Improving Forage Systems Viability for Beef Cow-Calf Pairs in the Southeast US

by

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Abstract

Improvement of grazing and nutritional management strategies in warm-season perennial forage systems in the Southeast US can lead to more efficient and sustainable cattle operations. Extending the grazing season, improving forage nutritive value, and reducing labor and feed costs during the winter months are two ways to achieve this goal. Alfalfa (*Medicago sativa* L.) can be interseeded into bermudagrass [[*Cynodon dactylon* (L.) Pers.].] to increase forage mass and quality and extend the grazing season. A 2-yr study was conducted in Shorter, AL to evaluate effects of harvest intensity and harvest frequency of alfalfa-bermudagrass mixtures on dry matter (DM) forage mass, nutritive value, canopy cover, botanical composition, and alfalfa persistence. Harvest height treatments included 5-, 10-, and 15-cm and harvest frequency treatments included 2-, 4-, and 6-wk intervals. Four blocks of 9 plots (1.5 × 4.5 m) were arranged in a randomized complete block design. In Yr 1, plots were harvested at assigned harvest intervals beginning Jun 11 and ending Sep 4, 2018, and in Yr 2 from Jun 4 to Oct 10, 2019. Seasonal forage mass was greatest at the 5-cm harvest height, intermediate at 10 cm, and least at 15 cm ($P < 0.0001$). Four and 6-wk harvest frequencies resulted in greater DM forage mass than 2 wk ($P = 0.0113$). Crude protein concentration was maximized at the 4-wk clipping interval ($P = 0.0003$). As harvest height increased, *in vitro* true dry matter digestibility (IVTDMD) increased ($P < 0.0001$). Alfalfa persistence was maximized at 5- and 10-cm clipping heights and 4- and 6-wk harvest intervals, which correlated with greater plant densities within those treatments. Results indicate that harvesting alfalfa-bermudagrass mixtures at a 10-cm height and 4-wk interval provided optimal forage mass and quality, while ensuring persistence of alfalfa. A forage mass estimation equation was developed using canopy height and stand variability measurements. However, a large amount of variation was observed in the dataset depending on alfalfa contribution levels, resulting in inaccurate forage mass predictions. In another 2-yr study, reduced-labor winter nutrition management systems were evaluated in Shorter, AL. Reduced-labor feeding systems may lower input costs during winter months in the Southeast US, when feed costs are typically high. Diet treatments included (i) rotational grazing of winter-annual mixture of oat (*Avena sativa* L.), ryegrass (*Lolium multiflorum* Lam.), and crimson clover (*Trifolium incarnatum* L.;RG); (ii) free-choice whole cottonseed + bermudagrass hay (FC); and (iii) 50:50 soyhull/corn gluten feed pellets fed every other day at 1% body weight (BW) + bermudagrass hay (RF). Objectives of this study were to evaluate the effects of diet on cow and calf performance under reduced-labor feeding systems. Three commercial cow-calf pairs were placed into 2-ha pens, with 3 pens per treatment, in a completely randomized design. Cattle on RG were rotated every 14 d. Greater percentages of CP and IVTDMD were observed in the RG system ($P < 0.0001$ and $P < 0.0001$, respectively) than other diets. Cow BW and average daily gain (ADG) were greater ($P < 0.0001$ and $P = 0.0014$) for RG than FC and RF, and calf ADG was not different among treatments ($P = 0.0706$). All systems provided viable reduced-labor options compared with daily feeding without negatively impacting animal performance.

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List of Abbreviations

ADF	Acid detergent fiber
ADG	Average daily gain
BCS	Body condition score
BW	Body weight
CP	Crude protein
CV	Coefficient of variation
DM	Dry matter
FC	Free choice
IVTDMD	*In vitro* true dry matter digestibility
K	Potassium
N	Nitrogen
NDF	Neutral detergent fiber
P	Phosphorus
RF	Reduced frequency
RG	Rotational grazing
RMSE	Root mean square error
SH:CGF	Soy hulls: corn gluten feed
T85	‘Tifton 85'
TDN	Total digestible nutrients
US	United States
WCS	Whole cottonseed

CHAPTER 1

INTRODUCTION

In the Southeast United States (US), warm-season perennial forages are commonly found on cattle operations as the base, primarily for cow-calf production (Hoveland, 2000). Due to the favorable climatic conditions in the Southeast US, forages have the potential to be grazed nearly year-round (Hancock et al., 2018). However, warm-season perennials are often of lesser nutritive value than other forage species and do not provide grazing during winter months. Efforts to improve forage quality and extend the grazing season have been the focus of many research trials to enhance forage system viability in the Southeast US (Hill et al., 1985; Hoveland et al., 1978; Mullenix and Rouquette, 2018; Rao et al., 2007; Rouquette, 2017).

Bermudagrass [*Cynodon dactylon* (L.) Pers.], a warm-season perennial grass, comprises much of the forage base in the Southeast US, especially the Coastal Plain region. It is a high-yielding forage that requires great amounts of nitrogen (N) fertilization as well as potassium (K) (Hancock et al., 2018). Bermudagrass provides moderate forage quality, but may not meet the needs of grazing cattle with greater nutritional needs, such as lactating cows (Ball et al., 2015). Recently, there has been interest in incorporating alfalfa (*Medicago sativa* L.), a cool-season perennial legume, into bermudagrass pastures and hay fields in the Southeast US. This is a result of breeding efforts that have improved persistence of the legume under southeastern US climate conditions and grazing systems (Smith and Bouton, 1993). Benefits of this practice include reduced N fertilizer inputs, improved forage quality, and greater seasonal growth distribution (Ball et al., 2015; Evers, 2011).

Defoliation management practices have a direct influence on forage mass, quality, and persistence in forage systems (Ball et al., 2015; Sanderson et al., 1997). Identifying appropriate harvest and grazing strategies, including both intensity and frequency parameters, to are important for the success and longevity of mixed grass-legume forage systems (Beuselinck et al., 1994). Many studies have evaluated forage mass, quality, and persistence responses of alfalfa and bermudagrass to varying defoliation management strategies (Beck et al., 2017a; Bouton and Gates, 2003; Corriher et al., 2007; Teixeira et al., 2007b). Stand persistence is vital for the producer to reap long-term benefits of establishing alfalfa into a warm-season perennial sod (Brown and Byrd, 1990; Heichel and Henjum, 1991; Stringer et al., 1994). Research by Beck et al. (2017) evaluated performance of alfalfa-bermudagrass mixtures under continuous and rotational stocking strategies. However, limited research has been conducted on new varieties of alfalfa or alfalfa-bermudagrass mixtures under a range of both harvest heights and rest intervals. To develop target grazing recommendations, a range of harvest regimes must be evaluated.

Additionally, to encourage further adoption of the practice of incorporating alfalfa into bermudagrass pastures, producers should have access to tools that easily estimate forage dry matter (DM) forage mass. Work has been done to estimate forage mass based on canopy height (Pasto et al., 1957; Sanderson et al., 2001). However, to estimate forage mass of mixed stands more accurately, measurements of stand variability should be incorporated into prediction equations (Alexander et al., 1962; Baxter et al., 2017). Limited data exist for estimating forage mass in mixed alfalfa-bermudagrass systems.

Although incorporating alfalfa into bermudagrass can extend the grazing season, there is still a portion of the year during which cattle producers may need to feed hay or supplement to cows. Identifying practices to reduce feed and labor input costs can lead to more profitable beef operations (Beaty et al., 1994a; Mullenix and Rouquette, 2018; Prevatt et al., 2018). Grazing winter-annual forages or feeding supplements at reduced frequencies are practices that may offset winter feed costs. Many studies have evaluated overseeding cool-season annual grasses and legumes into warm-season perennials (Gunter et al., 2012; Mckee et al., 2017; Mullenix and Rouquette, 2018). In terms of reduced-labor feeding, several studies have evaluated reduced-frequency feeding of fiber-based energy supplements or free-choice feeding of whole cottonseed (WCS); (DiLorenzo, 2012; Drewnoski et al., 2011; Hill et al., 2009).

Incorporating alfalfa into bermudagrass has been shown to improve forage quality and seasonal growth distribution, but optimal grazing management strategies have not been solidified. The objective of this research was to evaluate the effects of harvest height and frequency on forage mass, quality, and persistence of alfalfa-bermudagrass systems to develop target grazing recommendations for the mixture in the Southeast US. Additionally, identifying reduced-labor nutritional management strategies for the winter months may contribute to reduced input costs for cow-calf operations. Overall, the research projects presented herein will help contribute to improved viability of warm-season perennial forage-based cow-calf systems in the Southeast US.

CHAPTER 2

LITERATURE REVIEW

Warm-Season Forage Systems

Forages Adapted to the Southeast US

The United States (US) comprises multiple ecoregions based on climate conditions and soil types (Ball et al., 2015). These conditions influence the types of forages which are found in each respective region. In the southeastern region, mild climate and plentiful rainfall allow forages to be grown nearly year-round (Hancock et al., 2018). Forage systems are vital to cattle production systems, both beef and dairy, in the Southeast US and are typically based on perennial forages. Perennial forages regrow each year without being re-established, making them a desirable forage option for forage-livestock producers as the basis of the forage system in the region. The perennial forage base may be complemented by incorporating annual forages during times of the year when perennial forage production is low. Common warm-season perennial forages found in the Southeast US are bermudagrass and bahiagrass (*Paspalum notatum* Flügge), whereas the common cool-season perennial is tall fescue (*Lolium arundinaceum* [Schreb.] Darbysh.).

Perennial forages make up a large percentage of pastures in the Southeast US, comprising about 24 million hectares of pastureland in the region (Ball et al., 2015). Warm-season perennial forages tend to produce greater forage mass than their cool-season forage counterparts; however, they are generally lower in quality (Hancock et al., 2018). While warm-season perennial forages may provide an abundance of forage during the summer, their production and quality decline into the fall. Many beef cattle operations in the Southeast US are cow-calf operations and meeting nutrient requirements of cows can be challenging when forage nutritive value is low.

Nutrient requirements for beef cows range from 500 to 600 g kg^{-1} total digestible nutrients (TDN) and 7 to 12% crude protein (CP) for dry and lactating cows, respectively (Ball et al., 2015; NRC, 2016). Providing adequate nutrition to grazing cattle during the warm-season months supports maintenance requirements and desirable body condition throughout various stages of production. Identifying practices to improve quality and extend the grazing season length of warm-season perennials could be beneficial for producers to meet the needs of grazing livestock throughout much of the calendar year.

Bermudagrass

Bermudagrass likely originated in tropical Africa, but other proposed locations of origin include Australia, Eurasia, the Indo-Malaysian area, and the Bengal region of India/Bangladesh (Mitich, 1989). Reportedly, bermudagrass was first imported into Savannah, GA in 1751 by Governor Henry Ellis and its wide spread throughout the Southeast US was noted by James Mease in 1807 in his Geological Account of the United States (Mitich, 1989). It was originally treated as a weed, but significant advances to improve quality and forage mass were made by researcher and plant breeders in Georgia. Dr. Glenn Burton developed several hybrid bermudagrasses, including ‘Coastal,’ ‘Tifton 44,’ and ‘Tifton 85’ (T85), at the Georgia Coastal Plain Experiment Station in Tifton, GA from 1936 to 1997, and these releases continue to be recommended and planted throughout the southeastern US today (Hancock et al., 2018). Since this time, additional research from land-grant institutions and the USDA Agricultural Research Service, primarily in the Southeast US, have continued forage breeding efforts to identify new hybrid cultivars that are adapted to growing conditions in the region. Several seeded bermudagrass varieties have also been released and marketed through industry partners, although seeded types often exhibit lower forage mass characteristics than hybrid ecotypes. Over 8.1 million hectares of bermudagrass can be found in the Southeast US (Redfearn and Nelson, 2003).

‘Tifton 85’ bermudagrass, the latest hybrid bermudagrass released from the USDA program in Tifton, has exceptional forage mass characteristics and supports s high quality grazing and hay production. It is a highly digestible cross of ‘Tifton 68’ and stargrass (*Cynodon nlemfuensis* Vanderyst), an introduced species from South Africa known for its vigorous spread by aboveground stolons. ‘Tifton 85’ has larger stems and broader leaves than other bermudagrass cultivars, and its large rhizomes and stolons encourage rapid spread of above-and belowground plant growth. Hay forage mass and digestibility characteristics are considerably better than ‘Coastal,’ ‘Tifton 44,’ and ‘Tifton 78’ hybrid bermudagrass when harvested at the same stage of plant maturity. Best adapted to the Coastal Plain region, T85 is not as cold tolerant as ‘Coastal’ and, although it might survive most winters in the Piedmont region of Georgia, a severe winter would severely damage stands (Hancock et al., 2017). The Coastal Plain stretches across several states in the southern US. In Alabama, the area along and south of Interstate-20 corresponds with the Coastal Plain region of the state, where warm-season perennial forages are the predominant forage base.

Bermudagrass is high-yielding and forms a sod due to its extensive network of rhizomes and stolons. It has a deep root system and thrives best on well-drained fertile soils where ample moisture is available (Hancock et al., 2018). It is productive from spring through fall and is suitable for both hay production and grazing. Bermudagrass produces forage mass of 4.5 to 6.4 metric tons of hay per year and is average in nutritive value [(100 – 140 g kg^{-1} CP; 330 – 380 g kg^{-1} acid detergent fiber (ADF) ; 630 – 680 g kg^{-1} neutral detergent fiber (NDF); 520 – 580 g kg^{-1} total digestible nutrients (TDN)] and persistence (Ball et al., 2015). In the Coastal Plain region, bermudagrass generally grows from April through October, with peak growth occurring in the middle of the summer.

Forage mass in bermudagrass systems is greatly influenced by nitrogen (N) fertilization, and replenishing N that is removed during grazing or harvest is important for continued forage productivity. Bermudagrass is highly responsive to N fertilization. In a study by Burton et al. (1963), increasing N fertilizer rates up to 1,008 kg ha^{-1} increased dry matter (DM) production from ‘Coastal’ bermudagrass up to 15.82 Mg ha^{-1}. Literature indicates that bermudagrass forage mass generally increases linearly with N fertilization up to 448 kg N ha^{-1} (Stringer et al., 1994). Brink et al. (2004) reported T85 forage mass between 12,000 and 31,600 kg ha^{-1} when fertilized with N rates of 325 and 616 kg ha^{-1}. However, economically sustainable rates of N fertilization may vary in production systems because of the fluctuating costs of commercial fertilizer inputs. Personal communication with Alabama Extension Regional Agents indicates that in many cases less than 224 kg N ha^{-1} is applied annually to bermudagrass hay systems in Alabama, which may be in part related to N fertility input costs.

Potassium (K) is second only to N in concentration found in bermudagrass, and it is essential for high forage mass, stand maintenance, and persistence (Hancock et al., 2017). Burton et al. (1969) evaluated the effect of fertility (N, P, and K) levels and clipping frequency on forage productivity of ‘Coastal’ bermudagrass in Tifton, GA. The study found that omitting P and K from fertilizer that supplied 672 kg N ha^{-1} to ‘Coastal’ bermudagrass in soil with low-available K reduced forage mass by 45%. Literature reports increased shoot, root, and rhizome growth of bermudagrass in response to K fertilization (Belesky and Wilkinson, 1983; Cripps et al., 1989; Keisling et al., 1979). Trenholm et al. (1998) reported varied bermudagrass growth responses to

K fertilization depending on cultivar and photoperiod. However, the authors indicated that ample K fertility may promote successful overwintering and spring regrowth.

Bermudagrass has moderate forage quality compared with other warm-season forages. Nitrogen fertilization of bermudagrass stands may also improve its nutritive value by increasing CP concentrations and digestibility. A positive linear relationship between N fertilization and CP concentration was cited by Johnson et al. (2001) and Rao et al. (2007). Burton et al. (1963) found that increasing N fertilizer rates up to 1,008 kg ha^{-1} increased the CP concentration to 18 g CP kg^{-1}. However, inconsistent response of CP concentration to increased N fertilization were observed by Beck et al. (2017a) Small improvements in bermudagrass digestibility were observed by Johnson et al. (2001) following increasing rates of N fertilization. Rao et al. (2007) and Beck et al. (2017) reported a linear increase in total digestible nutrients (TDN) as N fertilization increased. Burton et al. (1969) evaluated effects of varying N-P-K ratios on ‘Coastal’ bermudagrass protein concentration and found that inadequate K, when very deficient, may reduce protein concentration by 3 to 10 percentage units. However, the authors also noted that applying P and K levels above rates needed for optimal dry matter production did not provide additional benefit for protein content.

Through proper management, bermudagrass can provide a large amount of high-quality forage for livestock. Fertility inputs and defoliation management are crucial to support bermudagrass stand persistence. However, due to its seasonal growth distribution of May to October, bermudagrass may need to be supplemented by incorporating secondary species to extend the grazing season and meet nutritional needs during the months when stored forages are fed to livestock.

Bahiagrass

Bahiagrass is a warm-season perennial grass that is adapted to the southern-most, subtropical regions of the US. It is adapted to sandy soils and tolerates low pH and low soil fertility. Bahiagrass has low to moderate forage nutritive value (500 – 560 g kg^{-1} TDN, 90 – 110 g kg^{-1} CP), depending on management, and has a forage mass potential of 6,700 to 11,000 kg DM ha^{-1} (Ball et al., 2015). Bahiagrass has a shallow, horizontal rhizomatous root system and a distinctive aboveground inflorescence with two racemes. Indigenous to South America, it thrives on light-textured soils and composes lawns, sports turf, and pastureland (Gates et al., 2016).

After being introduced in Florida in the early 1900s, it was cultivated throughout the state, the Coastal Plain, and the Gulf Coast regions of the southern USA and became naturalized in the region (Gates et al., 2016). Bahiagrass is productive from April through October (Ball et al., 2015). In a study by Stewart et al. (2007), herbage accumulation rates were 30, 62, and 15 kg DM ha^{-1} d^{-1} in May, July, and October, respectively, in continuously stocked ‘Pensacola’ bahiagrass pastures that received 120 kg N ha^{-1} per year. Its growing season becomes shorter moving from the Coastal Plain toward the Piedmont and to the north (Gates et al., 2016).

Several cultivars of bahiagrass have been released throughout the years; however, many studies have only evaluated their performance under N fertilization. Some evidence indicates that bahiagrass may associate with bacteria in the soil that can fix atmospheric N. A study by Santos et al. (2019) evaluated six bahiagrass cultivars (‘Argentine’, ‘AU Sand Mountain’, ‘Pensacola’, ‘TifQuik’, ‘Tifton-9’, and ‘UF-Riata’) under no N fertilization to determine performance and potential N fixation. Results from the trial showed total herbage accumulation, total N aboveground, and biological N fixation were not different among cultivars (2,835 kg DM ha^{-1}, 28 kg N ha^{-1} yr^{-1}, and 9 kg N ha^{-1} yr^{-1}, respectively). ‘AU Sand Mountain’ had greater *in vitro* digestible organic matter than other cultivars (494 g kg^{-1}). ‘Pensacola’ had a greater CP concentration than ‘Tifton-9’ (84 vs. 78 g kg $^{-1}$, respectively). Incorporating a forage species with a complementary growth pattern and high nutritive value may be beneficial in improving forage quality in the pasture system, resulting in optimal animal performance.

Applications for Beef Cow-Calf Systems

Forage and Grazing Management Applications

Many cow-calf operations in the Southeast US rely on warm-season perennials as the base of their forage program. Forage mass may be managed with appropriate stocking rates, but nutritive value in warm-season perennial forages may be lacking for animals with greater nutrient requirements, such as lactating cows or growing calves. Animal performance relies on both forage availability and nutritive value (Ball et al., 2001). Hill et al. (1993) conducted a grazing study comparing forage quality and steer performance on T85 and ‘Tifton 78’ pastures. In the 3-year grazing study, groups of four tester steers [initial body weight (BW) 269 kg] were assigned to graze 0.81-ha pastures of one of the bermudagrass cultivars and put-and-take management was used to manage forage mass to a target 2,800 kg DM ha^{-1}. Steer average daily gain (ADG) was not different among ‘Tifton 78’ and T85 treatments (0.65 and 0.67 kg, respectively), however, T85 supported more steer-grazing-days. Consequently, BW gain was greater for steers on T85 than ‘Tifton 78’ (1,156 and 789 kg ha^{-1}, respectively).

A study by Corriher et al. (2007) in Tifton, Georgia evaluated cow-calf performance on ‘Coastal’ and T85 bermudagrass pastures. The trial was 2 × 2 factorial of bermudagrass cultivar with or with access to creep-grazing pastures. Twelve cow-calf pairs were placed on 4.86-ha paddocks (n = 8) in early June, and put-and-take management was used to manage forage mass to a target 2,800 kg DM. Cows and calves on T85 pastures had greater average daily gain (0.14 kg and 0.94 kg, for cows and calves respectively) than those on ‘Coastal’ bermudagrass (0.04 kg and 0.79 kg, respectively). The same effect was observed for gain per ha, with cows gaining 57.1 kg ha^{-1} and calves gaining 261.9 kg ha^{-1} on T85 pastures, whereas cows and calves on ‘Coastal’ pastures gained 14.5 kg ha^{-1} and 202.6 kg ha^{-1}, respectively.

Forage growth and persistence in perennial grass systems are influenced by defoliation management practices. Defoliation stress encountered by a forage plant depends on intensity of defoliation and frequency of defoliation, whether in discrete well-spaced events or continuous removal (Sanderson et al., 1997). Defoliating aboveground forage growth at appropriate frequency or intervals during the growing season may decrease the potential for weed encroachment while optimizing forage mass and nutritive value (Ball et al., 2015). Ethredge et al. (1973) reported that bermudagrass harvested at a 3-week interval yielded 6,934 kg ha^{-1} and yielded 8,241 kg ha^{-1} at a 5-week harvest interval. Burton et al. (1963) also reported increased forage mass with longer harvest intervals, from 15,911 kg DM ha^{-1} harvested at 3 weeks to 22,089 kg DM ha^{-1} harvested at 6 weeks. These results are supported by Mandebvu et al. (1999) where T85 harvested after a 5-week rest period had increased DM forage mass compared with other rest periods.

Stubble height also has an impact on bermudagrass forage mass. Ethredge et al. (1973) reported major impact of clipping height on forage mass, where a change in clipping height from 14 cm to 0 cm increased average forage mass by 47.7%, and the forage mass increase from 7 cm to 0 cm was 24%. Liu et al. (2011) found that increasing stubble height to 24 cm decreased forage mass, but an 8-cm stubble height increased forage mass. The authors reported greater residual leaf area remaining post-harvest for the taller clipping heights. Additionally, Prine and

Burton (1956) reported increases in ‘Coastal’ bermudagrass forage mass with each 1-week delay in harvest from 1 to 6 weeks. A 5-year study by Holt and Lancaster (1968) evaluated effects of clipping practices on forage mass of ‘Coastal’ bermudagrass stands. The results revealed that greater DM forage mass were associated with clipping at a 5-cm stubble height than a 13-cm stubble height.

Forage quality and nutritive value are also influenced by defoliation management. In the studies cited in the defoliation frequency and height narrative above, selected papers reported the impacts of these practices on forage nutritive value. In an evaluation of clipping height and frequency on forage mass and energy content of ‘Coastal’ bermudagrass, Ethredge et al. (1973) clipped plots at 3, 5, and 7 wk and 0, 7, and 14 cm. The authors reported that forage net energy increased as harvest interval and clipping height were reduced. Burton et al. (1963) and Prine and Burton (1956) reported that increased cutting intervals caused a decline in CP concentrations. Liu et al. (2011) reported decreased CP concentrations in T85 that was harvested when longer periods of regrowth were allowed between cuttings. Hoveland et al. (1986) cited a decrease in CP concentration (160 g kg^{-1} DM to 70 g kg^{-1} DM) and digestibility (580 g kg^{-1} DM to 510 g kg^{-1}) when forage was harvested at the flower or boot stage compared with the vegetative stage, which reflects increasing forage maturity with longer periods of time between harvest events. Timing harvests to keep forages growing in the vegetative state optimizes forage quality, whereas mature forages become lignified and decline in nutritive value (Ball et al., 2015). Intensity of defoliation may interact with frequency to influence forage persistence and nutritive value, such that intense and frequent defoliation may decrease overall persistence, whereas intense defoliation with longer rest periods may result in high-quality forage without negatively impacting persistence over time.

Extending the grazing season

Due to warm-season perennials growing primarily in the warmer months of the year, the need for forage availability arises into the fall and winter. Extending the grazing season reduces production costs associated with winter feeding (Lalman et al., 2000). Traditional options for extending the grazing season in warm climate systems include stockpiling warm-season perennial forages and overseeding dormant warm-season sods with cool-season annuals. Stockpiling is a practice used to conserve forage for a later period when forage availability is reduced (Allen et al., 2011); typically, N is applied near the end of the summer months and forage is allowed to accumulate until it is needed for grazing. The viability of stockpiling bermudagrass is influenced by many factors including variety, climate conditions, duration of stockpiling, and N fertility inputs; however, this practice has the potential to reduce winter feed costs depending on hay cost, fall forage production, and harvest efficiency within a given year (Lalman et al., 2000).

Holland et al. (2018) conducted a study evaluating the effect of N fertilization on stockpiled T85 for cow-calf production. In the 2-yr study, pastures were clipped to a 10-cm stubble height on Aug 1 and individual 0.76-ha paddocks (n = 2 per treatment) received 56, 112, or 168 kg N ha^{-1} in the form of ammonium nitrate (NH_4NO_3) in mid- to late Aug. Forage was allowed to accumulate for approximately 8 wk. Paddocks were strip-grazed using temporary fencing. Although cow BW and body condition score (BCS) declined, N treatment did not influence overall pregnancy rate (88%). The authors concluded that fertilized stockpiled T85 was sufficient in productivity and nutritive value to support lactating beef cows without supplementation. Wheeler et al. (2002) reported the same decline in cow BW while grazing stockpiled bermudagrass with no supplementation and concluded that limited protein supplementation may improve cow performance and forage utilization in stockpiled warm-season forage systems during the winter months.

Overseeding and sodseeding are terms often used interchangeably to describe the practice of establishing annual forage crops into perennial, grass-dominant pasture fields without destroying the existing sod (Ball et al., 2015). Seed can be broadcast with or without disking or other tillage or planted into sod with a drill-type planter. Warm-season perennial pasture may be productive for six to eight months per year, whereas an area overseeded with cool-season annuals, such as annual ryegrass (*Lolium multiflorum* Lam.) and small grains, may provide eight to ten months of forage production per year (Ball et al., 2015). Cool-season annuals lengthen the production season and provide the highest nutritive value of any forage class (Rouquette, 2017). Mullenix and Rouquette (2018) discussed the importance of selecting small grains, alone or in a mixture, to match seasonal and total DM potential to ensure an adequate distribution of forage growth during the cool-season months, and potential positive impacts of overseeding in supporting nutritional requirements for various classes and types of livestock.

In a 3-yr study by Hoveland et al. (1978), cow-calf pairs were allowed to graze one of four 'Coastal' bermudagrass treatments: (a) not overseeded + 112 kg N ha^{-1}, (b) overseeded annual ryegrass+ 168 kg N ha^{-1}, (c) overseeded rye (*Secale cereale* L.), arrowleaf clover (*Trifolium vesiculosum* Savi), and crimson clover (*Trifolium incarnatum* L.) + 112 kg N ha^{-1}, or (d) overseeded arrowleaf and crimson clover with no N fertilizer. The study found that overseeding sod with rye and clover resulted in nearly doubled calf gain ha^{-1} and extended the grazing season 3 months longer than that of 'Coastal' bermudagrass alone. Authors also observed increased cow gain ha^{-1} and ADG by overseeding with clover.

Hill et al. (1985) evaluated four cow-herd feeding systems: ‘Coastal’ bermudagrass with and without sodseeded annual ryegrass, and ‘Pensacola’ bahiagrass with and without sodseeded annual ryegrass. The study found that sodseeding with annual ryegrass improved calf gains on each perennial grass during the spring. The authors evaluated cost of the systems and noted that increased input costs of sodseeding were recovered due to greater animal performance and increased grazing-days. Hoveland (1960) reported extended grazing season, increased forage mass, and improved animal performance as advantages of growing a winter legume on ‘Coastal’ bermudagrass. Utley et al. (1976) concluded that overseeding winter annuals into perennial sods required less land preparation and resulted in an uninterrupted grazing season from Jan through Oct.

Challenges Associated with Warm-Season Perennial Grass Systems

Although warm-season perennials provide support a large majority of forage needs for cattle operations in parts of the Southeast US, they are not without management challenges. Fertility costs for bermudagrass are relatively high compared with bahiagrass and other forages adapted to the region (Ball et al., 2015). Lack of maintenance fertilization may lead to stand decline, and decreased persistence of perennial-based systems in the region. Producer management of stands tends to favor more intensive defoliation management strategies that can open the plant canopy and encourage encroachment from undesirable weed species into the stand. Pest pressure from disease and insects can also be especially problematic in warm-season perennial systems. Mislevy and Dunavin (1993) outlined common insect and diseases: bermudagrass stem maggot (*Atherigona reversura),* fall armyworms (*Spodoptera frugiperda),* chinch bugs (*Blissus leucopterus),* grubworms (*Cyclocephala spp.*), mole crickets (*Gryllotalpa* *orientalis*), and billbugs (*Sphenophorus spp.)*, as well as diseases such as dollar spot (*Clarireedia spp.*), rust (*Puccina cynodonis*), and blight (*Rhizoctonia solani*). Proper defoliation management and mitigation of pests support greater forage productivity potential in these systems.

Legumes in Warm-Season Perennial Systems

Benefits and Challenges

Incorporating legumes into warm-season perennial systems could increase forage quality and forage mass during the summer months. Reported literature has highlighted that warm-season perennials, specifically bermudagrass, respond well to N fertility (Beck et al., 2017b; Johnson et al., 2001; Osborne et al., 1999). However because N fertilizer can be cost-prohibitive, producers may choose to incorporate legumes into pasture-based systems as a natural source of N. Improved forage quality and decreased reliance on synthetic N fertilizer are the main benefits of this practice (Sleugh et al., 2000).

Biological N fixation occurs as a result of a symbiotic relationship between legumes and soil bacteria (*Rhizobium* spp.). Within weeks of planting inoculated seed, root hair infection by bacteria occurs. Inoculation of seed with the appropriate strain of rhizobacteria is critical in the nodulation and subsequent N fixation process (Ledgard and Steele, 1992). Photosynthate sent into the soil by roots attract rhizobia bacteria, signaling bacteria to infect root hairs. Rhizobia return chemical signals, and root cortex cells multiply in preparation for infection. Bacteria enter through root hairs, attach to the root hair cell wall, then the root hair curls around to enclose the bacteria and the cell wall degrades. An infection thread membrane fuses with the cell membrane inside the root, encloses bacteria into vesicles, and travels through the root cells into the cortex where newly divided root cells will become the nodule. Bacteria further multiply, enlarge, and become bacteroids, and then begin the process of N fixation, or the reduction of molecular N (N_2) to ammonia (NH_3). It is estimated that 80 to 90% of N available to plants in natural ecosystems originates from biological N fixation (Rascio and La Rocca, 2008).

Ledgard and Steele (1992) discussed the importance of biological N fixation in pasture settings. They stated that amounts of N fixed from atmospheric N_2 in grass-legume pastures throughout the world range from 13 to 682 kg N ha^{-1} yr^{-1}. Challenges associated with biological nitrogen include soil N, moisture, and acidity status, seasonal fluctuations, legume persistence, plant nutrition, grazing management, and competition with other forages. Evers (2011) discussed the challenges associated with incorporating legumes into warm-season perennial systems. Legumes are more soil-specific than grasses, and the wide range in soil types in the southeastern US requires a variety of legume species. Legume persistence depends upon several environmental and management factors. Because the legume component is the most sensitive species in the system, emphasis should be placed on practices that favor its persistence (Beuselinck et al., 1994). Those practices include providing proper pH and mineral nutrition, phosphorus (P) and K fertility, and controlled cutting and grazing frequency.

Past and Current Use of Legumes in Warm-Season Systems

Warm-season grass-legume mixtures could be an option to meet nutritional needs of cows and growing calves in the summer months. Many studies have been conducted to evaluate legume contributions in cool-season mixtures (Gunter et al., 2012; Mckee et al., 2017; Mullenix and Rouquette, 2018; Pederson and Brink, 1991), although few studies have identified successful options for incorporating legumes into warm-season systems.

Extensive literature has reported the benefit of including annual or perennial clovers with cool-season forage mixtures to extend the grazing season and serve as a source of biological N fixation (Mullenix and Rouquette, 2018). Selected studies have reported carryover effects of these clovers into the warm-season growing months of the year and evaluated their relative contribution and persistence. White clover (*Trifolium repens* L.) has been an important forage crop in dallisgrass (*Paspalum dilatatum* Poir.) pastures, specifically in the Black Belt region of Alabama. During years with favorable growing conditions, white clover provides early, high-quality forage, and remains vegetative with adequate summer rainfall, extending the grazing season 30 to 60 days over dallisgrass monocultures (Evans et al., 1959). Carryover of forage DM in the early summer months by red clover (*Trifolium pratense* L.) overseeded into Eastern gamagrass [*Tripsacum dactyloides* (L.) L.] was reported by Mason et al. (2019).

Many legume options in warm-season perennials systems only provide short-season grazing; it has been more challenging to identify a legume that provided complementary grazing throughout the timeframe in which warm-season perennials produce the most growth. Beck et al. (2017) noted a N carryover effect in the early summer in bermudagrass pastures that had been interseeded with either red and white clover or alfalfa. Previous research in Florida has evaluated the efficacy of rhizoma peanut (*Arachis glabrata* Benth.) strip-planted into bahiagrass to improve forage nutritive value and decrease N fertilizer inputs (Castillo et al., 2015; Mullenix et al., 2014). C_4 grasses are adapted to tolerate heat and have an efficient water usage that provides them with a competitive advantage over legumes (Dilworth et al., 2008), impacting persistence of legumes in warm-season perennial grass systems. Because persistence of the legume component in C_4 grass systems has been somewhat limited, this may in part explain the relative lack of producer adoption of incorporating legumes into warm-season perennial grass-based systems.

Alfalfa as a Potential Legume Option for Interseeding

Growth Characteristics and Requirements for Alfalfa

Alfalfa is a high-yielding, perennial legume originating in Iran and central Asia (Ball et al., 2015). It was first introduced into the US in Savannah, Georgia in 1736. It is characterized by erect stems, a deep tap root, and trifoliate leaves arranged alternately on the stem. Distributed throughout the US, it grows best on deep, well drained soils with a pH of 6.5 or above. Known as the “Queen of Forages” due to its high CP concentration and excellent forage quality, alfalfa is an exceptional forage for livestock and wildlife. In early bloom stage, the target harvest timeframe for alfalfa, expected range in forage quality is 180 – 220 g kg^{-1} CP, 420 – 500 g kg^{-1} NDF, 320 – 360 g kg^{-1} ADF, and 610 – 640 g kg^{-1} TDN (Lacefield et al., 2009). Dehydrated alfalfa is used in poultry and livestock feedstuffs. It is the oldest forage crop documented in history, and over 400 cultivars have been approved for commercial release and use in farm operations since the 1960s (Ball et al., 2015; Hancock et al., 2015; USDA NRCS, 2002).

Maintaining a productive alfalfa stand requires close management and fertilization. The two macronutrients P and K are crucial for taproot development during the establishment phase and in maintaining longevity (Hancock et al., 2015). A study by Berg et al. (2009) evaluated influence of P and K fertility and defoliation management on alfalfa taproot carbohydrate storage. Alfalfa was fertilized with 400 kg K ha^{-1} yr^{-1} and 75 kg P ha^{-1} yr^{-1}, and taproot carbohydrate storage content decreased between defoliation day 0 and day 7 but then increased from day 7 to day 30, regardless of fertilization. Improved forage mass and stand persistence are also associated with P and K fertilization. Sanderson and Jones (1993) reported that after two years, stands declined from 495 to 98 plants m^{-2} when fertilized with 59 kg P ha^{-1}, whereas, unfertilized stands sustained 134 plants m^{-2}. However, contrasting results were reported by Berg et al. (2007) who observed that P and K fertilization increased alfalfa forage mass and helped sustain alfalfa stand persistence. Whereas P and K fertility are important for alfalfa stand longevity, N fertilization is not required due to the biological N fixation process. Alfalfa has the ability to produce upwards of 112 kg N ha^{-1} yr^{-1}, which could benefit other forage crops (Lacefield et al., 2009).

Tolerance to Defoliation

Grazing management practices greatly influence forage mass, quality, and persistence of alfalfa stands. Studies have evaluated continuous grazing of alfalfa (Smith et al., 1989), but because of the resulting in weed presence and decreased persistence, the recommended practice is rotational grazing (Bouton and Gates, 2003). In an evaluation of grazing-tolerant varieties of alfalfa in Eatonton, GA and Tifton, GA, various grazing management strategies were used. Stand persistence was measured as plant survival rate (final count of plants m^{-2}/initial count of plants m^{-2}). In Eatonton, plant survival was similar (52 – 53 %) for the rotational stocking and hay harvest treatments exhibiting better survival than in the continuously stocked treatment (38%). At Tifton, stand survival improved from continuous stocking (24%) to rotational stocking (46%) to hay harvest management (63%).

Alfalfa defoliation strategies have been evaluated to determine effect on forage mass and quality. A study by Teixeira et al. (2007) evaluated 28-day and 42-day regrowth cycles. Results indicated that the shorter regrowth cycle reduced alfalfa forage mass compared with the long regrowth cycle. Ventroni et al. (2010) results were similar where a 40-day cutting interval produced 2,053 g DM m^{-2} compared with 862 g DM m^{-2} from a 20-day interval. However, it is crucial to optimize the balance between forage mass and quality when considering harvest strategies. Brink et al. (2010) reported that more frequent harvests resulted in decreased forage mass but could improve forage quality. Riper and Owen (1964) harvested alfalfa cut at 5 and 12 cm and reported that forage mass was greater at the lower clipping height, but the 12-cm height supported greater CP concentrations. Similar results were reported by Smith and Nelson (1967) who found that, with an increase in harvest height from 2.5 to 15.2 cm, forage mass declined. In the same study, as harvest height increased, forage mass declined (Smith and Nelson, 1967).

Historical Limitations for Using Alfalfa in the South

Alfalfa has been grown throughout the Southeast US for many years, but due to pest pressure from the alfalfa weevil [(*Hypera postica* (Gyllenhal) (Coleptera: Curculionidae)] and climatic conditions, acreage declined in the 1950s and more cost-effective forages were utilized (Lacefield et al., 2009). Breeding efforts made by Dr. Joe Bouton at the University of Georgia in the late 1980s provided new varieties that were tolerant of southeastern US climate conditions and could with withstand grazing pressure, which created a resurgence of alfalfa growth in the region (Ball et al., 2015). Twenty-two cultivars were grazed continuously for 100 days in a study by Counce et al. (1984). Persistent and nonpersistent cultivars were examined for differences in topgrowth and carbohydrate utilization; persistent cultivars appeared to be less dependent on taproot reserves for topgrowth. Further selection for grazing resistant cultivars was conducted in central Georgia (Smith and Bouton, 1993). Selected populations of the cultivars 'Apollo', 'Florida

77', 'Spredor II', and 'Travois' had better stand persistence and forage mass than their original populations, indicating that grazing tolerance can be improved without sacrificing forage mass.

Mixed Alfalfa-Bermudagrass Systems

Overview and Establishment

Integration of alfalfa into bermudagrass has become increasingly popular in the Southeast US and may support the potential for more sustained legume contribution during the warm-season growing season than clovers or warm-season annual legumes. This mixture has shown potential to increase total forage mass, nutritive value, and extend the grazing season relative to bermudagrass monocultures (Beck et al., 2017a, 2017b, 2017c; Brown and Byrd, 1990; Stringer et al., 1994). The growth distribution of each species allows for complementary growth throughout the year, where alfalfa will be available starting in Mar and growing through Oct or Nov; bermudagrass will be most productive in Jun through Sep, whereas alfalfa experiences a summer dormancy known as “summer slump” (Ball et al., 2015; Ottman and Mostafa, 2020). To successfully establish alfalfa into bermudagrass, it is recommended to plant alfalfa in the fall (Oct) when bermudagrass to go dormant. Removing excess thatch by mowing bermudagrass sod to 5-cm and chemical suppression with glyphosate may ensure better seed-soil contact and reduce competition between newly established alfalfa and bermudagrass (Hancock et al., 2015). Herbicide withdrawal periods may influence when planting can occur depending on historical management of the bermudagrass stand. Some widely used pasture and hayfield herbicides have significant soil residual activity that can limit legume emergence and survivability if appropriate lay periods post-application are not followed. In addition to herbicide withdrawal, drought may also cause a delay in planting, which is more common during the late summer and early fall months of the year in the southeastern US. Planting in the spring is possible, but often not as successful as fall-planted stands due to plant competition from weeds or grasses emerging from dormancy (Hancock et al., 2015).

Forage Mass and Botanical Composition

Seeding rate and row spacing in grass-legume mixtures can have an impact on forage mass and botanical composition. A study was conducted evaluating the use of a no-till drill to plant alfalfa at various seeding rates (11, 22, 33, and 44 kg ha^{-1}) into suppressed bermudagrass sod. The lowest seeding rate resulted in lower alfalfa plant counts and reduced persistence after one year. Alfalfa persistence was greatest using the 44 kg ha^{-1} rate but the intermediate rates were not different (Jennings et al., 2016). Stringer et al. (1994) and (Brown and Byrd, 1990) evaluated row spacing effects on alfalfa performance.

One study comprising two experiments evaluated forage mass and botanical composition of alfalfa-bermudagrass mixtures compared with monocultures of each species (Brown and Byrd, 1990). In one experiment, ‘Apollo’ alfalfa was interseeded into ‘Coastal’ bermudagrass using 15-cm and 30-cm row spacings. Alfalfa was the dominant species during the spring in mixed stands, regardless of row spacing. The authors concluded that there were no differences in total forage mass based on row spacing, but mixtures provided greater forage mass than a bermudagrass monoculture fertilized with 100 kg N ha^{-1}. The mixed stand comprised 80% alfalfa in the first two years and 84% in the third year of the trial, and row spacing had no influence on composition (Brown and Byrd, 1990). Results from Stringer et al. (1994) supported these findings when evaluating the effect of row spacing and N fertilization on alfalfa-bermudagrass forage mass, botanical composition, and quality. They observed that alfalfa interseeded into bermudagrass on a 20-cm row spacing resulted in greater forage mass compared with bermudagrass monocultures fertilized with 224 kg ha^{-1}. Increased row spacing opened the canopy to reduce shading from competing forages (Stringer et al., 1994).

Percentage of legume contribution in mixed stands is the greatest factor in determining of the amount of potential N contribution to the system. Extension recommendations state that a grass-legume mixture should comprise a minimum of 30% legume to produce enough N to support the system without additional N fertility inputs. Haby et al. (1999) indicated that greater proportions of legume in mixed stands could result in greater N fixation, but may lead to decreased N transfer as species composition shifts towards the legume, resulting in less grass species to take up soil N.

Nutritive Value and Persistence Under Defoliation Management

Literature described to this point is somewhat dated and involved older varieties of alfalfa. Less work has been done with newer, improved varieties in the Southeast US. Beck et al. (2017a) conducted a series of studies evaluating the use of white and red clovers or alfalfa as a replacement for N fertilizer in bermudagrass pastures. Bermudagrass pastures (0.8 ha; n = 4 per treatment) were either interseeded with alfalfa, red and white clover, or fertilized with 0 N ha^{-1}, 56 N ha^{-1}, or 112 N ha^{-1}, and grazed by steers (approx. 250 kg) using put-and-take management. In an evaluation of herbage mass and pasture carrying capacity, the authors indicated that herbage mass was greater in the spring in alfalfa-interseeded pastures compared with N-fertilized pastures, but not different in the summer, and alfalfa accumulation decreased in the later summer (Beck et al., 2017b). A more grazing-tolerant alfalfa variety had to be replanted in the second year of the study. When evaluating nutritive value, they found that all pastures exceeded dietary recommendations for growing steers to maintain 0.9 kg d^{-1} ADG for CP and TDN, 118 and 617 g kg $^{-1}$ DM, respectively (Beck et al., 2017a). Beck et al. (2017c) evaluated rotational and continuous grazing management strategies for steers grazing alfalfa-bermudagrass pastures. The results indicated that, at equal stocking rates, rotational grazing can maintain greater alfalfa persistence, nutritive value, and forage allowance, and provided increased animal performance in late summer when the alfalfa stand was reduced in continuously stocked pastures.

While this work evaluated alfalfa-bermudagrass systems under grazing, it only utilized a single management system. To identify more specific defoliation management strategies, research should focus on a range of defoliation practices, both in intensity and in frequency, and their potential application for mixed stand management.

Tools for Yield Estimation in Mixed Stands

Sward-height measurement is non-destructive technique that facilitates forage mass estimation in grass-based, monoculture systems. There are several tools that are useful for estimating forage mass, but the rising plate meter and pasture ruler are likely the simplest to use. A rising plate meter has a weighted plate which slides over a shaft; when placed over a forage canopy, the plate compresses the forage and a measurement between the ground and plate is taken to determine height. A pasture ruler or grazing stick is a meter ruler with pasture management information inscribed on the side. The information found in the inscribed tables relates forage height to estimated forage mass in kg DM ha^{-1} per cm of available forage, and it is based on positive linear relationships determined through previous research (Sanderson et al., 2001). While measurements from a pasture ruler may be less accurate or precise than other ways of measuring forage mass, pasture rulers are producer-friendly tools for because they are low in cost and require little labor or resources to use. Sanderson et al. (2001) evaluated three tools for measuring forage mass in cool-season grass-legume pastures in Pennsylvania, Maryland, and West Virginia: an electronic capacitance meter, a rising plate meter, and a pasture ruler. Results from the study indicated that all three methods were inaccurate and imprecise compared with measuring forage mass by taking hand clipped samples. The authors suggested that region-specific calibrations are necessary for such tools to be useful. Dillard et al. (2016) reported that forcing the X intercept to zero increased precision of calibration equations when estimating forage mass in multispecies swards using a rising plate meter.

In mixed stands, species composition and canopy bulk density are variable, and forage mass estimation becomes more challenging. To estimate forage mass in mixed forage stands, measures of stand variability must be considered (Alexander et al., 1962; Baxter et al., 2017). Baxter et al. (2017) compared five nondestructive sampling techniques for predicting forage mass in alfalfa-tall wheatgrass [*Thinopyrum ponticum* (Host) Beauv.]: pasture ruler, rising plate meter, ImageJ, PowerPoint photo point count, and normalized difference vegetation index. The authors suggested that combining multiple measurements (canopy height + ImageJ) resulted in greater R^2 than models based on a single sampling procedure. Stand variability measurements such as canopy cover, botanical composition, and dry-weight-rank, combined with sward height may more accurately estimate forage mass in alfalfa-bermudagrass stands (Pasto et al., 1957). These measurements can be completed easily on-farm to provide real-time forage mass estimates to producers and may provide a practical approach for relating non-destructive estimates to destructive harvest data that can be more readily applied by stakeholders.

Producer Education and Adoption

The diffusion of innovations theory states that five main factors influence adoption of an innovation or practice including relative advantage, compatibility, complexity, triability, and observability (Rogers, 2003). One of the most impactful approaches for producers to learn about and observe whether a practice may be beneficial to their operation is through Extension demonstrations. These demonstrations are based on research questions pertaining to management of a given system. For example, what is the optimal defoliation management strategy for alfalfa-bermudagrass mixtures in the Southeast US? Integration of legumes into pastures in the Southeast US has been historically limited due to perceived lack of persistence, lack of awareness of adapted varieties, and knowledge of management requirements (Tucker et al., 2019). An increase in demonstrations relating adoption of alfalfa-bermudagrass in the Southeast US have taken place over the past few years, including research trials at various university research stations and demonstration stands on local producer-owned farms. These efforts have allowed researchers to update and refine Extension recommendations for successful establishment and management of mixed-stands in the region.

Cow-Calf Production During the Winter in Warm-Season Perennial Systems: Reduced Labor Feeding Systems

Opportunities and Challenges of Winter Production

In the Southeast US, many cow-calf operations rely on grazed warm-season forages that decline in productivity in the winter months. Cattle producers feed hay and supplemental feedstuffs for 90 to 120 days to maintain cows during the winter when fresh forages may not be available for grazing (Prevatt et al., 2018). Due to cost of feed and labor associated with winter feeding, production input costs increase when relying solely on conserved forages and supplemental feeds. Identifying alternative nutritional management strategies that could provide grazing or reduced labor options during this time of year may offset those costs (Beaty et al., 1994a; Mullenix and Rouquette, 2018). Advantages exist in the Southeast US in terms of climate and forage availability compared with other regions of the US (DiLorenzo, 2012). Incorporating annual legume-grass mixtures into winter management systems can increase forage mass, nutritive value, improve seasonal distribution, and reduce weed encroachment compared with monocultures (Sleugh et al., 2000). Improved forage quality from winter annuals can reduce the amount of supplemental feed required to maintain the cow herd, which may have a potential positive benefit in reducing annual cow carrying costs.

Nutritional needs of cows in the winter can be relatively high, especially when temperatures are low or in fall-calving systems where cows are in peak lactation during these months. DiLorenzo (2012) pointed out that climate conditions vary in production systems between and within states. Short winters in the southern-most parts of the US may lead producers to rely on stockpiling of warm-season forages, whereas locations with longer winters can make use of winter-annuals. Consequently, nutrition management strategies can be challenging to define. Ball et al. (2015) discussed specific challenges of overseeding cool-season grasses and legumes into warm-season perennial sods. Suppressing warm-season forage or waiting until it begins to enter dormancy is crucial in reducing competition with seedlings. During the spring, growth of overseeded winter annuals may compete with warm-season perennials; stocking pastures heavily during this time may avoid growth suppression. Establishing cool-season forages into clean-tilled soil may provide earlier forage availability for grazing during the winter months. However, proper equipment and a dedicated land area for prepared seedbed establishment is needed for this option to be successful. Another consideration is the cost associated with winter cow nutrition. The annual feed cost of maintaining a cow can represent 41 to 62% of the total costs, depending on location and management factors (DiLorenzo, 2012). These total input costs are greatly dependent on the amount and type of supplemental feedstuff used to carry cows through the winter period, and/or the relative contribution of stored or grazed forages to the animal diet during this time frame.

Options for Winter Management in the Coastal Plain Region

Forage Systems

Winter forage options include conserved forages, such as hay or baleage, or grazed forages, such as winter-annual grasses and legumes or stockpiled forage. A critical factor in the decision of winter grazing vs. hay plus supplement feeding is labor. The initial investment in winter annual establishment justifies intensive grazing management to maximize pasture production and quality (DiLorenzo, 2012). Overseeding and sodseeding are terms used to describe the practice of establishing annual forage crops into perennial, grass-dominated pasture fields without destroying the existing sod (Ball et al., 2015). Seed can be broadcast with or without disking or other tillage or planted into sod with a drill-type planter. Warm-season perennial pasture may be productive for six to eight months per year, whereas an area overseeded with cool-season annuals may provide eight to ten months of forage production per year (Ball et al., 2015).

Winter-annual mixtures containing small grains, annual ryegrass (*Lolium multiflorum* Lam.), and annual clovers (*Trifolium* sp.) may provide more early-season forage availability compared to ryegrass alone, reducing the need for supplementation during this time period

(Gunter et al., 2002; Mullenix and Rouquette, 2018). Using winter-annual grasses with varying individual growth distributions allows producers to further extend the timeframe of grazing. Rye is the forage species available for grazing earliest in the season, followed by oat (*Avena sativa* L.), triticale (*Triticosecale* Wittm.), and wheat (*Triticum aestivum* L.) in mid-season, and ryegrass provides forage growth as spring approaches.

Hoveland et al. (1961) evaluated the forage production of winter annuals sodseeded on dallisgrass-white clover pastures at the Black Belt Research & Extension Center in Marion Junction, AL. The study evaluated oat, rye, wheat, annual ryegrass, rescuegrass (*Bromus catharticus* Vahl), caley peas (*Lathyrus hirsutus* L.), and vetch (*Vicia villosa* Roth.). Over the 3-year study, cool-season annual forage mass was below that obtained when planted on a prepared seedbed; however, cool-season grass-legume combinations were more productive than dalligrass-white clover alone. The authors observed no carryover effect of sodseeding on grass-clover forage mass during the summer or fall and concluded that sodseeding could extend the grazing season and increase total forage mass. Fribourg and Overton (1973) reported that small grains overseeded on a bermudagrass sod produced 1.4 to 3.0 Mg ha^{-1} in the winter, and ryegrass yielded 3.5 to 5.0 Mg ha^{-1} in late winter and early spring. The authors concluded that overseeding resulted in higher total forage mass per unit land area and extended the grazing season. An evaluation of beef cattle performance on bermudagrass pastures overseeded with winter-annuals found that overseeding with rye and clover increased the length of the grazing season by three months compared with no overseeding (Hoveland et al., 1978). Overseeding resulted in increased total cow and calf gains per hectare with 897, 785, 690, and 511 kg ha^{-1} for rye-clover, clover, ryegrass, and bermudagrass sod alone, respectively.

DiLorenzo (2012) conducted a study in north Florida where heifers placed on dormant bahiagrass pastures received one of the following nutrition management treatments: (a) bahiagrass hay plus 50:50 soy hulls: corn gluten feed, (b) continuous grazing of triticale plus ryegrass, or (c) continuous grazing of rye plus ryegrass. Based on cost of gain, triticale plus ryegrass showed a significant advantage over other treatments. Heifers receiving hay plus supplement gained 0.5 kg d^{-1}, but this was not enough to offset the costs associated with hay/feed purchasing and labor costs. Heifers on the rye plus ryegrass paddocks showed poor weight gains, resulting in the highest cost of gain. These results indicate that animal performance can vary across nutritional management systems, and economics of each system must be evaluated to make appropriate management decisions.

Rotational grazing is a way to increase the efficiency of pasture utilization; however, the benefits must be weighed again the increased labor needed to move cattle fairly often (Ball et al., 2015; DiLorenzo, 2012). An evaluation of grazing management strategies compared management-intensive rotational grazing with continuous grazing (Paine et al., 1999). The results indicated that continuously grazed pastures had an inverse linear relationship between forage mass and quality, whereas rotationally grazed pastures had greater nutritive value at similar forage biomass levels in continuously grazed pastures. Aiken (1998) reported higher daily weight gains and higher stocking rates in rotationally stocked wheat-ryegrass pastures, but the more intensive 11-paddock system was not superior to a 3-paddock system. Adding any amount of rotational grazing will improve pasture use efficiency over continuous grazing, but can eventually become cost-prohibitive depending on labor costs and cattle performance. Gillespie et al. (2008) discussed the roles of labor and profitability in choosing a grazing management strategy. They reported that total labor costs were greater in rotationally grazed systems compared with continuously grazed systems. When combined with lower profits in cases of poor animal performance, rotationally grazed systems are not as readily adopted in some regions.

Self-Limiting Supplemental Feeds

During periods of hay feeding, producers may provide additional supplemental feed resources to help maintain animal production goals. Commodity byproducts available throughout the Southeast US create unique pricing opportunities for inclusion in beef cattle diets (DiLorenzo, 2012). However, it is important to evaluate the moisture content and nutrient profile of supplements and by-product feeds to ensure that they will meet cow nutrition requirements. Other considerations when selecting supplemental feeds are transportation and storage ability, local availability, labor and regulations associated with feeding by-products (Mullenix and Rankins, Jr., 2014). Supplemental feeding strategies that reduce labor are desirable from a farm-management standpoint. Self-limiting feeds are often marketed as potential options for reducing the frequency of feeding or controlling feed intake to a target amount per head daily. Types of self-limiting feeds include high-roughage feeds, high-fat feeds, and feeds mixed with mineral salts at a concentration of 0.05 kg for every 45 kg BW, as well as automated feeders and liquid feeders (Gadberry, 2016). Of commercial byproduct resources available, WCS contains 170 g kg^{-1} fat, which may serve as a potential intake limiter when fed free-choice (Jacobs and Mullenix, 2019). Inclusion of WCS in beef cattle diets is an easy way to provide both energy and protein but may oversupply fat and increase feeding costs if intake is not monitored. An intake study by Hill et al. (2009) indicated that mature cows allowed free-choice access to WCS would consume up to 4.06 kg DM d^{-1}, and although no noticeable adverse effects were observed as a result of high WCS consumption, the large amount of fat consumed could potentially decrease forage utilization in the rumen.

Mixtures of pelleted soy hulls and corn gluten feed are also commonly used in the Southeast US, and are often used in free-choice feeding situations by beef producers when backgrounding beef calves or as part of bull development systems (Mullenix, personal communication, 2020). This combination of byproducts is low in nonstructural carbohydrates and high in digestible fiber and ruminally degradable protein, allowing it to be fed less frequently without negative effects on digestion in certain feeding situations (Drewnoski et al., 2011).

Other feeding strategies that may decrease labor needs for the winter months may include feeding free-choice byproducts or reduced-frequency feeding, which reduce the need for daily hand-feeding supplemental feedstuffs. Previous studies have reported that steer performance does not differ when feeding a soy hull: corn gluten feed mixture at 2% of body weight every other day as opposed to 1% of BW daily (Drewnoski et al., 2011). Beck et al. (2014) reported no differences in animal performance in growing beef calves supplemented with DDGS daily versus every other day. Varying among each cattle operation, labor resources and feed costs must be considered to find feasible management strategies that minimize cost while optimizing cattle nutrition.

CHAPTER 3

INFLUENCE OF HARVEST STRATEGY ON FORAGE MASS AND NUTRITIVE VALUE OF ALFALFA-BERMUDAGRASS MIXTURES IN THE SOUTHEAST UNITED STATES

INTRODUCTION[1]

In the last several decades, there has been growing interest in interseeding high-quality legumes into existing warm-season perennial stands as a step towards improving forage, animal, and ecosystem sustainability in the Southeast US (Beck et al., 2017b; Bouton and Gates, 2003). Bermudagrass (*Cynodon dactylon* (L.) Pers.) is the most abundant perennial warm-season grass grown for pasture in the Southeast US. Alfalfa (*Medicago sativa* L.), once the dominant perennial legume species utilized in the Southeast US, is currently the only perennial legume option that can be interseeded into warm-season perennial sods to provide extended use and improved quality and be utilized within the first growing season.

Incorporating legumes into perennial warm-season grass pastures can produce significant economic and environmental benefits to Southeastern US livestock and forage systems (Brown and Byrd, 1990; Hancock et al., 2015). If grazing can begin earlier in the spring or extend later into the fall, reductions in fertilizer and application costs, need for supplemental feeds, and associated storage and feeding costs may accrue. Harvest timing and intensity have a direct influence on forage mass and quality of mixed grass-legume stands (Ball et al., 2001; Buxton, 1996). Determining the appropriate target grazing height and frequency may optimize forage mass and quality, while ensuring longevity of the stand.

To develop grazing recommendations, several phases of forage research must occur. Initially, plant selection results in the development of forage varieties well-suited to research

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[1] Target Journal: Crop Science

goals. Next, clipping trials are conducted in small plot settings to determine harvest management influence on forages. Results from clipping trials provide better-defined harvest strategies. Once optimal harvest strategies are determined, research can move toward larger-scale systems research such as grazing studies, where both plant and animal responses are evaluated. Each phase builds upon the previous one and is essential to developing forage-livestock system management recommendations.

The objective of this research is to determine the influence of harvest height and frequency on seasonal forage mass and nutritive value of alfalfa-bermudagrass mixtures under simulated grazing. This will help establish more defined defoliation parameters for use in mixed alfalfa-bermudagrass systems in the Southeast US.

MATERIALS AND METHODS

Research Site and Experimental Design

A 2-year simulated grazing small-plot trial was conducted during the 2018 – 2019 growing seasons at the E.V. Smith Research Center in Shorter, AL (32°26'31.3"N latitude, 85°53'51.1"W longitude). Research plots were located in a previously established ‘Tifton 85’ bermudagrass hayfield comprising Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) and Luverne sandy loam (fine, mixed, semiactive, thermic Typic Hapludults) (Web Soil Survey, 2020).Thirty-six plots (1.5 × 4.6 m) were organized in a randomized complete block design into four blocks, each comprising nine plots representing a 3 × 3 factorial of harvest height (5, 10, and 15-cm) and harvest frequency (2, 4, and 6-wk) treatments. Treatments represent varied grazing management practices on perennial warm-season grass pastures in the Southeast US.

Plot Establishment and Management

On Nov 27, 2017, pre-inoculated ‘Bulldog 805’ alfalfa seed was planted using a no-till drill (Great Plains, Salina, KS) in 36-cm rows at a rate of 28 kg ha^{-1} and no deeper than 1.3 cm following alfalfa establishment recommendations for the Southeast US (Hancock et al., 2015). Prior to planting, bermudagrass was clipped to a 5-cm stubble and sprayed with glyphosate (2.5 kg a.i. ha^{-1}). In Feb 2018, 45.5 kg ha^{-1} of potassium (muriate of potash; 0-0-62 N-P-K), 18.2 kg ha^{-1} of nitrogen (urea-ammonium nitrate; 32-0-0 N-P-K), and 1.4 kg ha^{-1} of boron (10% granular) were applied. On Mar 5, 2019, 112 kg ha^{-1} of potassium (muriate of potash; 0-0-62 N-P-K) was applied. On May 15, 2019, boron (10% granular) was applied at 3.4 kg ha^{-1}. To control annual grass weeds, pendimethalin (Prowl H2O ((N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine); BASF Ag Products, Floram Park, NJ) was applied on Jun 14, 2018 at a rate of 2.1 kg a.i. ha^{-1} and on Feb 18, 2019 at a rate of 1.1 kg a.i. ha^{-1}. Plots were scouted for insect pests at every harvest. Pea aphids (*Acyrthosiphon pisum*) were observed but did not reach the threshold for treatment. In the summer of 2019, rainfall was limited, and 1.27 cm of irrigation was applied on May 30 followed by 3.81 cm on Sep 17 for plot maintenance. Plots were clipped according to their respective clipping height × frequency treatment on Jun 11, Jun 25, Jul 9, Jul 19, Aug 6, Aug 21, and Sep 4, 2018; and on Jun 4, Jun 18, Jul 2, Jul 16, Jul 30, Aug 13, Aug 29, Sep 10, Sep 23, and Oct 10, 2019.

Response Variables

Seasonal Forage mass

Forage mass was determined by cutting a forage mass strip (1.0 × 4.6 m) from the center of each plot using a flail-type forage harvester (Carter Manufacturing Company, Inc., Brookston, IN). Plots were harvested based at their respective harvest height and frequency treatment combination. All harvested material was collected, and fresh weights were recorded. A grab sample was collected from each strip for nutritive value analysis and moisture correction calculations. Grab samples were weighed fresh and dried in a forced air oven at 60°C for 48 hours until a constant weight was reached to determine DM concentration. Grab sample data were used to convert the total aboveground fresh weight to total DM forage mass within plot. Forage DM forage mass from each harvest event was then totaled across the number of harvests per season for each respective treatment combination to determine seasonal forage mass. In Yr 1, 2-, 4-, and 6-wk plots were harvested 7, 3, and 2 times, respectively. In Yr 2, 2-, 4-, and 6-wk plots were harvested 10, 5, and 3 times, respectively.

Nutritive Value

Grab samples collected at harvest were ground to pass through a 1-mm screen using a Wiley mill (Thomas Scientific, Swedesboro, NJ) for wet chemistry analysis, then ground through a 1-mm screen in a Udy Cyclone Sample Mill (Tecator, Inc., Boulder, CO) for nutritive value determination. Nutritive value analysis was determined by near infrared reflectance spectroscopy (NIRS) at the University of Georgia Ruminant Nutrition Lab in Tifton, GA. Prior to scanning, ground samples (n = 361) were placed in a forced air oven at 55°C for 90 minutes, removed and thoroughly mixed, then approximately 5 g of ground sample were packed into cells and scanned.

Samples were analyzed using the 2019 alfalfa hay calibration equation or 2019 grass hay equation calibration provided by the NIRS Forage and Feed Testing Consortium (NIRSC, Hillsboro, WI) on a Foss 6500 NIR Spectrometer (NIRS; NIRSystems, Hilleroed, Denmark) that was standardized to the NIRSC master instrument to ensure prediction accuracy. The alfalfa hay equation calibration was used when 30% or more of the sample contained alfalfa as determined through botanical hand-separations and visual ground cover. When samples comprised less than 30% alfalfa, the grass hay calibration equation was used. These equations were developed by the NIRS Forage and Testing Consortium (Hillsboro, WI). Nutritive value data for neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), and in-vitro true dry matter digestibility at 48-h (IVTDMD) is reported with predictions fitting the allowable $H < 3.0$ (Murray and Cowe, 2004). Total digestible nutrients (TDN) was calculated using the grass and legume/grass mixture equations provided in Moore and Undersander (2002).

Forage quality parameters (CP and IVTDMD) for each harvest were validated using wet chemistry laboratory techniques for CP and digestibility. Dry combustion with a CN LECO 2000 (LECO Corp., St. Joseph, MI) was used to measure total C and N. Crude protein was calculated as N × 6.25. Forage IVTDMD was determined according to the Van Soest et al. (1991) modification of the Tilley and Terry (1963) procedure using the Daisy II incubator system (Ankom TechnologyTM, Macedon, NY). Ruminal fluid was collected at the Auburn University College of Veterinary Medicine from a cannulated Holstein cow that had free access to bermudagrass hay and was limit-fed a 15% CP supplement consisting of soybean hull pellets, corn gluten feed, and WCS, plus 8 oz of Megalac® (Volac Wilamar Feed Ingredients, Ltd; Hertfordshire, UK). Fluid was stored in thermos containers to maintain a temperature supportive of the microbial population and was transported to the Auburn University Ruminant Nutrition laboratory where it was immediately prepared for the batch-culture IVTDMD procedure. Figures 1 and 2 show the correlation between wet chemistry and NIR results for CP and IVTDMD, respectively. Correlation was stronger for CP results (R = 0.9052) than for IVTDMD results (R = 0.5558).

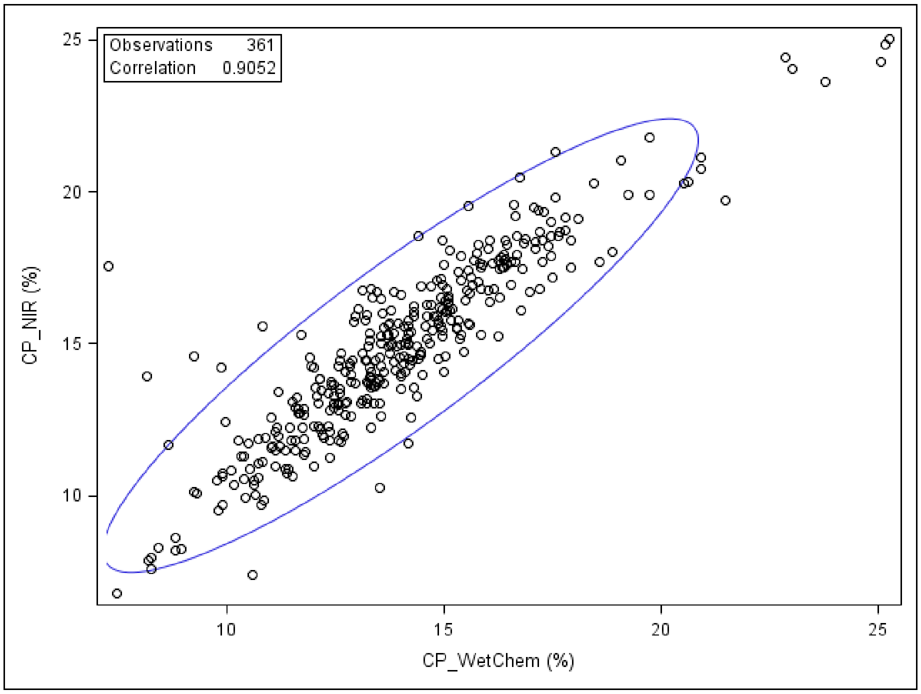

Figure 1. Pearson correlation between CP concentrations determined by wet chemistry and NIR with 95% prediction eclipse.

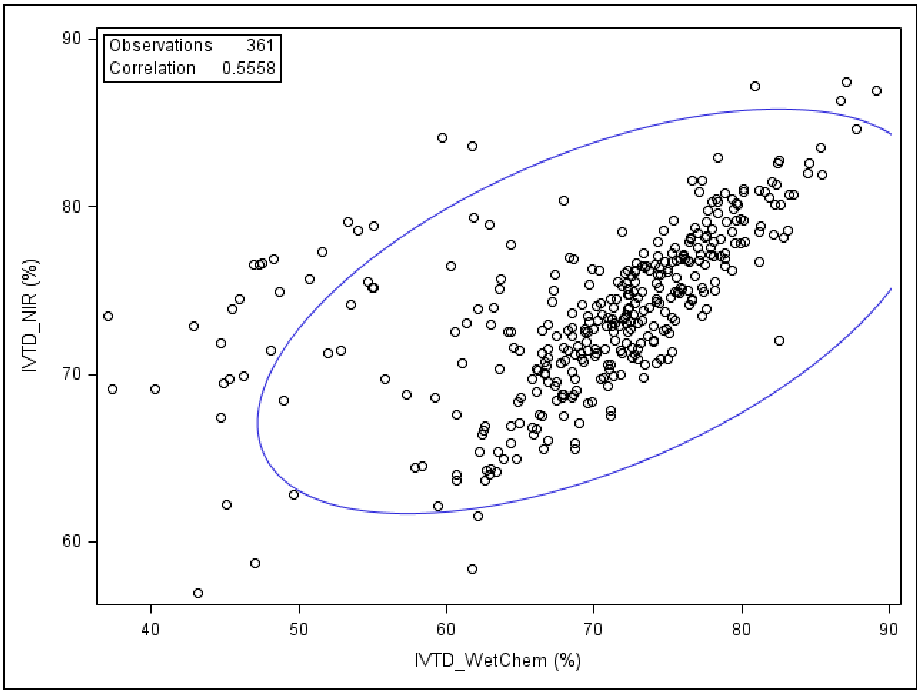

Figure 2. Pearson correlation between IVTDMD concentrations determined by wet chemistry and NIR with 95% prediction eclipse.

Statistical Analysis

Seasonal forage mass and forage concentrations of CP and IVTDMD were analyzed using the MIXED procedure in SAS 9.4 (SAS Institute, 1994) for a randomized complete block design. Independent variables were harvest height, harvest interval, date, and their interactions. Block and year were random variables. Treatment means were separated using the PDIFF option of the LSMEANS procedure (SAS Institute, 1994) and were determined to be significant when $\alpha = 0.05$.

RESULTS AND DISCUSSION

Weather instruments operated by Agricultural Weather Information Service, Inc. collected daily average ambient temperatures and daily total precipitation data throughout the experimental period. Monthly total precipitation and 100-yr average monthly total precipitation are presented in Figure 3. Monthly mean temperatures and 100-yr average monthly mean temperatures in Shorter, AL are presented in Figure 4. In Yr 1, rainfall followed the 100-yr average, except in Aug when rainfall was below average. In Yr 2, rainfall was below average for most of the growing season and became gradually drier as the growing season progressed. Although alfalfa's deep tap root makes it more drought tolerant than other legume species (Hancock et al., 2015), irrigation was applied twice during the season for stand maintenance purposes. Monthly mean temperatures tended to follow the pattern of the 100-yr average, except in Sep when temperatures were greater. In Yr 1, visual observations indicated that alfalfa growth began to slow in Sep, ending the harvest season earlier than anticipated. Slowed growth reduces the accumulation of root carbohydrate reserves, and it is important to stop harvesting alfalfa approximately 30 days before temperatures are expected to drop below -3°C to ensure adequate root reserves are present moving into winter (Hancock et al., 2015).

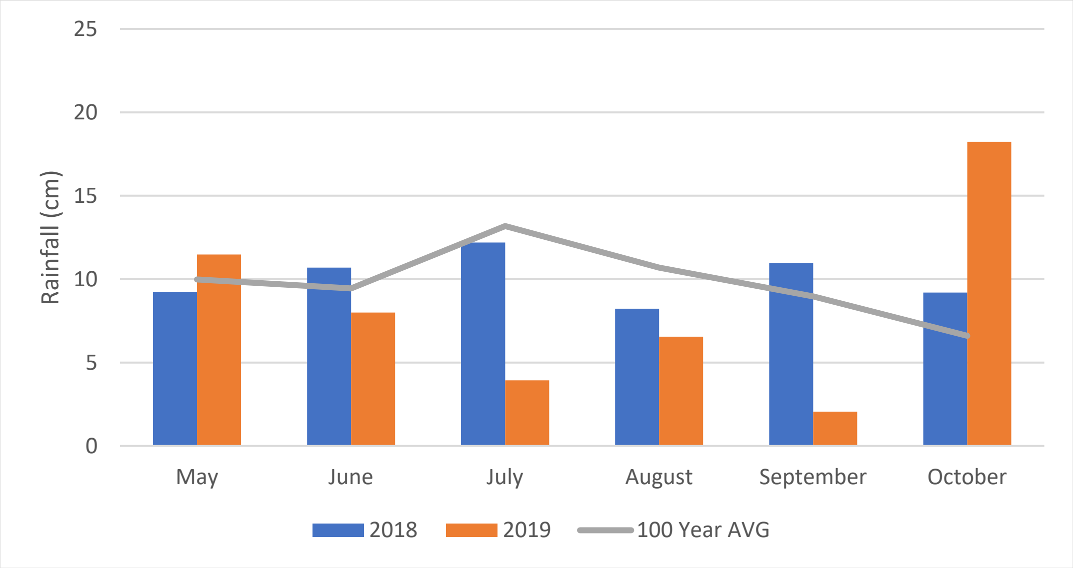

Figure 3. Monthly total precipitation (cm) for 2018, 2019, and 100-yr average in Shorter, AL. Data collected from Agricultural Weather Information Service, Inc.

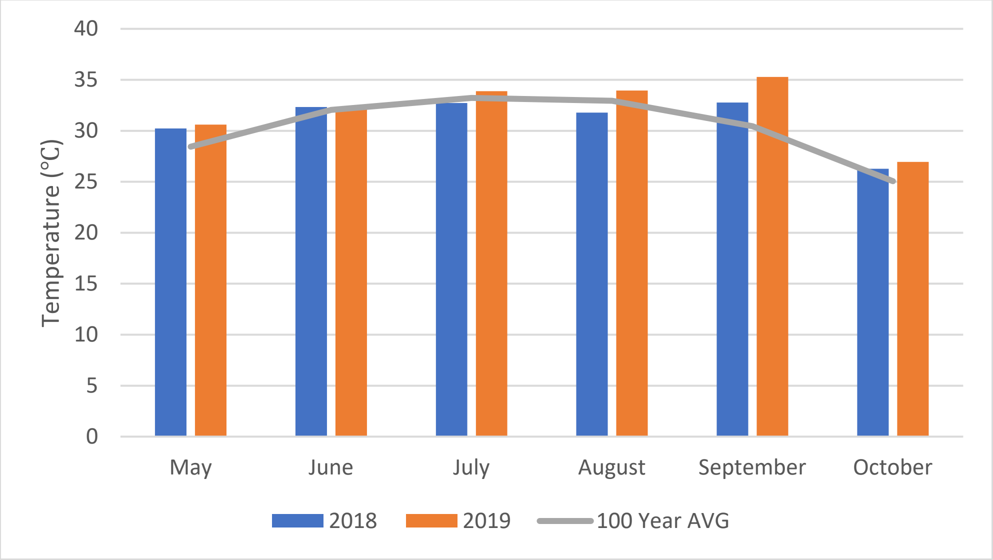

Figure 4. Monthly mean temperatures (°C) for 2018, 2019, and 100-yr average in Shorter, AL. Data collected from Agricultural Weather Information Service, Inc.

Seasonal Forage Mass

Harvest height and harvest frequency had significant effects ($P < 0.0001$ and $P = 0.0113$, respectively) on seasonal forage mass of the alfalfa-bermudagrass mixture, although a harvest height × frequency interaction was not observed ($P = 0.6132$). Forage mass decreased as harvest height increased (10,802 kg DM ha^{-1} for 5-cm, 9,062 kg DM ha^{-1} for 10-cm, and 6,222 kg DM ha^{-1} for 15-cm), as less plant material was harvested at taller clipping heights. Hendricks et al. (2020) reported greater seasonal forage mass than the current study when evaluating a mixture T85 and ‘Bulldog 805’ alfalfa clipped at a 2-cm height. Seasonal forage mass ranged from 7,877 to 11,788 kg DM ha^{-1} for bermudagrass monoculture and 14,755 to 22,654 kg DM ha^{-1} for alfalfa-bermudagrass. Durham and Hancock (2011) reported a seasonal average (3 yrs) of 9,193 kg DM ha^{-1} for pure stand ‘Bulldog 805’ alfalfa in Tifton, GA. Warm-season grass pastures vary in bulk density from top to bottom of the canopy (Sollenberger and Burns, 2001). This variation is compounded in mixed-species swards. Canopy bulk density in the present study varied such that bermudagrass had greater mass in the lower part of the canopy and alfalfa had a more even forage mass distribution throughout the canopy. Thus, plots harvested at lower stubble heights produced greater forage mass. However, maximizing forage mass by harvesting at a low clipping height may negatively impact alfalfa persistence. Greater alfalfa contribution was observed in the 5-cm clipping treatment, which likely contributed to the greater forage mass for that treatment. Additional canopy composition data are presented in Chapter 4.

Seasonal forage mass was 7,922 kg DM ha^{-1} when harvested at the 2-wk interval, 9,499 at 4-wk, and 8,665 at 6-wk, with the 2-wk and 4-wk seasonal forage mass being significantly different ($P = 0.0029$). Alfalfa contribution to botanical composition was 61% at the 4-wk harvest interval and 55% at the 6-wk interval, contributing to greater forage mass for those harvest intervals compared with 2-wk. Greater forage mass accumulation would be expected with lengthened harvest intervals. Additionally, forage residue left post-harvest may influence forage DM forage mass in subsequent harvests. Michelangeli et al. (2010) reported similar results for a monoculture of 'Tifton 85' bermudagrass, where DM forage mass increased with longer harvest intervals and at shorter clipping heights. The study reported seasonal forage mass values of 6,613 to 9,796 kg DM ha^{-1} for 21 to 35-d harvest intervals, respectively, and were less than DM forage mass reported in the current study. Seasonal forage mass values in the present study are similar to those reported by Brown and Byrd (1990) who reported a DM forage mass of 8,300 kg ha^{-1} for a mixture of “Tifton 44” bermudagrass and “Apollo” alfalfa planted on 15-cm rows with no nitrogen applied and 11,200 kg ha^{-1} for the same varieties on 30-cm rows. Similarly, Kallenbach et al. (2002) reported seasonal DM forage mass ranging from 8,300 to

11,100 kg ha^{-1} for pure stands of grazing-tolerant alfalfa cultivars. In the current study, forage mass characteristics were best optimized at the 4-wk harvest interval and 10-cm clipping height.

Nutritive Value

Date had a significant effect ($P < 0.0001$) on CP concentration, such that CP declined from 165 g kg^{-1} to 140 g kg^{-1} throughout the season. A decline in forage productivity and nutritive value is expected as vegetative growth slows down into the fall; however, alfalfa contribution decreased throughout the season in the current study, contributing to a lower nutritive value later in the year. Although lower than CP concentrations of most legume-grass mixed stands, which generally comprise cool-season grasses and legumes, concentrations of CP in the current study fall within the range for warm-season perennial grass monocultures. Winners of the Southeastern Hay Contest from 2009 – 2019 submitted samples of N-fertilized warm-season perennial hay with CP concentrations ranging from 110 to 190 g kg^{-1} (Dillard et al., 2020). Mandebvu et al. (1999) reported CP concentrations of 111 to 208 g kg^{-1} for N-fertilized 'Tifton 85' bermudagrass harvested at 7- or 2-wk intervals, respectively. Crude protein concentrations of non-fertilized 'Tifton 85' ranged from 88 – 121 g kg^{-1} in a study by Alderman et al. (2011), indicating that added N, whether from legumes or synthetic fertilizer, contributes to greater plant CP concentrations. Conversely, CP concentrations in the current study are less than in pure alfalfa stands. Cassida et al. (2006) reported CP concentration values that declined from 300 to 150 g kg^{-1} from May through September for alfalfa pastures. Another study reported that CP concentrations of three grazing and hay-type alfalfa cultivars ranged from 211 to 241g kg^{-1} when grown in pure stands (Kallenbach et al., 2002). The authors reported that forage quality was lowest in mid-summer, which may coincide with a summer dormancy time-period in the alfalfa growth curve where biomass production is generally less. Hendricks et al. (2020) reported

CP concentration values ranging from 95 to 152 g kg^{-1} for T85 and 75 to 247 g kg^{-1} for T85 mixed with ‘Bulldog 805’ alfalfa across all harvest months.

Harvest height, harvest frequency, and harvest height × frequency interaction effects on forage CP concentration are presented in Table 1. Harvest height did not have a significant effect on CP concentration (P = 0.3078). Concentration of CP was greatest (P = 0.0003) when alfalfa-bermudagrass was harvested at the 4-wk frequency and was not different from the 2-wk and 6-wk intervals (P = 0.7378). There was a significant harvest height × frequency interaction (P < 0.0001). At the 5- and 10-cm harvest heights, CP was greater at the 4- and 6-wk intervals, but at the 15-cm height, greater CP concentrations were observed at the 2- and 4-wk intervals. Clipping at a greater stubble height leaves lower portions of the canopy standing; this forage matures over time, resulting in lower nutritive value when harvested, especially when compounded by a longer harvest interval. The 4-wk harvest interval optimizes CP concentration while producing the greatest seasonal DM forage mass. Brown and Byrd (1990) reported a mean N concentration of 27.4 g kg^{-1} in an alfalfa-bermudagrass mixture, which is equal to approximately 170 g kg^{-1} CP. Forage CP concentrations reported by Stringer et al. (1996) were 215, 207, and 194 g kg^{-1} for alfalfa-bermudagrass mixtures with alfalfa planted on 20-, 40-, and 60-cm rows, respectively. In the current study, CP concentrations were less, likely due to increased weed pressure, but would still meet the nutrient requirements of most classes of livestock (NRC, 2016).

Table 1. Harvest height and frequency effects on crude protein concentration (g kg^{-1}DM basis) of an alfalfa-bermudagrass mixed stand in Shorter, AL.

	Harvest Frequency (wk)			
Harvest Height (cm)	2	4	6	Mean
	-----------------------------------g kg^{-1}-------------------------------------			
5	$146^{d,ef}$	160^{c}	$151^{cd,e}$	152
10	$137^{d,f}$	156^{c}	$154^{c,e}$	149
15	$154^{c,e}$	159^{c}	$129^{d,f}$	147
Mean	146^{b}	158^{a}	145^{b}	

$^{a-b}$ Within a row, means differ (P < 0.05, SEM = 6, n = 3).
$^{c-d}$ Within a row, means differ (P < 0.05, SEM = 7, n = 6).
$^{e-f}$ Within a column, means differ (P < 0.05, SEM = 7, n = 6).

Forage IVTDMD was not affected by date (P = 0.4060) and ranged from 730 to 740g kg^{-1} across the season. As harvest height increased, IVTDMD increased (710, 730, and 760 g kg^{-1} at 5, 10, and 15-cm, respectively; P < 0.0001). This response would be expected, as the leaf: stem ratio changes throughout the canopy (Ball et al., 2001) such that more leaves are present at the top of the plant, resulting in a greater proportion of digestible material harvested at a greater clipping height. Harvest frequency had a significant effect on IVTDMD (P < 0.0001). At the 2 and 4-wk intervals, IVTDMD was 740 and 750 g kg^{-1} respectively (P = 0.3955), and digestibility was less at the 6-wk harvest interval (710 g kg^{-1}). These data reflect that, as time between harvest intervals are lengthened, forage quality declines due to increased accumulation and lignification of the plant cell-wall fraction. However, IVTDMD values in the range of 710 to 760 g kg^{-1} would be sufficient for any class of livestock. A 600-kg cow of average milking ability requires 586 g kg^{-1} of total digestible nutrient per day during peak lactation, which coincides with the highest nutrient requirements for cattle (NRC, 2016). Digestibility values in the current study fall within the range reported by Hendricks et al. (2020), where IVTDMD values ranged from 775 to 829 g kg^{-1} for T85 and from 695 to 841 g kg^{-1} for T85 and alfalfa. Digestibility values in the current study are greater than reported values for bermudagrass monocultures in other literature.

Mandebvu et al. (1999) reported IVTDMD values of 622 to 510 g kg^{-1} for T85 from 3-wk to 7-wk harvest intervals. Alderman et al. (2011) also reported lower values, 467 to 563 g kg^{-1}, for nonfertilized bermudagrass harvested at 28-d intervals. The height × frequency interaction for forage IVTDMD was not significant ($P = 0.2919$).

Average total digestible nutrient (TDN) concentration for alfalfa-bermudagrass in the present study was 610 g kg^{-1}, which falls within the range of those reported by Beck et al. (2017b) in which TDN content of grazed alfalfa-bermudagrass mixtures ranged from 558 to 690 g kg^{-1} throughout the growing season. As with CP concentrations, the digestibility of forage in the current study would meet the requirements of most classes of grazing livestock.

CONCLUSIONS

Interseeding alfalfa into bermudagrass provided high-quality forage throughout the summer months. Extending the harvest interval resulted in a decline in forage quality but greater forage mass. In contrast, short harvest intervals had relatively low forage mass with greater quality, although continued intensive management under these parameters may negatively impact alfalfa persistence. The 4-wk, 10-cm treatment combination optimized both forage mass and quality components, which may provide management guidance for forage-livestock producers. Both IVTDMD and CP concentrations of alfalfa-bermudagrass mixtures across various harvest intervals and heights would meet or exceed the nutritional requirements of most grazing livestock. Results from this study indicate that timing of harvest has a significant influence on forage quality and forage mass and must be carefully considered to optimize both aspects for maintenance of stand productivity and longevity. Incorporating alfalfa into bermudagrass may move the Southeast US towards a longer grazing season while improving forage mass, quality and reducing traditional N inputs. To move into the next step of developing grazing recommendations, future research should focus on applying defoliation management strategies developed from small-plot studies to grazing trial evaluations.

CHAPTER 4

INFLUENCE OF HARVEST STRATEGY ON PERSISTENCE OF ALFALFA-BERMUDAGRASS MIXTURES IN THE SOUTHEAST UNITED STATES

INTRODUCTION[2]

Alfalfa was once the dominant perennial legume species utilized in the Southeast US; however, the harsh environment and elevated insect pressure soon eliminated many alfalfa stands (Ball et al., 2015). Growing interest in interseeding high-quality legumes, like alfalfa, into existing bermudagrass has regenerated alfalfa acreage in the Southeast US (Beck et al., 2017b; Bouton and Gates, 2003).

To reap the benefits of N production from legumes without applying synthetic fertilizer, a forage stand must be composed of at least 30% legumes (Collins et al., 2017). Consequently, when incorporating a legume into pastures or hay fields, care should be taken to utilize harvest management techniques which favor the persistence of the legume (Beuselinck et al., 1994). Defoliation timing and intensity have a direct influence on persistence of a stand. Breeding efforts have led to alfalfa varieties that are more grazing-tolerant (Bouton and Gates, 2003), and previous studies have evaluated such varieties in pure and mixed stands and under various harvest and grazing regimes (Beck et al., 2017; Kallenbach et al., 2002). Determining the appropriate target grazing height and frequency may optimize forage mass and quality, while ensuring persistence of alfalfa in alfalfa-bermudagrass mixtures.

The objective of this research was to determine the influence of forage harvest height and frequency on canopy cover, botanical composition, stand density, dry-weight-rank, and canopy light interception in alfalfa-bermudagrass mixed stands under simulated grazing. This research

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[2] Target Journal: Crop Science

will help to establish first-step recommendations towards more defined grazing parameters that favor legume persistence in mixed alfalfa-bermudagrass systems in the Southeast US.

MATERIALS AND METHODS

Research Site and Experimental Design

A 2-year simulated-grazing small-plot trial was conducted during the 2018 – 2019 growing seasons at the E.V. Smith Research Center in Shorter, AL (32°26'31.3"N latitude, 85°53'51.1"W longitude). Research plots were located in a previously established ‘Tifton 85’ bermudagrass hayfield comprising Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) and Luverne sandy loam (fine, mixed, semiactive, thermic Typic Hapludults) (Web Soil Survey, 2020).Thirty-six plots (1.5 × 4.6 m) were organized in a randomized complete block design into four blocks, each comprising nine plots representing a 3 × 3 factorial arrangement of harvest height (5, 10, and 15 cm) and harvest frequency (2, 4, and 6 wk) treatments. Treatments represent parameters of varied grazing management practices on perennial warm-season grass pastures in the Southeast US.

Plot Establishment and Management

On Nov 27, 2017, pre-inoculated ‘Bulldog 805’ alfalfa seed was planted using a no-till drill (Great Plains, Salina, KS) in 36-cm rows at a rate of 28 kg ha^{-1}, and no deeper than 1.3 cm following alfalfa establishment recommendations for the Southeast US (Hancock et al., 2015). Prior to planting, bermudagrass was clipped to a 5-cm stubble and sprayed with glyphosate (2.5 kg a.i. ha^{-1}). In Feb 2018, 45.5 kg ha^{-1} of potassium (muriate of potash; 0-0-62 N-P-K), 18.2 kg ha^{-1} of nitrogen (urea-ammonium nitrate; 32-0-0 N-P-K), and 1.4 kg ha^{-1} of boron (10%

granular) were applied. On Mar 5, 2019, 112 kg ha^{-1} of potassium (muriate of potash; 0-0-62 N-P-K) was applied. On May 15, 2019, boron (10% granular) was applied at 3.4 kg ha^{-1}. To control annual grass weeds, pendimethalin (Prowl H2O ((N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine); BASF Ag Products, Floram Park, NJ) was applied on Jun 14, 2018 at a rate of 2.1 kg a.i. ha^{-1} and Feb 18, 2019 at a rate of 1.1 kg a.i. ha^{-1}. Plots were scouted for insect pests at every harvest. Pea aphids (*Acyrthosiphon pisum*) were observed but did not reach the threshold for treatment. In the summer of 2019, rainfall was limited, and 1.27 cm of irrigation was applied on May 30 followed by 3.81 cm on Sep 17 for initiation and stand maintenance at the beginning and end of the evaluation, respectively. Plots were clipped according to treatment designation using a flail-type forage harvester (Carter Manufacturing Co., Inc., Brookston, IN) on Jun 11, Jun 25, Jul 9, Jul 19, Aug 6, Aug 21, and Sep 4, 2018; and on Jun 4, Jun 18, Jul 2, Jul 16, Jul 30, Aug 13, Aug 29, Sep 10, Sep 23, and Oct 10, 2019.

Response Variables

Canopy Cover, Botanical Composition, and Stand Density

Vegetative cover, botanical composition, and stand density were measured at the first, mid-point, and final harvests of the growing season in each year of the study. Vegetative cover was measured pre-harvest by visually estimating the percent stand of each component (alfalfa, bermudagrass, weeds and/or bare area) to the nearest 5% within three randomly placed 0.1-m^2 quadrats within the plot. Within-quadrat material was harvested via hand-clipping to a 2-cm height and collected for botanical composition analysis. Material was hand separated into botanical components (alfalfa, bermudagrass, and weeds) and dried, and individual components were weighed to estimate component forage mass and contribution to the stand. Alfalfa stand density was rated by counting the number of alfalfa plant crowns within three 0.1-m^2 quadrats placed at random locations within the plot.

Dry-Weight-Rank

Dry-weight-rank was measured at every harvest according to methods of Mannetje and Haydock (1963). Five 0.1-m^2 quadrats were placed randomly within plot, and canopy height was measured within quadrat using a pasture ruler. Species within quadrat were visually assessed and ranked as first, second, or third based on relative contribution to stand. Each component proportion was multiplied by 70.2, 21.1, and 8.7, respectively, and added to give the dry-weight percentage of each species in the stand. These fixed multipliers, cited by Mannetje and Haydock (1963), were derived from fifteen sets of pasture botanical composition data as a way to estimate mixed species stand contribution.

Canopy Light Interception

Canopy light interception data were collected in each plot before the first, mid-point, and final harvests within each year of the study. Measurements were taken pre-harvest between 0700 and 0900 h. Leaf area index was measured by collecting one above canopy light (A) reading followed by four (B) readings beneath the plant canopy, one at each corner of the plot, using a LI-2200C Plant Canopy Analyzer (LI-COR Biosciences, Lincoln, NE) with the 90° lens cap in place. The plant canopy analyzer is a non-destructive method for estimating leaf area index and light interception.

Statistical Analysis

Canopy cover, botanical composition, stand density, dry-weight-rank, and canopy light interception were analyzed using the MIXED procedure in SAS 9.4 (SAS Institute, 1994) for a randomized complete block design. Independent variables were harvest height, harvest interval, date, and their interactions. Block and year were random variables. Treatment means were separated using the PDIFF option of the LSMEANS procedure (SAS Institute, 1994) and were determined to be significant when $\alpha = 0.05$.

RESULTS AND DISCUSSION

Weather instruments operated by Agricultural Weather Information Service, Inc. collected daily average ambient temperatures and daily total precipitation data throughout the experimental period. Weather instruments were located in Shorter, AL. Monthly total precipitation and 100-yr average monthly total precipitation are presented in Figure 5. Monthly mean temperatures and 100-yr average monthly mean temperatures in Shorter, AL are presented in Figure 6. In Yr 1, rainfall followed the 100-yr average, except in Aug when rainfall was below average. In Yr 2, rainfall was below average for most of the growing season, resulting in irrigation being applied twice during the season. Monthly mean temperatures tended to follow the pattern of the 100-yr average, except in Sep of both years, when temperatures were greater.

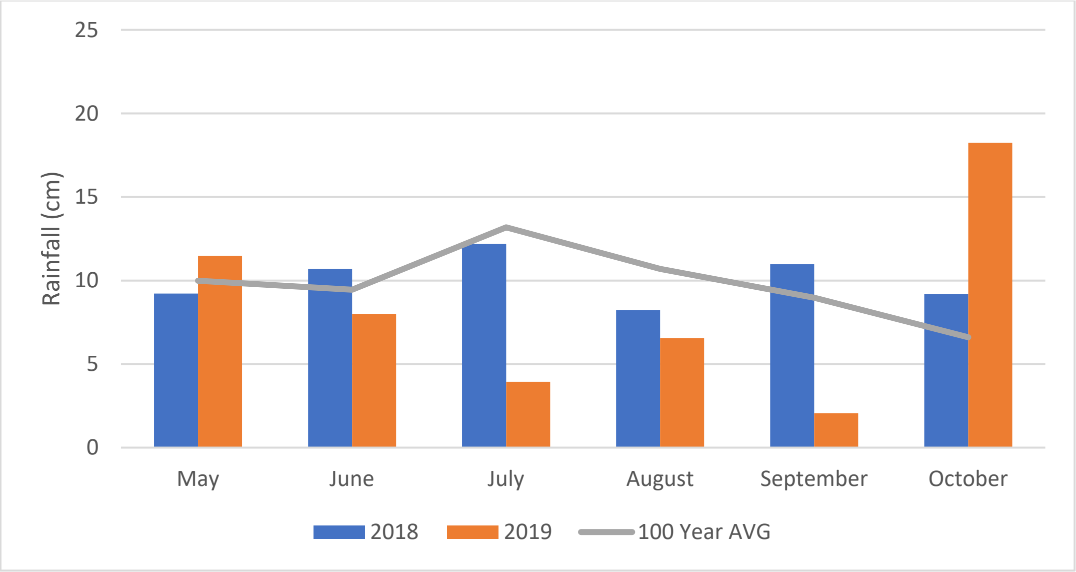

Figure 5. Monthly total precipitation (cm) for 2018, 2019, and 100-yr average in Shorter, AL. Data collected from Agricultural Weather Information Service, Inc.

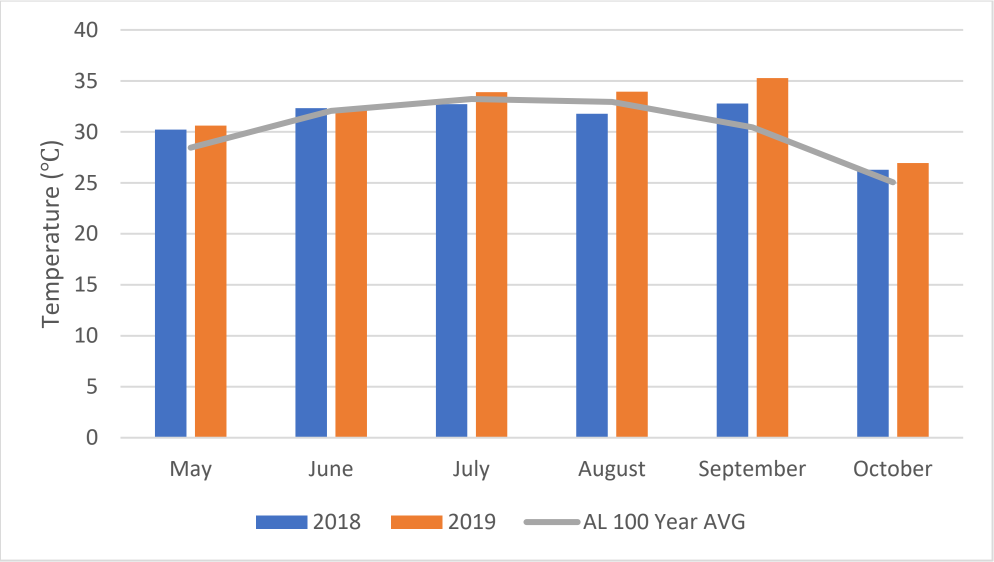

Figure 6. Monthly mean temperatures (°C) for 2018, 2019, and 100-yr average in Shorter, AL. Data collected from Agricultural Weather Information Service, Inc.

Botanical composition

Botanical composition change followed the same pattern as canopy cover. Alfalfa decreased ($P < 0.0001$) from 75% to 28% contribution in the stand during the growing season, whereas bermudagrass and weeds increased ($P = 0.0077$ and $P < 0.0001$, respectively) from 14% to 23% and 10% to 49%, respectively, throughout the season. Harvest height × harvest frequency effects on each species' contribution to botanical composition are presented in Figure 7. Alfalfa contribution was greater ($P < 0.0001$) in the height × frequency combinations where harvest interval was 4 or 6 weeks. Botanical composition is based on weight from manual separation of individual species components. Mass from alfalfa is distributed more evenly throughout the canopy compared with bermudagrass and other grasses present. Clipping at greater harvest heights may leave the bulk of bermudagrass behind post-harvest, whereas the taller parts of alfalfa plants contribute more weight. Conversely, contribution from other species in the stand was greater ($P = 0.0371$) in the height × frequency combinations where harvest interval was 2 weeks, with the greatest contribution at the 5-cm height. Bermudagrass differed ($P = 0.0002$) among treatments, but contribution was relatively low (below 30%) across all height × frequency combinations. In a study by Brown and Byrd (1990), alfalfa contribution declined from 100% at the beginning of the season to a low point in August and increased again in the fall, and it never fell below 50% throughout the season. In the current study, weed encroachment was problematic, especially in intensive harvest regimes and lowered overall alfalfa contribution. Weed control prior to planting and throughout the growing season is important for alfalfa to remain a significant contributor to total stand composition.

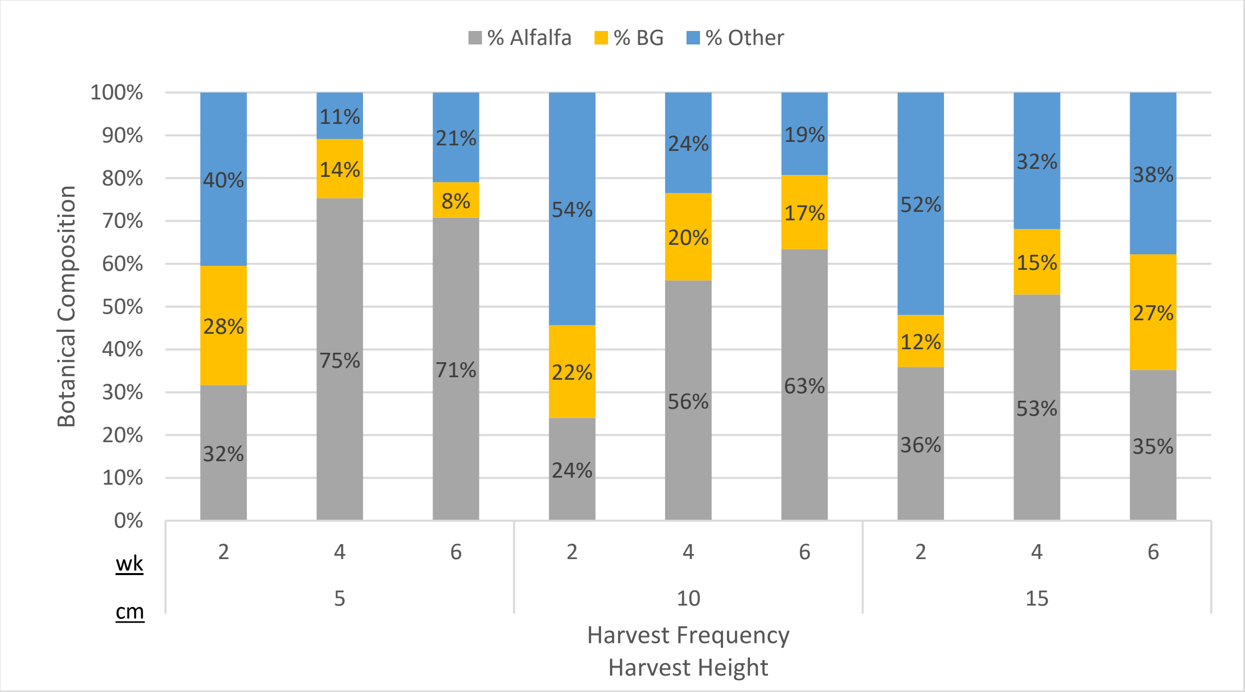

Figure 7. Influence of harvest frequency and height on botanical composition of an alfalfa-bermudagrass mixed stand in Shorter, AL.

Canopy Cover

Visual observations and evaluation of forage stands are simple and inexpensive compared with other measurements of forage productivity; these real-time observations can assist producers in estimating forage mass and composition of pastures and hay fields. Canopy cover is the proportion of the ground area covered by the canopy when viewed vertically (Allen et al., 2011). This measure influences light interception and is an indicator of forage persistence and overall productivity of the stand. Canopy cover varied by species throughout the growing season in mixed alfalfa-bermudagrass stands under various defoliation strategies across the 2-yr trial. Alfalfa contribution was greatest ($P < 0.0001$) in the early part of the season at 68% and declined to 30% of the stand by the end of the growing season. Bermudagrass contribution increased ($P = 0.0366$) from 17% to 23%, but not to the extent that weed pressure increased ($P < 0.0001$) by the end of the growing season (11% to 42%). Weeds commonly observed in the stand were hairy crabgrass (*Digitaria sanguinalis*), little barley (*Hordeum pusillum* Nutt.), and Johnsongrass [*Sorghum halepense* (L.) Pers.]. Bare ground increased ($P = 0.0172$) but remained below 7% throughout the season, which reflects changing canopy characteristics that favored increased competition from weeds.

Harvest height × frequency interaction effects on alfalfa contribution to canopy cover are presented in Table 2. Alfalfa contribution was greatest at the 4-wk × 5-cm, 6-wk × 5-cm, and 6-wk × 10-cm harvest regimes ($P < 0.0001$). At the 2-wk interval, alfalfa contribution was relatively low ($P < 0.0001$), regardless of harvest height, and did not differ between 4- and 6-wk rest periods. As harvest height increased, alfalfa contribution decreased ($P = 0.0002$). Across the growing season, the optimal stand contribution by alfalfa in an alfalfa-bermudagrass mixed stand is ~50% to provide N derived from the legume to the system, while favoring the persistence of both species. This target was achieved at all heights within the 4-wk harvest interval. However, a minimum of 30% legume contribution is needed to maintain sufficient forage productivity without N-fertilization (Collins et al., 2017). The 30% minimum contribution was achieved at most height and frequency combinations within the current study, except for the most intensive 2-wk harvest regimes. Date × harvest frequency greatly impacted ($P = 0.0004$) alfalfa contribution, especially at the 2-wk harvest interval. When clipped at a 2-wk interval, alfalfa contribution declined by 73% by mid-season and by 88% at the end of the season across the 2-yr evaluation. In Aug of each year, lack of forage DM availability in 2-wk plots resulted in three of nine (Yr 1) and six of nine (Yr 2) plots not being harvested. Alfalfa growth decreases during its summer dormancy period, further impacting decreased alfalfa contribution in 2-wk plots. This tremendous decline indicates that harvesting at a 2-wk interval is detrimental to the longevity of alfalfa. Bermudagrass canopy cover was not different among harvest heights ($P = 0.6944$) or harvest frequencies ($P = 0.9333$). Contribution by bermudagrass remained low throughout the season, though it increased ($P = 0.0366$) slightly throughout the growing season. Low contribution was likely due to weed pressure.

There was a significant harvest date × harvest frequency interaction (Table 3; $P = 0.0144$), where bermudagrass decreased throughout the season at the 2-wk harvest interval but increased at the 4 and 6-wk intervals. The decline in bermudagrass at the 2-wk interval was likely due to depletion of root reserves used for regrowth. As forage is harvested every 2-wk without time to regrow, the canopy opens and allows weeds to outcompete other species. Visual bermudagrass contribution was greatest ($P < 0.0001$) at the 2-wk × 5-cm, 4-wk × 10-cm, and 6-wk × 15-cm harvest height by harvest frequency combinations, respectively. Harvest height × frequency interaction effects on contribution by weeds to canopy cover are presented in Table 4.

Weed pressure increased ($P < 0.0001$) with increasing harvest heights. At the 2-wk harvest interval, weed pressure was greatest ($P < 0.0001$), with intermediate weed contribution at the 6-wk interval, and lowest at the 4-wk interval. Among harvest height × harvest frequency combinations, weed pressure was the greatest at all heights within the 2-wk harvest interval. Following the opposite pattern of alfalfa, weed pressure greatly increased ($P < 0.0001$) throughout the season at all harvest frequencies, but especially at the 2-wk interval. At the 2-wk harvest interval, weed contribution increased by 513% by mid-season and by 555% at the end of the season. As alfalfa contribution declined, weed pressure increased, indicating that a 2-wk harvest interval opens the canopy to allow weeds to flourish. These results are in agreement with Hoveland et al. (1996), where grazing tolerant ‘Alfagraze’ alfalfa was harvested at 2, 4, and 6-wk intervals. The authors reported that alfalfa contribution declined greatly with more frequent harvest intervals, and grass encroachment was greatest at the 2-wk harvest interval. There was a significant harvest height × frequency effect (Table 5; $P = 0.0039$) on bare ground contribution to total canopy cover . The 4-wk × 5-cm harvest treatment resulted in the greatest amount of bare ground. At the lowest clipping height, persistence of all species was reduced and likely contributed to increased bare ground in those plots.

Table 2. Harvest height and frequency effects on alfalfa contribution to canopy cover (%) in an alfalfa-bermudagrass mixed stand in Shorter, AL.

	Harvest Frequency (wk)			
Harvest Height (cm)	2	4	6	Mean
5	$28^{g,ij}$	$60^{f,i}$	$64^{f,i}$	50^{a}
10	$22^{h,j}$	$48^{g,j}$	$63^{f,i}$	44^{b}
15	$34^{g,i}$	$52^{f,ij}$	$29^{g,j}$	38^{c}
Mean	28^{e}	53^{d}	52^{d}	

$^{a-c}$ Within a column, means differ ($P < 0.05$, SEM = 4.60, n = 3).
$^{d-e}$ Within a row, means differ ($P < 0.05$, SEM = 4.60, n = 3).
$^{f-h}$ Within a row, means differ ($P < 0.05$, SEM = 5.40, n = 6).
$^{i-j}$ Within a column, means differ ($P < 0.05$, SEM = 5.40, n = 6).

Table 3. Harvest height and harvest frequency effects on bermudagrass contribution to canopy cover (%) in an alfalfa-bermudagrass mixed stand in Shorter, AL.

	Harvest Frequency (wk)			
Harvest Height (cm)	2	4	6	Mean
5	$29^{a,c}$	$15^{b,d}$	$12^{b,d}$	19
10	18^{d}	26^{c}	18^{d}	21
15	$9^{b,d}$	$18^{b,cd}$	$28^{a,c}$	18
Mean	19	20	19	

$^{a-b}$ Within a row, means differ ($P < 0.05$, SEM = 9.10, n = 6).
$^{c-d}$ Within a column, means differ ($P < 0.05$, SEM = 9.10, n = 6).

Table 4. Harvest height and frequency effects on weeds contribution to canopy cover (%) in an alfalfa-bermudagrass mixed stand in Shorter, AL.

Harvest Height (cm)	Harvest Frequency (wk) 2	4	6	Mean
5	$38^{g,k}$	$11^{h,k}$	$22^{i,k}$	24^{c}
10	$57^{g,j}$	$20^{h,jk}$	$16^{h,k}$	31^{b}
15	$53^{g,j}$	$26^{h,j}$	$40^{i,j}$	40^{a}
Mean	49^{d}	19^{e}	26^{f}	

$^{a-c}$ Within a column, means differ (P < 0.05, SEM = 6.32, n = 3).
$^{d-f}$ Within a row, means differ ($P < 0.05$, SEM = 6.32, n = 3).
$^{g-i}$ Within a row, means differ (P < 0.05, SEM = 6.91, n = 6).
$^{j-k}$ Within a column, means differ (P < 0.05, SEM = 6.91, n = 6).

Table 5 Harvest height and frequency effects on bare ground contribution to canopy cover (%)in an alfalfa-bermudagrass mixed stand in Shorter, AL.

Harvest Height (cm)	Harvest Frequency (wk) 2	4	6	Mean
5	5^{f}	$14^{e,g}$	2^{f}	7^{a}
10	3	6^{h}	4	4^{b}
15	4	4^{h}	3	4^{b}
Mean	4^{d}	8^{c}	3^{d}	

$^{a-b}$ Within a column, means differ (P < 0.05, SEM = 1.58, n = 3).
$^{c-d}$ Within a row, means differ ($P < 0.05$, SEM = 1.58, n = 3).
$^{e-f}$ Within a row, means differ (P < 0.05, SEM = 2.04, n = 6).
$^{g-h}$ Within a column, means differ (P < 0.05, SEM = 2.04, n = 6).

Stand Density

Harvest height × frequency interaction effects ($P < 0.0001$) on alfalfa stand density are presented in Table 6. Stand density is measured as number of alfalfa crowns per 0.1-m^2. The number of alfalfa crowns was greater ($P < 0.0001$) at the 4 and 6-wk harvest frequencies, illustrating that these intervals favor persistence of alfalfa. The greatest alfalfa crown densities were observed when stands were defoliated to a 5-cm stubble height and allowed to rest for 4 or 6-wk intervals between harvests, or when the 6-wk harvest interval was clipped to a height of 10 cm. This result agrees with what was observed for canopy cover, where the 4-wk harvest interval resulted in greater alfalfa contribution. Greater alfalfa plant densities were correlated with alfalfa contribution to botanical composition in the 4 and 6-wk plots harvested to 5-cm. Undersander et al. (2011) indicates that, during a seeding year, 25 to 30 alfalfa plants should be present per square foot in a pure stand of alfalfa. Following this guideline for a mixed alfalfa-bermudagrass stand, 12 to 15 plants per square foot is a target for the seeding year, assuming a 50% contribution from each desirable forage component in the stand. Alfalfa plant numbers were lower than this level of contribution in the current study, likely due to weed encroachment. Additionally, the changes in stand density in the present study are means that reflect changes across seasonal sampling dates, which indicates that there are times during the year where alfalfa contribution may be greater than others. Alfalfa contribution is greater in the spring and fall, whereas bermudagrass production dominates in the summer. This complementary growth distribution makes the mixture a desirable option for extending the grazing season.

Table 6. Harvest height and harvest frequency effects on alfalfa stand density (# of crowns 0.1 m^{-2}) in an alfalfa-bermudagrass mixed stand in Shorter, AL.

Harvest Height (cm)	Harvest Frequency (wk)			Mean
	2	4	6	
5	$5^{c,ef}$	8^{c}	$8^{c,e}$	7
10	$3^{d,f}$	7^{d}	$9^{c,e}$	6
15	$6^{cd,e}$	7^{c}	$4^{d,f}$	6
Mean	5^{b}	7^{a}	7^{a}	

[a-b] Within a row, means differ ($P < 0.05$, SEM = 1.46, n = 3).
[c-d] Within a row, means differ (P < 0.05, SEM = 1.54, n = 6).
[e-f] Within a column, means differ (P < 0.05, SEM = 1.54, n = 6).

Dry-Weight-Rank

Dry-weight-rank and canopy cover are measurements that can be used by forage-livestock producers to visually assess persistence characteristics in a mixed stand of alfalfa and bermudagrass. Date had significant effects on alfalfa and contribution from other species for dry-weight-rank ($P < 0.0001$ and $P < 0.0001$, respectively). Alfalfa decreased from 63 to 29% throughout the season, whereas other species increased from 13 to 37%. The most common other species found in the stand were hairy crabgrass, little barley, and curly dock (*Rumex crispus* L.). Bermudagrass remained relatively constant ($P = 0.0690$) across the season, ranging from 22 to 28%. The same patterns were observed in canopy cover.

Harvest height × harvest frequency interaction effects on alfalfa, bermudagrass, and other species dry-weight-rank is presented in Figure 8. Alfalfa dry-weight-rank was greater ($P < 0.0001$) at the 5 and 10-cm harvest heights within the 4 and 6-wk intervals, following the same pattern as alfalfa contribution to botanical composition. Bermudagrass dry-weight-rank differed among treatments ($P = 0.0009$), for which it was greatest at the 2-wk harvest interval when the mixture was defoliated at 5 or 10 cm, and least at the 6 wk harvest frequency when harvested to a stubble height of 5 cm. When forage is not clipped regularly, it enters the reproductive stage and growth plateaus; a thick stubble of stems accumulates and shades out or restricts new growth (Ethredge et al., 1973). Dry-weight-rank of other species or bare ground dry-weight-rank was not different among height × frequency combinations ($P = 0.3728$).

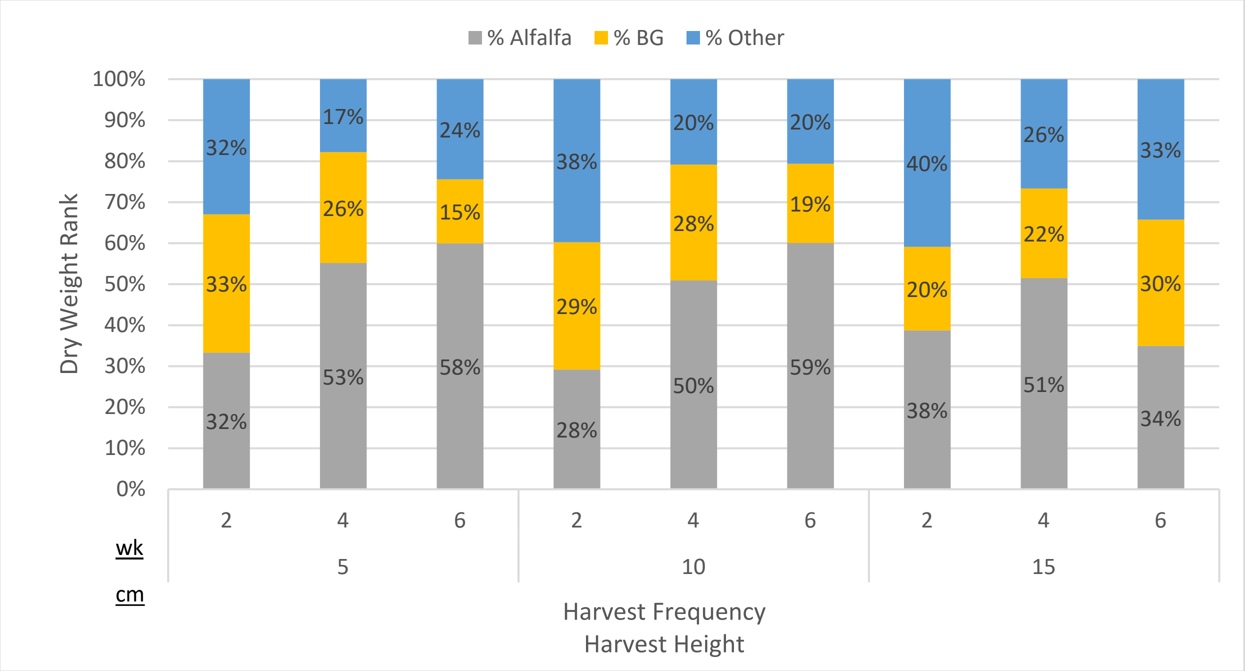

Figure 8. Influence of harvest frequency and height on dry-weight-rank of alfalfa, bermudagrass, and other species or bare ground in an alfalfa-bermudagrass mixed stand in Shorter, AL.

Canopy Light Interception

Date, harvest frequency, and date × frequency interaction effects are presented in Table 7 for canopy light interception. Leaf area index decreased ($P < 0.0001$) throughout the season and increased ($P = 0.0006$) as harvest frequency decreased. This response was similar to that of canopy cover, where shortened photoperiod in the fall reduced canopy cover as forage growth slowed, and decreased harvest frequency resulted in greater canopy cover. There was a significant harvest date × frequency interaction ($P = 0.0052$) where LAI was equal among harvest frequency intervals early in the season, but at the end of the season was greater at the 6-wk interval. LAI is an indicator of canopy light interception but does not indicate which species are present. This measurement relates to overall sward density. Photoperiod decreases as the growing season moves into the fall months, and growth of tropical forages such as bermudagrass begins to slow (Sinclair et al., 2001). ‘Bulldog 805’ alfalfa has a fall dormancy rating of 8, meaning it can grow later into the fall than varieties with a lower fall dormancy rating. However, with day length decreasing, overall growth of both species slows down contributing to decreased sward density and canopy light interception.

Table 7. Date and harvest frequency effects on canopy light interception (leaf area index) in an alfalfa-bermudagrass mixed stand in Shorter, AL.

Item	Harvest Frequency			
Date	2 weeks	4 weeks	6 weeks	Mean
Early-Season	4.7^{g}	4.6^{g}	4.6^{g}	4.6^{a}
Mid-Season	$2.2^{f,h}$	$2.8^{f,h}$	$3.9^{e,h}$	3.0^{b}
Late-Season	$3.0^{ef,i}$	$2.4^{f,h}$		3.0^{b}
Mean	3.3^{d}	3.3^{d}	4.0^{c}	

[a-b] Within a column, means differ ($P < 0.05$, SEM = 1.05, n = 3).
[c-d] Within a row, means differ ($P < 0.05$, SEM = 1.05, n = 3).
[e-f] Within a row, means differ ($P < 0.05$, SEM = 1.07, n = 6).
[g-i] Within a column, means differ (P < 0.05, SEM = 1.07, n = 6).

CONCLUSIONS

Fall-planted alfalfa into bermudagrass provides potential for increased forage mass and greater seasonal distribution. Harvest regimes that favor alfalfa persistence must be utilized to ensure longevity of the stand. Weed control is crucial before planting and during the growing season. Short harvest intervals and intensive harvest strategies such as the 2-wk × 5-cm management combination result in greater weed pressure and reduced alfalfa contribution. Finding an optimal balance of harvest height and frequency ensures adequate sunlight to both desired species and allows for rest and regrowth following harvest. Results from this study indicate that a 4-wk harvest interval favors alfalfa contribution and persistence, although bermudagrass contribution was low throughout the project overall due to increased weed pressure. Additional small-plot research with increased weed control may further define harvest strategies that optimize persistence of alfalfa-bermudagrass mixtures. However, results from this study provide information that may help guide future research with grazing management of alfalfa-bermudagrass mixtures. A grazing study which applies the optimal 4-wk rotation interval and 5 to 10-cm grazing stubble height to alfalfa-bermudagrass pastures may provide further information on alfalfa-bermudagrass production and persistence characteristics under animal defoliation.

CHAPTER 5

DEVELOPMENT OF A FORAGE MASS ESTIMATION TOOL FOR ALFALFA-BERMUDAGRASS MIXTURES [3]

INTRODUCTION

As acreage of bermudagrass (*Cynodon dactylon* (L.) Pers.) interseeded with alfalfa (*Medicago sativa* L.) increases in the Southeast US, the need arises for a tool for producers to estimate forage mass in pastures and hayfields to aid in making appropriate harvest timing or grazing management decisions in forage-livestock operations. Inaccurate estimates of forage mass may result in stocking and harvest management mistakes, which are costly if the forage supply is inadequate (Sanderson et al., 2001).

Measuring sward height is a non-destructive technique that facilitates forage mass estimation in grass-based, monoculture systems. A pasture ruler or grazing stick, available to producers through local Extension and Natural Resource Conservation Services, is a meter ruler with pasture management information inscribed on the side. The information found in the inscribed tables relates forage height to estimated forage mass in kg DM ha^{-1} per cm of available forage, and it is based on positive linear relationships determined through previous research (Sanderson et al., 2001). In mixed stands, species composition is variable and forage mass estimation becomes more challenging. To estimate forage mass in mixed forage stands, measures of stand variability must be considered (Alexander et al., 1962; Baxter et al., 2017). Stand variability measurements such as canopy cover, botanical composition, and dry-weight-rank, combined with sward height may more accurately estimate forage mass in alfalfa-bermudagrass stands (Pasto et al., 1957). These measurements can be completed easily on-farm to provide real-

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[3] Target Journal for Publication: Crop Science

time forage mass estimates to producers and may provide a practical approach for relating non-destructive estimates to destructive harvest data that can be more readily applied by stakeholders.

The objective of this research is to develop forage mass-estimation metrics for alfalfa-bermudagrass mixtures that combines stand variability and sward height measurements. This information can be used to create a decision tool to help producers estimate forage mass in mixed stands in a simple and practical way.

MATERIALS AND METHODS

Research Site

Mixed alfalfa-bermudagrass non-destructive and destructive harvest data forage mass was collected from two experimental locations in Alabama and Georgia across two years (2018-2019) for forage mass tool development. In Alabama, plots were established at the Auburn University E.V. Smith Research Center (32°26’30.6”N, 85°53’50.0”W) in Shorter on Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) and Luverne sandy loam soils (fine, mixed, semiactive, thermic Typic Hapludults) (Web Soil Survey, 2020). In Georgia, plots were established at the University of Georgia Tifton Campus (31°30’00.7”N, 83°31’18.1”W) in Tifton on Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with slopes ranging from 0 to 8% (Web Soil Survey, 2020).

Plot Establishment and Management

At both locations, thirty-six plots (1.5 × 4.6 m) of cultivar ‘Bulldog 805’ alfalfa (Athens Seed Co., Athens, GA) were interseeded into an existing ‘Tifton 85’ hybrid bermudagrass stand (Burton et al., 1993) using a randomized complete block design with nine treatments and four replications at all locations. Plots were established using a no-till drill planting at 35.5-cm row spacing in October 2017 at 27 kg ha^{-1} pure live seed in AL, and February 2018 at 13.5 kg ha^{-1} pure live seed in GA.

The project site was established as a simulated grazing trial to determine forage mass, persistence, and nutritive value of alfalfa-bermudagrass mixtures under a range of potential harvest management strategies. Soil testing information, fertility and pest management practices for the experiment are described in Ch. 3 and 4, respectively. Harvest treatments included a combination of harvest heights (5, 10, 15 cm) and harvest frequencies (2, 4, 6 wk) for nine total treatment combinations, and response variable data were collected in summer 2018 and 2019, respectively. In the spring, when alfalfa maturity reached mid-bloom stage (25% of plants have flowers), a clean-off harvest was performed in which all plots were harvested to 7.6 cm. Data collection began annually at all locations two weeks after the clean-off harvest. In Alabama, the harvest season was from Jun 11 through Sep 4, 2018 and from Jun 4 through Oct 10, 2019 with 2-, 4-, and 6-wk plots harvested 7, 3, and 2 times, and 10, 5, and 3 times, respectively. In Georgia, the harvest season was from Jun 2 through Oct 9, 2018 and May 2 through Oct 17, 2019 with 2-, 4-, and 6-wk plots harvested 10, 5, and 4 times, and 13, 7, and 5 times, respectively

Destructive Harvest Canopy Estimates

Forage mass was determined by cutting a forage mass strip (1.0 × 4.6 m) from the center of each plot sing a Carter flail-type forage harvester (Carter Manufacturing Company, Inc., Brookston, IN) or a Swift Forage Plot Harvester IV (Thompson, 1972). Plots were harvested at their respective assigned harvest height and frequency treatment combinations. All harvested material was collected, and fresh weights were recorded following field sampling. A grab sample was collected from each strip for nutritive value analysis and moisture correction calculations. Grab samples were weighed fresh and dried at 60°C for 48 hours until a constant weight was reached to determine DM concentration. Grab sample data were used to convert the total aboveground fresh weight to total DM forage mass within plot.

Non-Destructive Canopy Measurements

Vegetative cover, botanical composition, and dry-weight-rank measurements were used to determine species contribution in mixed alfalfa-bermudagrass stands. Canopy height was also measured with each dry-weight-rank measurement using a grazing stick. These non-destructive observations were used to develop forage mass estimation equations as a potential measure that could be used by producers to assess stand DM production potential prior to harvest. Vegetative cover was measured pre-harvest by visually estimating the percent stand of each component (alfalfa, bermudagrass, weeds and/or bare area) to the nearest 5% within three randomly placed 0.1-m^2 quadrats within the plot. Within-quadrat material was harvested via hand clipping to a 2-cm height and collected for botanical composition analysis. Material was separated into botanical components (alfalfa, bermudagrass, and weeds) and individual components were weighed to estimate component forage mass.

Dry-weight-rank was measured at every harvest according to methods of Mannetje and Haydock (1963). Five 0.1-m^2 quadrats were placed randomly within plot, and canopy height was measured within quadrat using a pasture ruler. Species within quadrat were visually assessed and ranked as first, second, or third based on relative contribution to stand. Each component was multiplied by 70.2, 21.1, and 8.7, respectively, which represent fixed multipliers based on order of species prevalence in the stand and added to give the dry-weight percentage of each species in the stand.

Data Analysis

Individual non-destructive and destructive harvest observations for alfalfa-bermudagrass were split randomly into calibration and prediction data sets for cross-validation before conducting statistical analysis in SAS 9.4 (SAS Institute Inc., 2016). Canopy height was the independent variable. For each data set, height was linearly regressed on measured forage mass using PROC REG (SAS Institute Inc., 2016). The whole data set was analyzed, as well as three subsets of data based on alfalfa dry-weight-rank percentage (0 – 30%, 31 – 50%, and >50% alfalfa). Precision of the calibration models was evaluated by the coefficient of determination (R^2_{cal}), root mean square error ($\mathrm{RMSE}_{\mathrm{cal}}$), and coefficient of variation ($\mathrm{CV}_{\mathrm{cal}}$). Calibration models were applied to the prediction data sets to evaluate predictive ability. The relationship between predicted and measured forage mass was determined using PROC CORR and PROC REG (SAS Institute Inc., 2016). Precision of each prediction was evaluated using calculated R^2_{pred}, $\mathrm{RMSE}_{\mathrm{pred}}$, and $\mathrm{CV}_{\mathrm{pred}}$ values. Statistical associations between forage DM forage mass, height, and stand variability measurements were determined by stepwise regression using PROC REG (SAS Institute Inc., 2016). Parameter estimates, SE, variable *P*-values, model fit *P*-value, and Mallows C(p) are reported.

RESULTS AND DISCUSSION

Canopy Characteristics

Mean and range of canopy characteristics of alfalfa-bermudagrass mixtures managed under varying defoliation frequencies and intensities are provided in Table 8. Mean canopy height was 25 cm across the summer growing season. Mean alfalfa dry-weight-rank averaged 28.9%, indicating relatively low contribution of alfalfa to the total dry matter. Forage mass had a large range in values throughout the season. As forage harvest frequency increased, alfalfa-bermudagrass mixtures defoliated to lower stubble heights had less residual leaf area remaining post-clipping, which impacted long-term stand persistence. It is important to have a range of observed values to build accurate prediction equations; however, the range in harvest management strategies and their effects on forage regrowth throughout the management season were likely sources of variation contributing to relatively low r^2 values, given that there were not an equal number of observations for each harvest scheme.

Table 8. Range and mean of height, alfalfa contribution, and forage mass measurements of alfalfa-bermudagrass plots in Shorter, AL.

Variable	N	Mean	Min	Max
Canopy Height (cm)	775	25	3.04	68.6
Alfalfa Dry-Weight-Rank (%)	775	28.9	0	100
Alfalfa Canopy Cover (%)	396	30.9	0	96.7
Forage Mass (kg DM ha^{-1})	775	1181.6	15.6	8332.2

Table 9 presents the Pearson correlation coefficients between estimates of variability evaluating alfalfa contribution to total forage mass. All stand variability measurements had strong, significant positive correlations with one another. The strongest relationship was between canopy cover and botanical composition, likely due to visual estimation of canopy cover and botanical separation being performed on the same sample. However, dry-weight-rank has strong correlations with both canopy cover and botanical composition, indicating that it is potentially a good indicator of alfalfa contribution if estimated correctly through training of the evaluator.

Table 9. Pearson correlation coefficients for relationships between estimates of stand variability evaluating alfalfa contribution to total forage mass (n = 396 observations) in an alfalfa-bermudagrass stand.

Item	Canopy Cover	Botanical Composition	Dry-Weight-Rank
Canopy Cover	1.00000	0.90283	0.81265
		$P > 0.0001$	$P > 0.0001$
Botanical Composition	0.90283	1.00000	0.82624
	$P > 0.0001$		$P > 0.0001$
Dry-Weight-Rank	0.81265	0.82624	1.00000
	$P > 0.0001$	$P > 0.0001$	

Model Evaluation for Canopy Characteristics

Measured forage mass was linearly regressed with sward height for each data set to generate the equations found in Table 10. Variance explained by the calibration model is indicated by R^2_{cal}.The calculated root mean square error ($RMSE_{cal}$) is a measure of the difference between measured forage mass and forage mass estimated by the calibration model. Variability in forage mass estimates relative to the mean is described by CV_{cal}. R^2_{cal} and $RMSE_{cal}$ were lowest for the data subset where alfalfa contribution was 0-30% alfalfa. This was the subset of data with the greatest number of observations. However, the minimum target contribution for a legume in a mixed stand is 30%. While the estimates in this alfalfa contribution may be more accurate, overall low legume contribution would be a negative attribute for overall mixed alfalfa-bermudagrass system success. Figure 9 illustrates the relationships between height and measured forage mass for each dataset.

Table 10. Calibration equations used to predict forage mass of alfalfa-bermudagrass mixtures formed by regressing measured forage mass on canopy height and comparison of model precision.

Data set	Calibration Equation	N[a]	r^{2b}	RMSE[c]	CV[d]
All	forage mass = 60.4x - 316.6	388	0.4134	952.1	82.8
0-30% alfalfa	forage mass = 59.3x - 342.7	230	0.4490	670.9	86.3
31-50% alfalfa	forage mass = 59.2x - 306.0	76	0.3376	999.3	75.0
>50% alfalfa	forage mass = 43.3x + 490.2	82	0.1456	1308.2	60.6

[a] N = number of observations

[b] r^2 = variance explained by the calibration model

[c] RMSE = root mean square error; difference between measured forage mass and mass estimated by calibration equation

[d] CV = coefficient of variation; variability in mass estimates relative to the mean

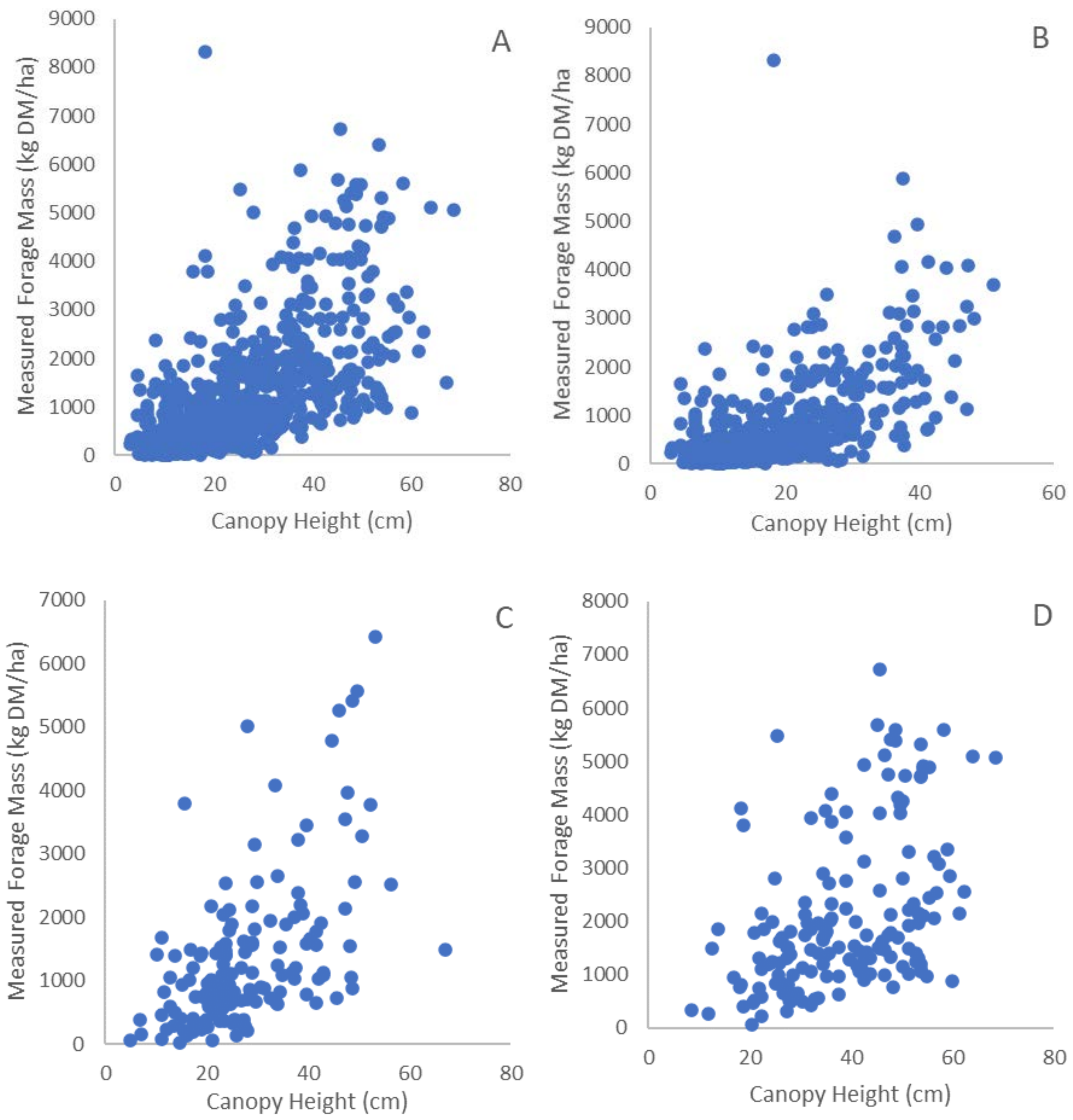

Figure 9. Relationship between average canopy height and measured forage mass for the whole dataset (A), and data subsets with 0 – 30% alfalfa (B), 31 – 50% alfalfa (C), and >50% alfalfa (D).

Graphs in Figure 10 illustrate the relationship between measured forage mass and predicted forage mass when canopy height is used as a predictive measure. Ideally, the slope of the line created by this regression would be equal to 1 and the intercept equal to 0, but was not the case for any of the data sets in this study. A 1:1 line is presented on each graph as a reference. Forage mass was underestimated by prediction equations in the current study.

There was a positive linear relationship between canopy height and forage mass, which follows relationships reported in other literature (Baxter et al., 2017; Michalk and Herbert, 1977; Sanderson et al., 2001). However, height was not an accurate predictor of forage mass, which may be due to structural variability in the canopy where alfalfa plants become less dense as the stems elongate and grow taller than bermudagrass. Canopy morphology plays a role in forage mass and must be considered when estimating forage mass based on height (Gomes et al., 2018). As alfalfa contribution increased, precision of the predictions decreased, which may be in part due to fewer observations.

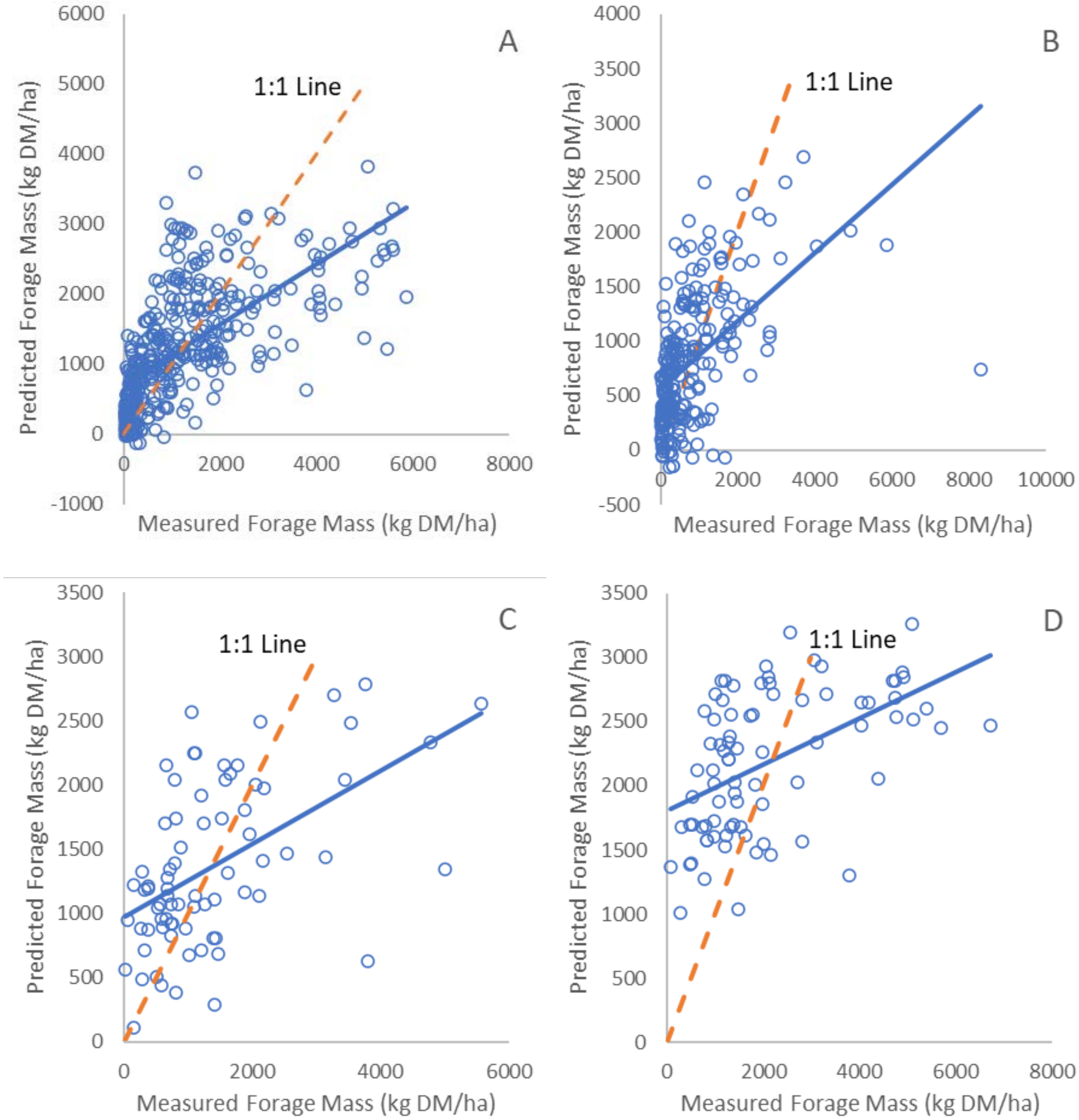

Figure 10. Relationship between measured forage mass and predicted forage mass by each data set: all observations (A), and data subsets with 0 – 30% alfalfa (B), 31 – 50% alfalfa (C), and >50% alfalfa (D).

Table 11 illustrates the comparison of predictive accuracy of determining forage mass from alfalfa dry-weight-rank percentage. In this study, R^2_{pred} was lower than the corresponding R^2_{cal} in the data subsets that were split by alfalfa contribution (0 – 30 and 31-50% alfalfa), but slightly greater for the whole data set and >50% alfalfa data set. The difference in R^2_{cal} and R^2_{pred} were 1.4% decrease, 38.7% increase, 20.8% increase, and 69.3% decrease in variance for the whole data set, 0-30%, 31-50%, and >50% alfalfa, respectively. Adding additional response variables into the model may improve the R^2 value further. Baxter et al. (2017) created a model to predict forage mass in alfalfa-tall wheatgrass pastures using both canopy height and growth stage of each species in the mixture.

Table 11. Comparison of predictive accuracy for determining forage mass of alfalfa-bermudagrass mixtures by considering alfalfa dry-weight-rank.

Data Set	N	r2	RMSE	CV
All	387	0.4191	635.1	51.3
0-30% alfalfa	230	0.2754	506.1	62.7
31-50% alfalfa	75	0.2674	547.7	40.1
>50% alfalfa	82	0.2465	476.8	21.8

Pearson correlation coefficients between forage mass predictions from the equations in Table 10 and measured forage mass from the prediction data set are presented in the Table 12. The greatest correlation between predicted forage mass and measured forage mass was found when the whole data set was analyzed. However, all data sets had a R of 0.5 or greater, indicating moderate positive relationships between the values.

Table 12. Pearson correlation coefficients for relationships between forage mass predictions and measured forage mass.

Data Set	R	P
All	0.64851	<0.0001
0-30% alfalfa	0.52775	<0.0001
31-50% alfalfa	0.52661	<0.0001
>50% alfalfa	0.50576	<0.0001

The relative ability of canopy response measures to explain variance in canopy forage mass characteristics was evaluated using stepwise regression analysis. The best model selected by the stepwise procedure had a significant influence ($P < 0.0001$) when height, alfalfa DWR, and alfalfa CC were all included in the model (Table 13). The R^2 value indicated that the model only moderately explained the variation in forage mass; however, the value falls within the range of those reported in other forage mas estimation literature. Baxter et al. (2017) reported R^2 values of 0.59 to 0.75 for various methods of forage mass estimation in alfalfa-tall wheatgrass pastures. Dillard et al. (2016) reported R^2 ranging from -0.013 to 0.500 for linear equations derived from measuring canopy height with a rising plate meter in multispecies swards. The authors found that forcing the *X* intercept to zero improved R^2 values to 0.774 to 0.874. In the current study, R^2 was not improved by forcing the *X* intercept through zero. The alfalfa-bermudagrass mixture in the current study had heavy weed pressure, which may have contributed towards inaccurate predictions for the mixture due to stand variance. Additionally, continued observations across a wider range of alfalfa contribution (more observations per level of contribution) may be helpful. Although there was a great amount of variability in the dataset, the R^2 of the model (0.4209) is satisfactory value to further improve upon with future research.

Table 13. Stepwise regression of height, alfalfa dry-weight-rank, and alfalfa canopy cover as predictors of forage mass of alfalfa-bermudagrass mixtures.

Dependent Variable	Independent Variable	Parameter	SE	Variable P-Value	Model P-Value	R^2 of Model	Mallows C(p)
Forage mass	Intercept	-183.5	126.3	0.1470	<0.0001	0.4209	4.0
	Height	43.3	5.2	<0.0001			
	Alf DWR	-8.2	3.7	0.0264			
	Alf CC	19.9	3.3	<0.0001			

IMPLICATIONS OF RESEARCH

Combining estimations of stand variability with canopy height may be a way to improve the accuracy of estimating forage mass in mixed stands. Identifying practical but accurate ways of estimating stand variability is critical. The best method for estimating stand variability is one that has a strong correlation with botanical composition. Dry-weight-rank and canopy cover are both strong predictors of botanical composition in alfalfa-bermudagrass mixtures. However, when these stand variance measures are used in combination with canopy height as a forage mass predictor in mixed stands, a large amount of variance was observed in accuracy of forage mass prediction, depending on the level of alfalfa contribution in the stand. A more robust data set may improve predictions, as would incorporating multiple measurements of stand variability into the prediction equation. Additional research and model development are needed to identify the best method(s) of evaluating stand variability and to improve precision of prediction equations. This research will lead to a tool for producers to use on-farm to estimate forage mass of mixed alfalfa-bermudagrass stands.

CHAPTER 6

EVALUATION OF COOL-SEASON ANNUALS OR REDUCED LABOR SUPPLEMENTATION SYSTEMS FOR WINTERING COW-CALF PAIRS[4]

INTRODUCTION

Beef cattle production is a major enterprise in Alabama, and grazed forages comprise the basis for beef cattle nutrition programs in the Southeast US. Cattle producers typically feed hay and supplemental feedstuffs for 90 to 120 days to maintain cows during the winter when fresh forages may not be available for grazing (Prevatt et al., 2018). Relying on conserved forage resources and supplemental feeds can increase production input costs including feed costs and labor needs. Alternative management systems could provide grazing or reduced labor options during this time of year to offset those costs (Beaty et al., 1994b; Mullenix and Rouquette, 2018).

Winter-annual mixtures containing small grains, annual ryegrass (*Lolium multiflorum* Lam.), and annual clovers (*Trifolium sp.)* may provide more early-season forage availability compared with annual ryegrass alone, reducing the need for supplementation during this time period (Gunter et al., 2002; Mullenix and Rouquette, 2018). Other feeding strategies that may decrease labor needs for the winter months include feeding free-choice byproducts or bulk feeding, which reduce the need for daily hand-feeding supplemental feedstuffs. Whole cottonseed is a high-energy cotton byproduct that is easily accessible in the Southeast US and can be an economical way to supplement beef cattle (Jacobs and Mullenix, 2019). Mixtures of pelleted soy hulls and corn gluten feed are also commonly used in the Southeast US and are readily accessible feed resources in most parts of Alabama. This combination of byproducts is low in nonstructural carbohydrates and high in digestible fiber and ruminally degradable protein,

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allowing it to be fed less frequently without negative effects on digestion (Drewnoski et al., 2011). Previous studies have reported that steer performance does not differ when feeding this mixture at 2% of body weight (BW) every other day as opposed to 1% of BW daily (Drewnoski et al., 2011). The objective of this study was to determine animal performance and the relative viability of three winter management scenarios for maintaining lactating beef cow-calf pairs under reduced labor input systems.

MATERIALS AND METHODS

All procedures and experimental protocols were approved by the Institutional Animal Care and Use Committee (Protocol No. 2017-3193).

Research Site and Experimental Design

A 2-year experiment was conducted during the fall of 2017 – 2019 growing seasons at the E.V. Smith Research Center in Shorter, AL (32°26'31.3"N latitude, 85°53'51.1"W longitude). Nine 2-ha paddocks were assigned one of three nutritional management treatments with 3 replications per treatment in a completely randomized design. Treatments included rotationally grazed winter-annuals (RG), reduced frequency feeding of a pelleted 50% soybean hulls and50% corn gluten feed mixture (SH:CGF) plus *ad libitum* hay (RF), and free-choice supplementation of WCS plus *ad libitum* hay (FC).

Forage Establishment

In each year of the study, three 2-ha paddocks were prepared for RG treatment and seeded with ‘RAM’ oat (*Avena sativa* L.) planted at 100 kg ha^{-1} using a no-till drill (Great Plains, Salina, KS), and 33 kg ha^{-1} ‘Dixie’ crimson clover (*Trifolium incarnatum* L.) and 22 kg ha^{-1}

‘Marshall’ annual ryegrass were planted with a cultipacker spreader (Brillion Fram Equipment, Brillion, WI) on Oct 26, 2017 and Oct 23, 2018 (Yr 1 and Yr 2, respectively). In Yr 1, 112 kg N ha^{-1} was applied using 17-17-17 fertilizer on Feb 2, 2018. In Yr 2, 17-17-17 fertilizer was applied at 392 kg ha^{-1} for a rate of 66 kg N ha^{-1} during seedbed preparation, and an additional 46 kg N ha^{-1} was applied on Feb 20, 2019 to achieve the seasonal target 112 kg N ha^{-1}. Paddocks were split in half with temporary electric fencing to facilitate rotational grazing, and were initially stocked with 3 cow-calf pairs. Put-and-take animals (cow-calf pairs) were adjusted every 14 d to manage excess forage to a target height of 25 cm. Grazing was initiated on Jan 23, 2018 and. terminated on Apr 5, 2018 after 73 grazing days in Yr 1 and initiated Jan 28, 2019 and terminated Apr 23, 2019 after 86 grazing days in Yr 2. Grazing termination occurred when canopy height was less than 10 cm and forage mass in RG paddocks could no longer support 3 tester cow-calf pairs.

Feed Supplementation Management

Paddocks that were not planted with winter annuals were assigned to either RF or FC. In RF paddocks, cows were provided 50:50 SH:CGF at 1% of their body weight (BW) per day plus free-choice access to ‘Tifton 85’ bermudagrass (*Cynodon dactylon* (L.) Pers.) hay. The amount of supplement was doubled and fed every other day to reflect a bulk feeding, reduced labor management scenario. In FC paddocks, WCS and ‘Tifton 85’ bermudagrass hay were provided free choice for cow-calf pairs. Feed troughs were filled with an average of 100 kg of WCS at every refill; refills occurred every 3 to 4 days throughout the trial. Cows consumed an average of 4.4 kg/hd/d of WCS. Hay bales were 1.2 × 1.5 m rolls and were replaced every 21 d in both RF and FC treatments. Bermudagrass hay averaged 9.6% crude protein (CP) and 50.8% total digestible nutrients (TDN) on a DM basis. Nutrient concentrations of each feedstuff were 17.2% CP and 75.9% TDN, and 21.8% CP and 99.4% TDN for 50:50 SH:CGF and WCS on a DM basis, respectively.

Response Variables

Forage Mass

Forage production of winter annuals was measured using a double-sampling method (Wilm et al., 1944) every 14 d. In RG paddocks, seventy forage heights were recorded from both the pre- and post-graze sides of each 2-ha paddock using a FILIPS RPM (Agriworks, Ltd., Feilding, New Zealand). Five calibration samples were taken from both the pre- and post-graze sides of 3 paddocks assigned to the RG treatments by recording forage heights and clipping forage from a 0.1-m^2 quadrat to a stubble height of approximately 5 cm. Samples were placed in cloth bags and transported to Auburn University Ruminant Nutrition laboratory for drying. Samples were oven-dried at 50º C for 48 hr and weighed to determine forage mass. Dried, air-equilibrated samples were ground in a Wiley Mill (Thomas Scientific, Swedesboro, NJ) to pass a 1-mm screen, and final concentration of DM was determined by oven-drying at 100º C according to procedures of AOAC (1995).

Animal Performance

Twenty-seven commercial Angus × Hereford cow-calf pairs were stratified by body weight and randomly assigned to treatments in each year of the study. Three pairs were placed on each paddock (n = 3). After a 7-d adaptation period on their respective treatments, cows and calves were weighed again to obtain an initial BW (620 ± 51 kg and 101 ± 16 kg for cows and calves, respectively). Cow-calf pairs were weighed in the morning of each weigh date unshrunk and cows body condition scored every 28 d to determine BW change and calf average daily gain (ADG).

Laboratory Analysis

Forage concentration of N was determined by the Kjeldahl procedure (AOAC, 1990), from which CP was calculated as N × 6.25. Forage IVTDMD was determined according to the Van Soest et al. (1991) modification of the Tilley and Terry (1963) procedure using the Daisy II incubator system (Ankom TechnologyTM, Macedon, NY). Ruminal fluid was collected at the Auburn University College of Veterinary Medicine from a cannulated Holstein cow that had free access to bermudagrass hay and was limit-fed a 15% CP supplement consisting of soybean hull pellets, corn gluten feed, and WCS, plus 0.23 kg of Megalac® (Volac Wilamar Feed Ingredients, Ltd; Hertfordshire, UK). Fluid was stored in thermos containers to maintain a temperature supportive of the microbial population and was transported to the Auburn University Ruminant Nutrition laboratory where it was immediately prepared for the batch-culture IVTDMD procedure.

Weather Data

Weather instruments operated by Agricultural Weather Information Service, Inc. collected daily average ambient temperatures and daily total precipitation data throughout the experimental period. Weather instruments were located in Shorter, AL. Temperature data and total precipitation are reported in Figures 11 and 12.

Statistical Analysis

Winter-annual forage mass and nutritive value, supplement nutritive value, cow weight, cow body condition score (BCS), and calf weight were analyzed using the MIXED procedure in SAS 9.4 (SAS Institute, 1994) for completely randomized design. Independent variables for forage mass, nutritive value, and performance data included date, nutritional management treatment, and date × nutritional management treatment interaction. Pen and year were random variables. Treatment means were separated using the PDIFF option of the LSMEANS procedure (SAS Institute, 1994) and were determined to be significant when $\alpha = 0.05$.

RESULTS AND DISCUSSION

Monthly mean temperatures and 20-yr average monthly mean temperatures in Shorter, AL are presented in Figure 11. Monthly total precipitation and 20-yr average monthly total precipitation are presented in Figure 12. Monthly mean temperatures tended to follow the pattern of the 20-yr average, except in Feb of Yr 1 and Yr 2, when temperatures were greater. In Yr 1, rainfall was greater than average in Oct, followed by a dry period until Jan, when precipitation totals began to follow the 20-yr average. In Yr 2, heavy rainfall occurred after planting and into Jan, then rainfall fell below average until Apr. Low precipitation levels in Feb and Mar resulted in RG paddocks being rested for 2 weeks in Mar due to inadequate forage mass.

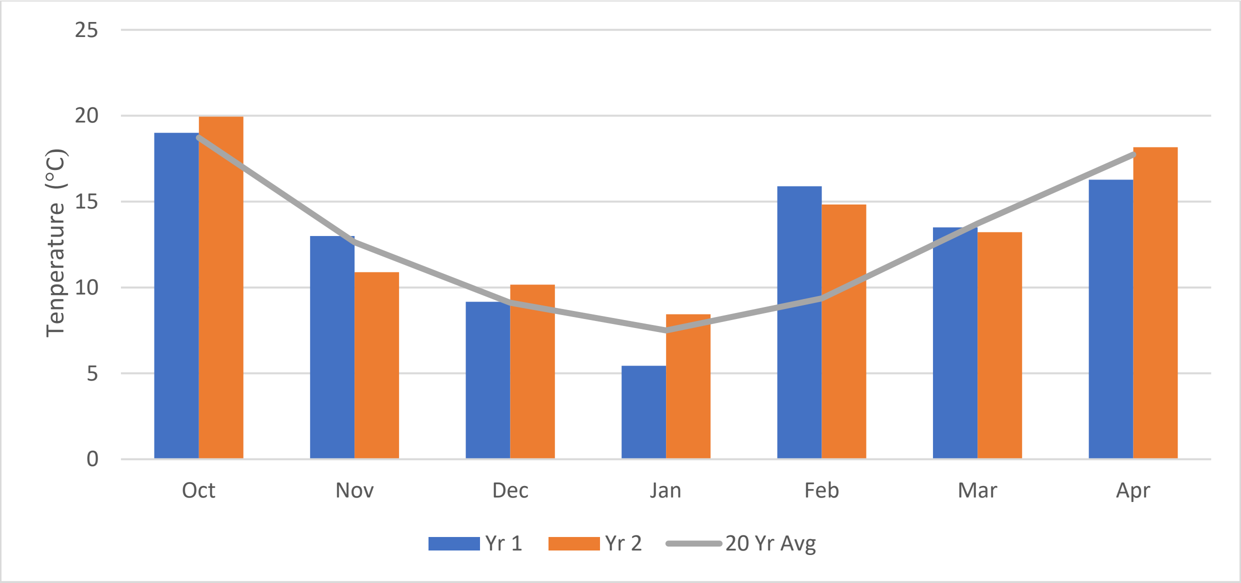

Figure 11. Monthly mean air temperatures (°C) for Yr 1, Yr 2, and 20-yr averages for Shorter, AL. Data collected from Agricultural Weather Information Service, Inc.

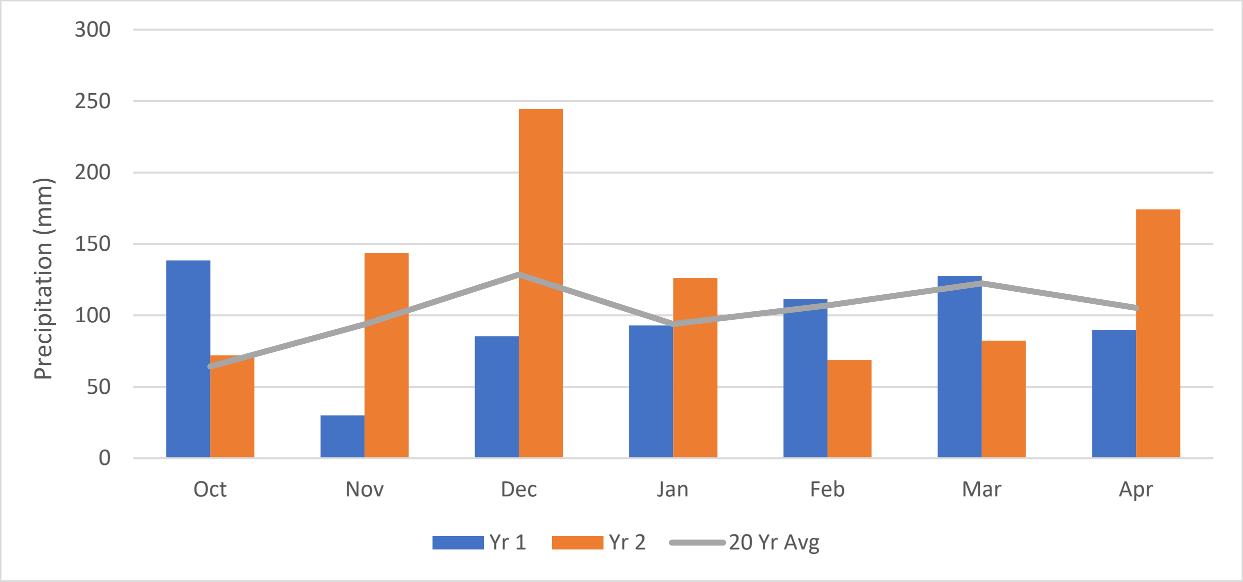

Figure 12. Monthly total precipitation (mm) for Yr 1, Yr 2, and 20-yr averages for Shorter, AL. Data collected from Agricultural Weather Information Service, Inc.

Seasonal Forage Mass and Nutritive Value of Winter Annuals

Seasonal forage mass, and CP and TDN concentrations of RG are presented in Figure 13. Average forage production every 14 d was 1,604 ± 526 kg DM/ha, and total seasonal forage DM production was 14,676 kg DM/ha. A study in Arkansas evaluating cow-calf performance on winter annuals reported forage mass values of 1,788 ± 668 kg ha^{-1} during the winter and 2,116 ± 368 kg ha^{-1} during the spring (Beck et al., 2016). Mckee et al. (2017) reported similar seasonal forage availability (15,800 kg DM ha^{-1}) in Yr 1 of a grazing study using a small grain, annual ryegrass, and clover mixture in northern Alabama. The mixture provided 68 and 57 days of grazing, in Yr 1 and Yr 2, respectively, in the study by Mckee et al. (2017). Winter-annuals in the current study provided 73 days of grazing in Yr 1 and 86 d in Yr 2, respectively. Longer grazing seasons for winter-annuals can be expected in the central to southern region of Alabama depending on planting date and efficiency of use. Mullenix et al. (2014) reported grazing season lengths of 117 to 134 d for triticale (× *Triticosecale* Wittmack), wheat (*Triticum aestivum* L.), and annual ryegrass, each planted alone into prepared seedbeds in Oct in Headland, AL. In Camden, AL, various mixtures of oat, cereal rye (*Secale cereal* L.), annual ryegrass, and crimson clover were planted in Sep into prepared seedbeds over a period of 10 years, and although supplement was provided in periods of inclement weather or limited forage availability, cattle grazed for an average of 186 d (Harris et al., 1971). Number of grazing days in the current study may have been increased with an earlier planting date or more intensive grazing management.

Concentration of CP fluctuated in grazed winter-annuals ($P = 0.0036$) throughout the season, but never fell below 130 g kg^{-1} on a DM basis. Total digestible nutrients declined ($P < 0.0001$) throughout the season to no less than 710 g kg^{-1} on a DM basis. Values of CP and TDN concentration fall within ranges of reported values for cool-season annuals (Ball et al., 2015).

Beck et al. reported (2016) 250 ± 21 g kg^{-1} CP and 698 ± 32 g kg^{-1} TDN for cool-season annuals from Jan through Apr. Both of these nutritive value parameters indicate that RG provided high amounts of digestible energy throughout the growing season and a diet which met or exceeded the requirements of a 600-kg beef cow of average milking ability (NRC, 2016).

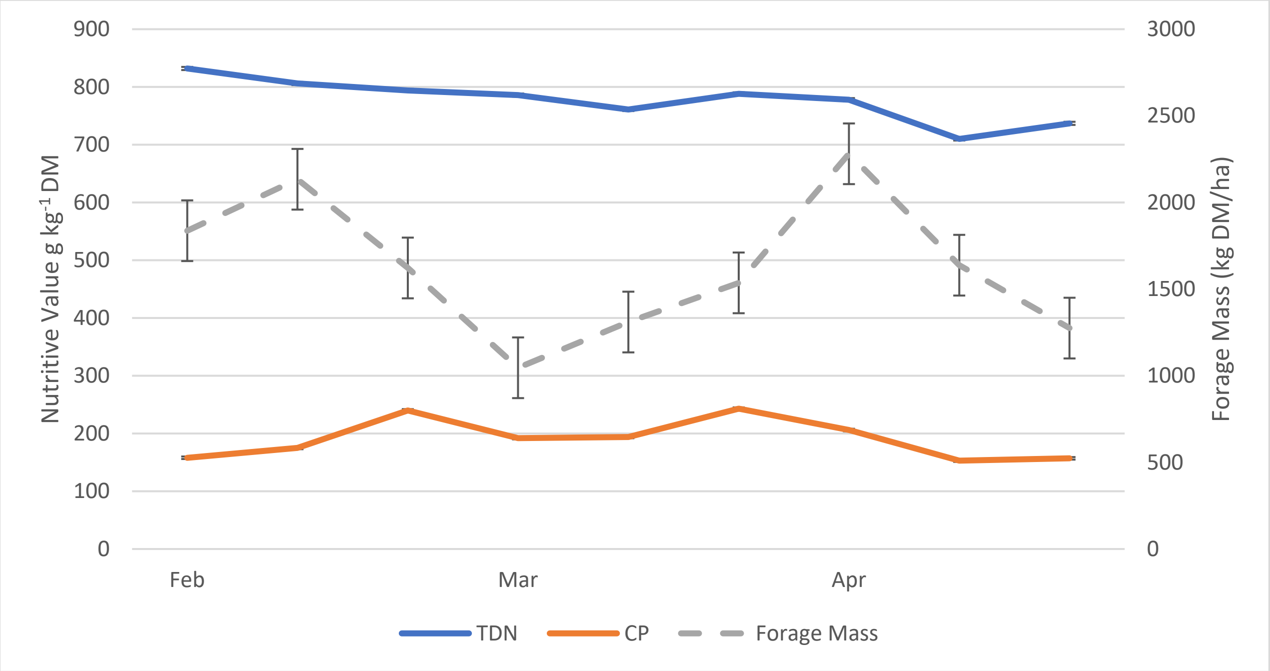

Figure 13. Seasonal forage mass (kg DM/ha) and CP and TDN concentrations (%) of oat, ryegrass, and clover mixture in Shorter, AL. For TDN, SEM = 27.06. For CP, SEM = 21.715. For forage mass, SEM = 1751.5.

Nutritive Value of Diets

Nutritive value of diet as influenced by nutritional management system is presented in Table 14. Differences were observed for TDN ($P < 0.0001$) and CP ($P < 0.0001$) concentrations of the diets used in each respective management system scenario. Concentration of TDN was greatest for RG, intermediate for RF, and least for FC. Poor hay quality contributed to lower TDN values for RF and FC. The TDN requirement for a 600-kg cow of average milking ability is

555 g kg^{-1} diet DM (NRC, 2016). Whereas RG and RF met this requirement, the calculated diet value for FC system was less than animal nutrient requirements; however, cow performance was not negatively impacted by diet in this study. Winter annuals in RG had the greatest CP concentration, while RF and FC did not differ. All diets provided CP concentrations adequate for lactating beef cows (NRC, 2016), but RG provided superior nutritive value to RF and FC. Cows consumed an average of 4.4 kg WCS hd^{-1} d^{-1} in the FC system. This value agrees with a study by Hill et al. (2009) where non-lactating, non-pregnant beef cows consumed 4.06 kg WCS hd^{-1} d^{-1}. Due to the high fat content of WCS, the recommended feeding level is no more than 0.5% BW, as excess fat in the diet may interfere with fiber digestion (Hill et al., 2009). While intake of WCS in the current study was above the recommended feeding level cited by Hill et al. (2009), negative impacts were not observed in terms of animal performance or health during the trial. However, previous trials have reported that feeding WCS free-choice may become cost prohibitive and intake may be erratic if cows are allowed to consume large amounts with no regulation (Hill et al., 2009), which is a consideration that should be taken into account by producers who may consider using this practice to reduce feed labor requirements in the winter months.

Table 14. Total digestible nutrients (g/kg) and crude protein concentration (g/kg) of winter management system diets for cow-calf pairs in Shorter, AL.

Item	TDN[1]	CP
-	------------------------------ g/kg DM	------------------------------
RG	781^{a}	190^{a}
RF	594^{b}	120^{b}
FC	535^{c}	113^{b}
SEM	14	10

[1] For RG, TDN was calculated by subtracting 11.9 from IVTDMD value (Van Soest, 1994).

Animal Performance

Nutritional management strategy effects on animal performance are presented in Table 15. Cow BW and BCS were greatest ($P < 0.0001$ and $P = 0.0014$, respectively) on RG. Calves nursing cows on RG and FC performed similarly, with calf BW being the least when nursing cows on RF ($P = 0.0041$). Calf ADG was not different ($P = 0.0706$) among nutritional management strategies, indicating that all diets supported adequate lactation for calf growth. Calf ADG in the current study was greater than that of calves nursing cows grazing winter-annuals as supplement in Arkansas where calf ADG ranged from 0.93 to 0.96 kg (Gunter et al., 2012). Drewnoski et al. (2011) reported ADG of 0.24, 0.87, and 0.89 kg for beef steers (approx. 260 kg BW) supplemented with 50:50 SH:CGF 2, 3, and 7 times per week, respectively. Scruggs (2010) supplemented 275 kg BW heifers grazing stockpiled tall fescue with 0.5, 1.0, and 1.5% BW of 50:50 SH:CGF and reported ADG of 0.47, 0.71, and 0.85 kg hd^{-1} d^{-1}, respectively. Date effects on animal performance are presented in Table 16. Cow BW and BCS increased ($P < 0.0001$ and $P = 0.0173$, respectively) throughout the season. Calf BW increased ($P < 0.0001$) while ADG decreased ($P = 0.0005$). Literature indicates that cows must have a minimum BCS of 5 at the time of pregnancy testing to achieve pregnancy rates of 90% or greater, and cows with a BCS of 6 at breeding have more successful pregnancy rates than cows at BCS 4 or 5 (Fields and Sand, 1993). In the current study, cows maintained BCS of 6 throughout the trial, even while in peak lactation, while calves gained similarly on each treatment, which demonstrates that all three nutritional management systems are potentially viable options for winter management of cow-calf pairs.

Table 15. Nutritional management effects on cow and calf performance in reduced-labor feeding systems in Shorter, AL.

Item	Cow BW	Cow BCS	Calf BW	Calf ADG
-	kg	-	kg	kg d^{-1}
RG	671^a	6.3^a	156^a	1.4
RF	626^b	6.0^b	146^b	1.2
FC	628^b	6.0^b	160^a	1.3
SEM	48	0.1	5	0.1

$^{a-b}$ Within a column, means differ ($P < 0.05$).

Table 16. Harvest date effects on cow and calf performance in reduced-labor feeding systems in Shorter, AL.

Month	Cow BW	Cow BCS	Calf BW	Calf ADG
-	kg	-	kg	kg d^{-1}
Jan	621^d	6.0^b	101^d	-
Feb	635^c	6.0^b	139^c	1.4^a
Mar	648^b	6.3^a	174^b	1.3^b
Apr	661^a	6.2^a	204^a	1.1^c
SEM	48	0.1	5	0.1

$^{a-d}$ Within a column, means differ ($P < 0.05$).

CONCLUSIONS

Reducing labor or feed costs are priorities for profitable beef cow-calf systems in the Southeast US. Nutritional management strategies such as extending the grazing season, reducing feeding frequency, or feeding in bulk can accomplish this goal during the winter management season. This study indicates that rotational grazing of winter annuals, feeding fiber-based supplements that are low in non-structural carbohydrates every other day as opposed to daily, or bulk feeding WCS with access to hay provide potentially viable options for beef producers to maintain cows during the winter months while reducing labor inputs compared to traditional daily hay feeding and supplementation. An economic analysis of the results is needed to determine cost of production associated with each system.

IMPLICATIONS

To move towards the next step of developing grazing recommendations, future research should focus on applying defoliation management strategies developed from small-plot studies to grazing trial evaluations. Additional small-plot research with increased weed control may further define harvest strategies that optimize persistence for alfalfa-bermudagrass mixtures. However, in grazing-based systems, weed species observed in the present study would not be problematic to research outcomes. Additional research and model development are needed to identify the best method(s) of evaluating stand variability and to improve precision of prediction equations. In terms of producer application, incorporating alfalfa into bermudagrass may move the Southeast US towards a longer grazing season while improving forage yield and quality and reducing traditional N inputs. Proper defoliation management will greatly impact forage performance and longevity and should be the focus of producer education and on-farm management plans. Additionally, identifying winter nutrition management strategies that reduce labor and feed costs can ensure successful cow maintenance while reducing overall costs. Implementing these forage management practices can ensure long-term forage system viability for cow-calf pairs in the Southeast US.

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