. Mean cool season forage biomass (kg DM/ha) by harvest across herbicide type and rate in 2023-2024 at the Wiregrass Research and Extension Center in Headland, AL. ^{ABC}Means without a common letter are significantly different ($P < 0.0001$). All treatment plots were harvested on 8 February 2024 (Harvest 1), 21 March 2024 (Harvest 2), and 17 April 2024 (Harvest 3).



	Glyphosate	Paraquat	Glyphosate	Paraquat	Control
	High		Low		
🟦 Broadcast	8	2533	250	2742	1983
🟧 Drilled	1983	3208	2242	3042	3225

	Control	**Glyphosate High**	**Glyphosate Low**	**Paraquat High**	**Paraquat Low**
Mean	2604^{A}	996^{B}	1246^{B}	2871^{A}	2892^{A}
SE	86.1	86.1	86.1	86.1	86.1

Figure 17. Mean warm season bahiagrass forage biomass (kg DM/ha) within herbicide and planting method in 2023-2024 at the Wiregrass Research and Extension Center in Headland, AL. ^{ABC}Means without a common letter are significantly different ($P < 0.0001$). Standard Error (SE) based on the average herbicide treatment across planting methods. Herbicide rate = glyphosate: 0.42 kg ae ha (low) / 0.84 kg ae ha (high); paraquat: 1.12 kg ai ha (low) / 2.24 kg ai ha (high).

Botanical Composition

Cool-season annual botanical composition was not affected by herbicide treatment or planting method (*P* = 0.32). Ryegrass dominated the botanical composition of all plots regardless of herbicide treatment or harvest during the cool season. However, there was a harvest effect (*P* < 0.0001) in which harvest three had a greater composition of ryegrass than harvests one or two. In harvest one ryegrass averaged 87.3 % of the stand composition followed by triticale (6.7%), clover (4.5%), and weeds (1.5%). In harvest two ryegrass averaged 85.3% of stand composition followed by triticale (11.2%), clover (2.0%), and weeds (1.5%). In harvest three ryegrass made up 100% of stand composition.

Table 3. Cool season annual yield and botanical composition by harvest date, planting method and herbicide treatment. All treatment plots were harvested on 8 February 2024 (Harvest one), 21 March 2024 (Harvest two), and 17 April 2024 (Harvest three). Herbicide = herbicide treatment; Rate = glyphosate: 0.42 kg ae ha (low) / 0.84 kg ae ha (high); paraquat: 1.12 kg ai ha (low) / 2.24 kg ai ha (high)

Cool-Season Harvest One

Planting method	Herbicide	Rate	Biomass kg DM/ha	Triticale%	Ryegrass%	Clover%	Weed%
Drilled	Glyphosate	High	1383	3%	92%	2%	2%
Drilled	Glyphosate	Low	1675	6%	88%	2%	5%
Drilled	Paraquat	High	1283	5%	93%	1%	1%
Drilled	Paraquat	Low	1567	2%	93%	3%	2%
Drilled	Control		1283	4%	94%	1%	2%
Broadcast	Glyphosate	High	1250	9%	82%	7%	1%
Broadcast	Glyphosate	Low	1342	12%	80%	7%	0%
Broadcast	Paraquat	High	1075	12%	78%	11%	0%
Broadcast	Paraquat	Low	1492	8%	85%	6%	1%
Broadcast	Control		1533	6%	88%	5%	1%

Cool-Season Harvest Two

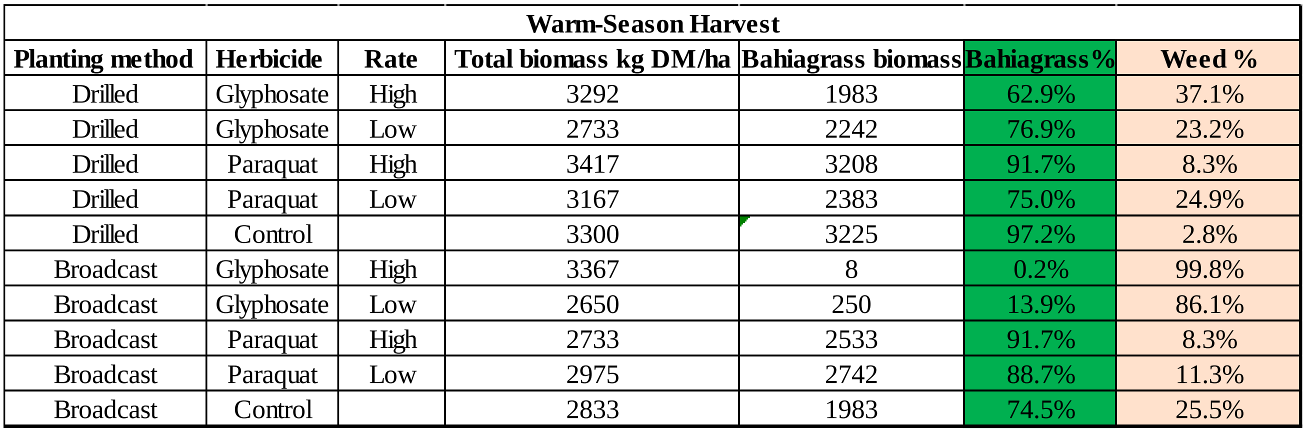
Planting method	Herbicide	Rate	Biomass kg DM/ha	Triticale%	Ryegrass%	Clover%	Weed%
Drilled	Glyphosate	High	1800	11%	89%	0%	0%
Drilled	Glyphosate	Low	1892	8%	87%	0%	5%
Drilled	Paraquat	High	1983	12%	85%	0%	4%
Drilled	Paraquat	Low	1983	11%	86%	2%	1%
Drilled	Control		1875	6%	90%	0%	5%
Broadcast	Glyphosate	High	2517	14%	83%	3%	0%
Broadcast	Glyphosate	Low	2525	16%	80%	4%	0%
Broadcast	Paraquat	High	2450	9%	87%	4%	0%
Broadcast	Paraquat	Low	2592	12%	85%	3%	0%
Broadcast	Control		2550	13%	82%	4%	1%

Cool-Season Harvest Three

Planting method	Herbicide	Rate	Biomass kg DM/ha	Triticale%	Ryegrass%	Clover%	Weed%
Drilled	Glyphosate	High	767	0%	100%	0%	0%
Drilled	Glyphosate	Low	850	0%	100%	0%	0%
Drilled	Paraquat	High	842	0%	100%	0%	0%
Drilled	Paraquat	Low	850	0%	100%	0%	0%
Drilled	Control		958	0%	100%	0%	0%
Broadcast	Glyphosate	High	725	0%	100%	0%	0%
Broadcast	Glyphosate	Low	717	0%	100%	0%	0%
Broadcast	Paraquat	High	700	0%	100%	0%	0%
Broadcast	Paraquat	Low	817	0%	100%	0%	0%
Broadcast	Control		717	0%	100%	0%	0%

In the warm season harvest, there was an effect of herbicide treatment ($P < 0.0001$) in which plots treated with either a high or low application rate of glyphosate experienced significantly increased weed pressure due to the suppression of bahiagrass. No-till drill planted plots treated with glyphosate averaged 30.1% weed composition followed by no-till plots treated with paraquat (16.6%) and control plots (2.8%). Broadcast planted plots treated with glyphosate averaged 92.5% weed composition followed by control plots (25.5%) and paraquat treated plots (9.8%). Notable weed species present in glyphosate treated plots were common bermudagrass (*Cynodon dactylon)*, crabgrass (*Digitaria ciliaris)*, and carpetweed (*Mollugo verticillata*).

Table 4. Warm season harvest (7 August 2024) forage biomass and botanical composition by planting method and herbicide treatment. Herbicide = herbicide treatment; Rate = glyphosate: 0.42 kg ae ha (low) / 0.84 kg ae ha (high); paraquat: 1.12 kg ai ha (low) / 2.24 kg ai ha (high)



Warm-Season Harvest						
Planting method	**Herbicide**	**Rate**	**Total biomass kg DM/ha**	**Bahiagrass biomass**	**Bahiagrass %**	**Weed %**
Drilled	Glyphosate	High	3292	1983	62.9%	37.1%
Drilled	Glyphosate	Low	2733	2242	76.9%	23.2%
Drilled	Paraquat	High	3417	3208	91.7%	8.3%
Drilled	Paraquat	Low	3167	2383	75.0%	24.9%
Drilled	Control		3300	3225	97.2%	2.8%
Broadcast	Glyphosate	High	3367	8	0.2%	99.8%
Broadcast	Glyphosate	Low	2650	250	13.9%	86.1%
Broadcast	Paraquat	High	2733	2533	91.7%	8.3%
Broadcast	Paraquat	Low	2975	2742	88.7%	11.3%
Broadcast	Control		2833	1983	74.5%	25.5%

Forage Nutritive Value

There was no effect of treatment on forage CP, NDF, or ADF for the cool season harvests (P = 0.07). However, there was an effect of harvest for all forage nutritive value parameters (P < 0.0001). Forage CP was significantly higher in harvest two (18.6%) than in harvest three (12.8%) and harvest one (12.6%). Forage NDF was significantly lower in harvest one (33.9%) than in harvest three (40.5%) and harvest two (41.9%). Forage ADF was significantly lower in harvest one (22.2%) followed by harvest two (22.7%) and harvest three (24.1%).

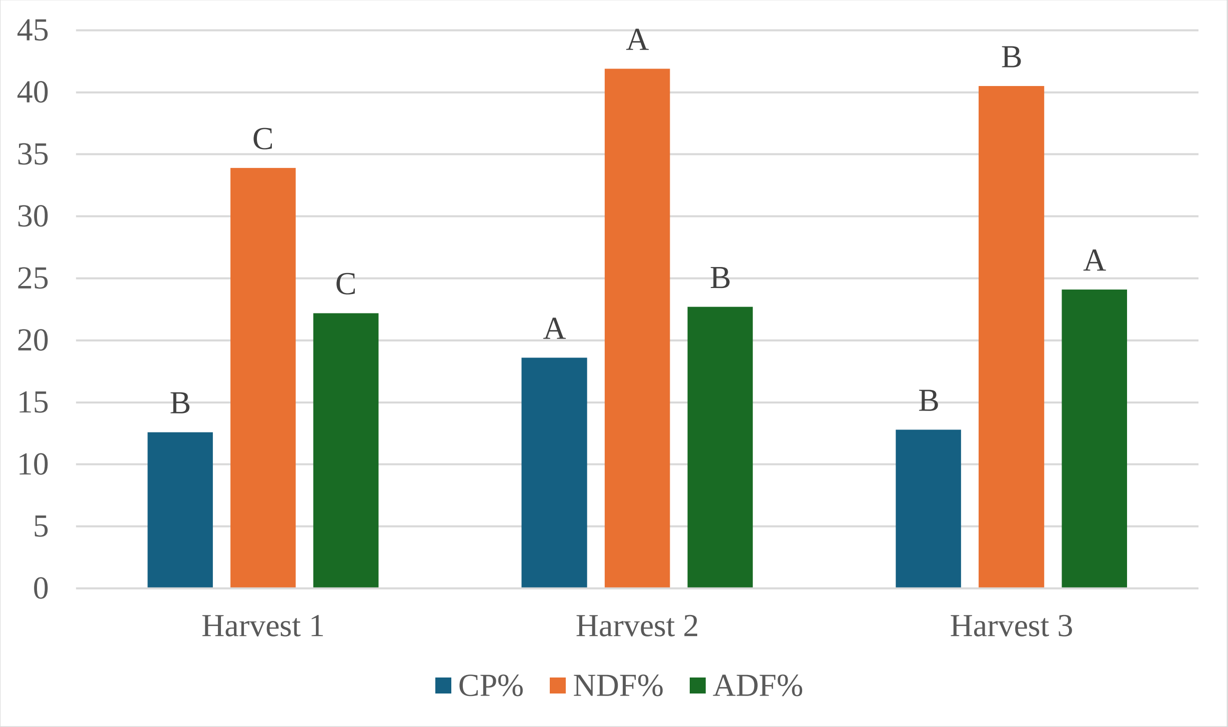


Figure 18. Mean cool season crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) percentage (%) by harvest in 2023-2024 at the Wiregrass Research and Extension Center in Headland, AL. ^{ABC}Means without a common letter are significantly different (P < 0.0001). All treatment plots were harvested on 8 February 2024 (Harvest 1), 21 March 2024 (Harvest 2), and 17 April 2024 (Harvest 3).

Discussion

Forage Biomass

Overall, all study plots produced approximately 1,500 kg DM/ha for the cool season with no effect of herbicide treatment or rate. A study in Arkansas evaluating cow-calf performance on winter annuals overseeded into bermudagrass reported greater forage mass values of 1,788 kg DM/ha during the winter and 2,116 kg DM/ha during the spring (Beck et al., 2016). However, a study conducted in Alabama by Hoveland et al. (1981) reported similar forage mass (1,488 kg DM/ha) of cool-season annuals overseeded on bahiagrass plots treated with glyphosate and paraquat to induce chemical dormancy. Glyphosate was applied at 0.28 kg ae ha, 0.56 kg ae ha, and 1.12 kg ae ha and paraquat was applied at 0.56 kg ha to the bahiagrass sod. Hoveland et al., (1981) reported a significant difference in cool season annual yield in which the glyphosate treated plots had greater biomass than paraquat and control treatments. In contrast, there was no effect of herbicide treatment or rate on cool season harvest for the first year of this study. The absence of a treatment effect in our study was possibly due to the long drought that occurred in the fall when the experiment was established. Cool season annuals were planted on 18 October 2023, but germination was delayed and stand establishment was not complete until mid-November even with irrigation. This delay in germination and establishment did not allow for accumulation of fall growth and suppressed any early yield effect of treatments. In addition, the lack of rainfall leading up to and during establishment also suppressed bahiagrass growth which may have impeded its competition with cool season forages in fall in control plots (personal observation). Both herbicide treatments resulted in suppression, with paraquat achieving desiccation in 48 hours and glyphosate in approximately 2 weeks. Herbicide treatment affected forage biomass in the warm season bahiagrass harvest in which glyphosate treatments (625 kg DM/ha) suppressed yield by an average of 1,669 kg DM/ha as compared to control treatments (2,294 kg DM/ha). Bahiagrass suppression in a study in Alabama by Hoveland et al. (1981) that reported glyphosate treated bahiagrass plots were suppressed by 1,100 to 1,700 kg DM/ha as compared to non-treated control treatments. Warm-season perennial suppression by fall applied glyphosate for overseeding ryegrass was also observed in a Texas study by Evers (2002). In this study glyphosate was applied at a rate of 0.56 kg ae to a dallisgrass sod and reported 15% or less stand recovery in the following warm seasons. These observations could be attributed to the systemic nature of the glyphosate mode of action in which the herbicide is translocated throughout the plant. Glyphosate inhibits 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), a key enzyme in the shikimate biosynthetic pathway. It is most active in meristematic tissue; thus, glyphosate has to translocate to the meristematic tissue to be effective (Shaner, 2006) Glyphosate translocates in the plant from a source to sink direction. Up to 70% of absorbed glyphosate can translocate out of the treated leaves to the root and shoot apices (Velini et al., 2009). Applying this type of mode of action in the fall when bahiagrass is preparing for dormancy could heighten the risk of plant death as the plant is transporting nutrients and carbohydrates stored in vegetative and reproductive parts to the roots and rhizomes (Adhikari et al., 2017). Paraquat, however, has limited systemic movement and rapid desiccation that results from diverting electrons from photosystem I (PSI) in the chloroplasts. Paraquat catalyzes the production of superoxide from water via photosynthetic electron transport. The resulting fast production of superoxide ions overwhelms the endogenous protective mechanisms and leads to a chain of further reactions which eventually results in reactive oxygen species rapidly devastating cell membranes and cause desiccation of plant tissues (Hawkes, 2014). This mode of action, because of its low affinity for translocation, appears to be a safer nonselective herbicide alternative to glyphosate.

Botanical Composition

The cool season stand composition was dominated by ryegrass with little triticale or clover production regardless of herbicide treatment or planting method. This could be in part to the allelopathic tendencies of ryegrass that resulted in suppression of other stand components (Amini et al., 2009). In addition, poor clover production may have been attributed to the low pH of the study area and the direct fertilization using a synthetic N source which both can negatively impact clover production (Ball et al., 2015). The warm season stand composition was affected by herbicide treatment ($P = 0.0001$). Plots treated with glyphosate had more weed and less bahiagrass composition as compared to the control and paraquat treated plots. This was mainly due to the suppression of bahiagrass in the glyphosate plots which created more bare soil allowing for increased emergence and growth of weeds.

Forage Nutritive Value

There was no herbicide treatment effect on cool-season annual forage nutritive value. However, all nutritive value parameters recorded were adequate to support brood cows in the first months of pregnancy (requirements: 7% CP and 48% TDN), those in mid-lactation (requirements: 9% CP and 54% TDN), and cows in peak lactation (60 to 80 days after calving; requirements: 12% CP and 60% TDN) (NRC, 2016). There was an effect of harvest in which harvest two had the greatest CP percentage followed by harvest one and then harvest three. The greater CP in harvest two is most likely attributed to the two N applications applied after harvest one and before harvest two totaling 112 kg/ha of N. Harvest one only received 56 kg/ha of N and harvest three did not have a direct application of N in order to slow cool season annual growth to reduce possible suppression of bahiagrass. An increase in CP was also reported in a study in Alabama by Mullenix et al. (2012) in which cool-season annuals mixtures of oats, cereal rye, and annual ryegrass received an application of N fertilizer in early March. There was also an effect of harvest for forage NDF and ADF in which harvest one had the highest digestibility. This is consistent with Mullenix et al. (2012) which reported increasing NDF and ADF values from the start to end of the study evaluating cool-season annuals mixtures of oats, cereal rye, and ryegrass. These finding were probably due in part to the maturity stage of the forages at the time of each harvest in which the forages were more physiologically mature with each subsequent harvest. As forage maturity increases, cell-wall concentration increases with the accumulation of cellulose, hemicellulose, and lignin which correlates to lower forage quality and digestibility (Moore et al., 2020).

Conclusion

To fully realize the benefit of cool-season annual production in overseeding systems, it is necessary to plant as early in the fall as possible. This will ensure greater production of cool-season annuals to reach as many grazing days as possible during the cool season (Myer et al., 2008). For this reason, herbicide treated sods in conjunction with earlier cool season stand establishment could affect cool season forage growth as compared to non-herbicide treated sods. The slow stand establishment observed in this study may have attributed to the lack of herbicide treatment effect. However, a ‘chemical dormancy’ was achieved for both herbicide treatments, but a lingering suppression into the warm season of bahiagrass in the glyphosate treatments may suggest that its specific mode of action would not be ideal to utilize when overseeding cool season annuals in bahiagrass sods. Continued research is needed to replicate this effect and pursue other herbicide mode of actions for inducing chemical dormancy in conjunction with earlier cool season stand establishment in overseeded bahiagrass.

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