EVALUATION OF WARM-SEASON ANNUAL FORAGES IN FORAGE-FINISHING BEEF CATTLE SYSTEMS IN THE SOUTHEAST

by

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(Under the Direction of Dennis W. Hancock)

ABSTRACT

A three year trial was conducted to evaluate the performance of sorghum x sudangrass [*Sorghum bicolor var. bicolor*bicolor var. sudanense* (SS)], brown-midrib sorghum x sudangrass (BMR), pearl millet [*Pennisetum glaucum* (L.) R.Br.; (PM)], and pearl millet planted with crabgrass [*Digitaria sanguinalis* (L.) Scop.; (PMCG)] in a Southeastern forage-finishing beef production system. In a randomized complete block design, 16 pastures (0.81-ha) were assigned to one of four forage treatments and were subdivided for rotational grazing. British-cross beef steers (n = 32; 3 yr average: 429±22 kg) grazed for 70, 63 and 56 days in 2014, 2015 and 2016, respectively. Forage DM yield was least ($P < 0.01$) for PMCG at the initiation of the grazing trial, while BMR was greater ($P < 0.01$) than SS at week 6. Higher stocking densities were maintained on SS than PM and PMCG ($P < 0.01$) at days 0, 6, 13 and 20 in 2014 and PMCG ($P < 0.01$) on days 0, 6, 13, and 20 in 2015. Stocking densities of BMR was greater ($P < 0.01$) than PM and PMCG on day 0, 6, and 13 in 2014. Sorghum x sudangrass forage systems produced greater ($P < 0.12$) total gains per unit of land than PM in 2014 and 2015. Forage treatment did not affect ($P > 0.17$) total gain, total ADG, or BW at any time point. No differences ($P > 0.05$) in forage treatments were observed for carcass characteristics associated with yield grade, quality grade, proximate analysis or variables associated with the break-even analysis. Additionally, a study was conducted to help producers identify superior varieties of sorghum x sudangrass (SS), pearl millet (PM), and forage sorghum [*Sorghum bicolor* (L.) Moench; (FS)] that consistently performed well. Differences found among varieties indicate that SS, PM, and FS should be selected based on tested yield performance. Cattle performed similarly on all forage treatments indicating that SS, BMR, PM, and PMCG may be used interchangeably. Furthermore, break-even analysis of animal production indicated that utilizing these warm-season annual forages in forage-finishing beef systems has the potential to be a profitable enterprise in the Southeast.

INDEX WORDS: Warm-season annuals, Forage-finishing, Grass-fed, Beef cattle, Forages, Grazing

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DEDICATION

This work is dedicated to all of the professors who have mentored me during my graduate career. To my wonderful family, my loving parents, T.J. and Brenda, and to my brother, Jeremy, thank you for all of your support and helping me make my dreams a reality.

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CHAPTER 1

INTRODUCTION

Recently, consumer demand for locally sourced, forage-finished beef products has increased. This increase of interest by health conscious consumers has primarily been stimulated by reports that grass-finished beef is a leaner product and has an altered n-3 fatty acid and conjugated linolenic acids (CLA) profile compared to conventionally raised beef (Duckett et al., 2007; Duckett et al., 2009). Consumer preference in addition to their willingness to pay up to 25% more for grass-finished beef products compared to traditional beef (Lacy et al., 2007), has led to a niche market for grass-finished cattle producers in the Southeast.

The mild climate of the southeastern United States allows for a variety of forage species to be produced throughout most of the year, making it a potentially economical location for grass-finishing beef systems. Although the use of cool-season annual and perennial forages provide a high quality diet for finishing cattle during the fall, winter, and spring months, there are fewer forage options available for grass-finishing beef during the summer period, and producers will often have to carry cattle over until fall or spring finishing can occur to meet targeted finish weights. Typically, most cow-calf operations take advantage of the higher yielding warm-season perennial species such as bermudagrass (*Cyndon dactylon* L. Pers.) and bahiagrass (*Paspalum notatum* Flugge); however, these species do not contain adequate nutrient concentrations needed for rapid lean and adipose tissue growth in grass-finishing cattle (Schmidt et al., 2013). Instead, warm-season annual forages such as sorghum x sudangrass [*Sorghum* *bicolor* (L.) x *S. Arundinaceum* (Desv.)] and pearl millet (*Pennisetum glaucum* L.R. Br.), with their rapid DM production, forage nutritive value, and water use efficiency, make them ideal forages for use in summer finishing programs in the Southeast.

It has been well established in the literature that low forage availability and nutritive value are major determinants of animal growth (Ball et al., 2001). Chemical composition of forages can vary greatly and can depend on factors such as plant species and varieties within species, proportion of leaf to stem, stage of maturity, and climatological conditions (Allen, 1996; Ball et al., 2007). Fiber concentrations in forages are highly correlated with dry matter (DM) digestibility (Jung and Allen, 1995), and diets with increased digestibility often produce larger animal gains. Thus to utilize warm-season annuals in a forage-finishing system, their forage quality, as well as changes in chemical composition and digestion throughout their growing season, must be understood.

Although there is an abundance of literature comparing grass vs grain finishing systems (Bennett et al., 1995; Leheska et al., 2008; Duckett et al., 2013), little is known about the implications of varying cultivars of forage on animal performance and carcass characteristics. Specifically, there has only been one report in the literature comparing the effects of warm-season annual species on animal performance and final carcass yield and quality characteristics. Schmidt et al. (2013) reported no differences in quality grade and yield grade of cattle finished on pearl millet or cowpea pastures; however, differences were observed in fat thickness as well as fatty acid composition of the loin muscle and may be a reflectance of the chemical composition of grazed forage treatments.

Although the work of Schmidt et al. (2013) introduced the possibility of forage species to impact carcass characteristics, a more detailed understanding of the effects of warm-season annual forages is needed. The objectives of this study were to compare yield, forage distribution, nutritive value, animal performance, and carcass merit of four warm-season annual grass forage systems in Southeastern forage-finishing beef operations.

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CHAPTER 2

LITERATURE REVIEW

Warm-Season Annual Forages

Introduction to Forages

In the Southeastern U.S., forages account for a significant portion of beef cattle diets and inclusion levels can differ based on environment, availability, and stage of production. Forage is important for proper rumen function and is an economical source of nutrients for ruminants. In general, forages used in beef cattle nutrition can be divided into four main groups; cool-season annuals, cool-season perennials, warm-season annuals, and warm season-perennials. It is estimated that the Southern U.S. contains 24 million hectares of perennial forages and another 19 million acres of annual pastures (Ball et al., 2015). Perennial forages make up the majority of the grasses and legumes in our nations pasture land. A primary reason for this is that perennial pastures do not have to be planted each year, and they have a relatively low cost of production once established. Although, cool and warm season perennial forages are most notably used in cow-calf production systems, neither can stand alone in providing a year round forage supply that meets the nutrient requirements of growing or finishing animals. Specifically, grass-finishing requires forage species that are high in nutritive value and palatability to produce desirable rates of weight gains that are associated with adipose and lean tissue growth. During the spring, fall, and winter months, a mixture of cool-season annuals and perennials can provide adequate forage for grass-finishing cattle, however, in the summer months, there are fewer high quality forage options available (Schmidt et al., 2013). Bermudagrass (*Cyndon dactylon* L. Pers.) and Bahiagrass (*Paspalum notatum* Flugge) are high yielding warm-season perennial forages but are typically low in palatability and do not contain adequate nutrient concentrations to provide rapid growth in a grass-finishing system. However, the high nutritive value and palatability of warm-season annuals paired with their water use efficiency make them desirable forages to produce grass-finished beef during the summer months in the Southeast.

Warm-Season Annual Forages

Warm-season annual forages, also known as summer annuals, are forage species that are quick to establish and complete their life cycle in one growing season, particularly during the warm months of summer. These forages can produce substantial amounts of tonnage when temperatures are above 27° C. Summer annual forages have been found to be advantageous when included in perennial grazing systems because they help to extend the grazing season and can often provide emergency forage during drought conditions when other species may not grow (McCartney et al., 2009). There are several summer annual forages that have been proven to be useful in grazing systems and include pearl millet, crabgrass and several species within the sorghum family. This review will help to clarify differences and similarities among warm-season annual grasses and provide insight as to where they fit in forage systems, particularly in the Southeastern United States.

Sorghum x Sudangrass

The sorghum family is native to Northeast Africa (Ball et al., 2015). Since their introduction into the United States, species in the sorghum family have been bred specifically for both DM production and for forage quality attributes that have the potential to impact animal performance. Grasses in the sorghum family include grain and forage sorghums, sudangrass, and sorghum x sudangrass hybrids. Sorghum x sudangrass [*Sorghum bicolor* (L.) x *S. arundinaceous* (Desv.)] is a hybrid cross between forage sorghum and sudangrass. Thus, plants grow erect producing forage that is intermediate in size compared to sorghum and sudangrass and ranges from 1.5 to 3.7 m tall, depending on the variety. Most often, sorghum x sudangrass is either grazed or ensiled and used as a stored feedstuff. The forage has characteristically thick stems which makes it difficult to cut as a hay crop (Ball et al., 2015), even with the use of mechanical preparation methods such as a mower-conditioner.

Establishment of sorghum x sudangrass hybrids should occur during spring when soil temperatures at 5-10 cm in depth reaches 18^{o} C (Ball et al., 2015). Although the crop is relatively tolerant of low soil pH, values less than 5.7 may cause a severe reduction in yield (Miller, 1984). Generally, sorghum x sudangrass hybrids perform best when drilled into a well-prepared, firm seedbed. Seeds are round in shape and should be planted at a depth of 2.5 to 5 cm and at 22.4 to 33.6 kg ha^{1} (Undersander, 2003; Hancock, 2017) in well drained soils. Utilizing press wheels or a cultipacker will ensure good seed to soil contact and promote germination. Grazing of sorghum x sudangrass pastures should not occur before the plants reach 61 cm tall. To promote a timely regrowth, grazing should be managed to avoid clipping plants below 20-30 cm in height. Harvesting forage below this point can cause damage to the axillary buds, the primary growing points on the plant. Rotational grazing should be used to ensure both efficient utilization and timely regrowth of sorghum x sudangrass stands.

Popularity of sorghum x sudangrass hybrids over perennial pastures in humid climates can be attributed to its rapid growth and DM production during a short growing season and a high overall nutritive value. Seventeen years of research at the University of Georgia has shown that improved varieties of sorghum x sudangrass hybrids are capable of producing over 16.9 Mg ha^{-1} of DM. Comparably, McLaughlin et al. (2004) found that in a 2 yr study, sorghum x sudangrass fertilized with swine effluent produced 17.3 and 20.6 Mg ha^{-1} of DM while common bermudagrass only produced 5.6 Mg ha^{-1} during the establishment year and 21.3 Mg ha^{-1} of DM thereafter. In a study comparing the effects of harvest date on yield and chemical composition of three sorghum x sudangrass varieties, Beck et al. (2007a) reported that increasing harvest interval from 34 to 63 days significantly increased forage production, with DM values averaging 1,120 kg of DM ha^{-1} on d 34 and 7,433 kg of DM ha^{-1} on d 63. As expected, crude protein (CP) concentration decreased with increasing harvest interval and was highest on d 34, ranging from 10.8 to 12.6 % of DM, depending on variety.

In the Southeast, sorghum x sudangrass hybrids are particularly advantageous during drought conditions because they have been adapted to, and are productive in, semiarid regions where annual precipitation can be as low as 400 mm (McCartney et al., 2009). When moisture is limited or unavailable, cessation of growth will occur until water is once again available to sustain green tissue production (Miller, 1984). In an evaluation of the impact of drought, Schittenhelm and Schroetter (2014) found that drought stress caused a 51% reduction in above ground DM of corn compared to 35% in sorghum x sudangrass. Similar findings have also been reported by Singh and Singh (1995) who reported that DM production of maize was less than that of sorghum during severe drought conditions (3.0 and 4.1 t ha^{-1}, respectively) . When compared to corn, sorghum x sudangrass's impeccable drought tolerance results from an increased cuticle thickness and fewer stomata.

One major concern for producers utilizing sorghum x sudangrass as a forage is its potential to accumulate toxic levels of both prussic acid and nitrates. Prussic acid poisoning, also known as cyanide poisoning, can occur when cattle graze forage that is young, drought stressed, or has become injured from frosts. Prussic acid concentrations are highest in young, leafy tissues. Similarly, high nitrate levels can occur from the accumulation of nitrate nitrogen in the plant during drought conditions when the growth of the plant slows or stops. With time, both prussic acid and nitrate concentrations can deteriorate to safe levels in standing forages. To prevent prussic acid poisoning of livestock, it is best to wait until young plants have reached 60-65 cm tall before grazing (McCartney et al., 2009) and allow a recovery period of forage growth after drought or frost have occurred. To reduce the risk of nitrate poisoning, pastures should not be fertilized with nitrogen during drought. Since nitrate concentrations are highest in the stem and at the base of the plant, grazing pressure should allow cattle to only remove the leafiest parts of the plant. Aforementioned grazing management strategies can greatly reduce the chances of problems associated with prussic acid or nitrates in animals grazing sorghum x sudangrass.

The warm, humid climate of the Southeast is favorable for many insect pests in forage crops. In Florida, the white sugarcane aphid [*Melanaphis sacchari* (Homoptera: Aphididae)] has caused damage to sugarcane [*Saccharum officinarum*, L.] crops as early as 1977. However, in 2012 the sugarcane aphid added a host preference for forages in the sorghum family, including sorghum x sudangrass. This pest causes damage to sorghum crops by sucking plant sap from xylem tissues (Singh et al., 2004) on the underside of the leaf and, as a byproduct of their feeding, the aphids leave behind a honeydew like substance on the plant. Although the sugarcane aphid is small in size, it can quickly multiply into large populations. Large infestations can lead to serious injury to leaves and sometimes even death of the entire plant. The key to avoiding crop damage is to scout fields often. Since this is a relatively new problem in sorghum species, there are few management recommendations currently available. A preliminary threshold for treatment with 0.06-0.15 kg ha^{-1} of Sivanto (flupyradifurone) has been recommended at 0.06-0.15 kg ha^{-1} when 25% of pre boot stage plants are infested or when leaves contain 50 or more aphids per leaf (Buntin, 2017b).

Pearl Millet

Pearl millet (*Pennisetum glaucum* L.R. Br.) is a warm-season annual forage that is native to North Central Africa where it is primarily used as a cereal crop (Andrews and Kumar, 1992). In the U.S., improved varieties for use as forage for grazing livestock were first bred by Dr. Burton and W. W. Hanna at the University of Georgia (Ball et al., 2015). Pearl millet is an erect bunchgrass that grows 0.9-2.4 m tall and is productive from late May to September. It has the ability to perform well in soils that are acidic and low in organic matter (Andrews and Kumar, 1992), making it an attractive summer annual forage for the Southeast. Seed should be planted at 1.3-2.5 cm in depth at 11.2-16.8 kg ha^{-1} and fertilization application based on soil test recommendations. Grazing of pastures should be avoided until plants reach a height of 61 cm. Once pastures have been grazed to a stubble height of 15-20 cm, removal or rotation of livestock will help promote timely regrowth and prevent over grazing. Pearl millet's extensive DM production capabilities are due to a heavy tillering potential in which regrowth occurs from basal buds located at the base of the plant.

When moisture is adequate or soil fertility is improved, pearl millet can rapidly produce large amounts of high quality forage for grazing, green chop, or use as a stored feed. Recent performance tests from the University of Georgia have indicated that pearl millet varieties have the potential to produce over 14.7 Mg ha^{-1} of DM. McLaughlin et al. (2004) reported that in a 3 yr study, 'Tifleaf 3' pearl millet produced 12.5 and 15.7 Mg ha^{-1} of DM in non-drought years compared to common bermudagrass which produced 5.6 Mg ha^{-1} of DM in the establishment year and 21.3 Mg ha^{-1} during the third year. However in the same study, sorghum x sudangrass vastly outperformed pearl millet producing 17.3 and 20.6 Mg ha $^{-1}$ of DM.

Warm-season annual forages such as pearl millet, are often attractive to forage-finishing beef producers because of their high concentrations of digestible nutrients. Bosworth et al. (1980) compared in-vitro dry matter digestibility (IVDMD) of two warm season forages, 'Millex 23' pearl millet and 'Coastal' bermudagrass at the vegetative, boot, and heading stages. The authors found no difference in IVDMD at the vegetative and boot stages but at the heading stage, pearl millet had an IVDMD of 60%, which was greater than the 43% IVDMD of the bermudagrass. Similarly, Wilkinson et al. (1968) reported CP content of bermudagrass and pearl millet harvested at 21 d to be 18.1 and 22.4% of DM, respectively, while lignin content of bermudagrass was 7.9% of DM compared to the 6.6% of pearl millet. Other studies have published similar findings (Schmidt et al., 2013), indicating that pearl millet forage may have a nutritional advantage over warm-season perennial grasses.

Like many other warm-season annual grasses, pearl millet has outstanding heat and drought tolerance and as a result, has become a popular forage crop in the humid-subtropical regions of the Southeast. Reduced leaf area and leaf number are the primary indications of water stress in pearl millet plants and can result in decreased DM yield and quality. Rostamza et al. (2011) reported the impacts of moisture on forage yield and quality in the pearl millet variety 'Nutrifeed'. Irrigation treatments were 40, 60, 80, and 100% depletion of total available soil water (ASW). Their research found that total DM decreased (19.5, 18.1, 14.0, and 10.0 Mg ha^{-1}, respectively) while leaf to stem ratio increased (1.64, 1.80, 2.00, and 2.56, respectively) with decreasing soil water availability and was attributed to drought stressed plants having fewer leaves than the more irrigated plants. Interestingly, as a percentage of DM, forage total digestible nutrients (TDN; 54.7, 54.5, 53.2, 51.4%) and crude fiber (CF; 39.5, 38.6, 37.8, and 36.6%) decreased with drought stress while CP (15.6, 15.9, 17.4, and 19.2%) and acid detergent fiber (ADF; 32.8, 33.0, 34.7, and 36.4%) increased with decreasing inputs of moisture. The authors contributed the increase in CP as a function of elevated nitrogen levels in the plant, since pearl millet is a strong nitrogen accumulator during drought situations.

Like the sorghum family, pearl millet can have high nitrate levels that can cause nitrate poisoning in livestock. Most often, plants accumulate nitrates during drought stress. This process occurs when plants take nitrogen up from the soil but limited moisture causes growth to cease, therefore preventing plants from turning nitrate nitrogen into plant proteins. In the plant, nitrates are stored in highest concentrations in the stems and at the base of the plant. It is recommended that grazing be delayed a few days after a rainfall event that follows a dry period to allow plants to utilize stored nitrate nitrogen and turn it into green tissue. However, unlike the sorghum family, pearl millet does not produce prussic acid and therefore cyanide poisoning is not of concern to grazing animals.

The environment of the Southeastern U.S. makes it a favorable habitat for insect pests in almost all sectors of the agricultural industry. Pearl millet has several insects that can cause significant damage to the crop if left untreated. The chinch bug [*Blissus leucopterus leucopterus* (Say) (Heteroptera: Blissidae)] and the false chinch bug [*Nysius raphanus* Howard (Heteroptera: Lygaeidae)] are common pests of warm-season grasses with pearl millet being the preferred plant of choice (Ni et al., 2009). In the Midwest, it is estimated that the chinch bug has caused over 19 million dollars in damage annually to sorghum crops in Kansas and up to 11.3 million in Nebraska (Spike et al., 1994). Chinch bugs have eight different life stages ranging from egg to nymphal and winged adults and are most commonly found between the leaves and the stem at the base of the plant. Producers can utilize beta-cyfluthrin or zeta-cypermethrin 14-21 days after emergence to prevent early damage to the pearl millet crop (Hudson and Buntin, 2017). Since the pesticides must penetrate the canopy in order to be effective, secondary applications should be made after grazing or harvesting and before the canopy has closed. A seed treatment with Imidacloprid is also available and can suppress Chinch bug pressure on seedlings for 2-3 weeks, but has a 45 day grazing restriction (Buntin, 2017a). Failure to treat pearl millet once an infestation has been discovered can lead to crop damage and in severe cases, complete stand loss.

Crabgrass

Crabgrass (*Digitaria* spp.) originated in South Africa and is a low-growing annual grass that is present in most cultivated fields and pastures in the southeast. Although crabgrass is considered to be an annual forage, its ability to reseed prolifically ensures is survivability year after year and allows it to simulate a perennial forage. The forage distribution of crabgrass typically ranges from May to September (Ball et al., 2015) and management of the forage late in the growing season is crucial for seed development and stand persistence the following year. Although little information is available on crabgrass management in pasture systems, Pitman et al. (2004) reported that soil disturbance is crucial for volunteer stand development.

Establishment of crabgrass pastures or hay fields should be done by drilling crabgrass at 0.64 cm deep or by using a broadcast spreader. It should be noted that crabgrass seed is small, approximately 1mm wide and 3 mm long (Dalrymple, 2001), and may cling to drop tubes when drilled due to static electricity. For best results, crabgrass seed should be planted with sand or a substance similar in size to the crabgrass seed in a 2:1 mixture to reduce static cling and ensure an evenly distributed stand. Some crabgrass seed is now sold with a seed coating that reduces static, improves distribution, and maintains moisture around the seed during germination. Regardless, using the press wheels on a no-till drill or a cultipacker following a broadcast seeding will increase seed to soil contact and may improve germination while decreasing the chances of seed loss due to wind and heavy rainfall events.

In many farming scenarios, volunteer crabgrass is considered a weed as a result of its persistence in monoculture forage systems. However, improved varieties of crabgrass are palatable, highly digestible, and high yielding during the months of summer. In 1988, the Samuel Roberts Noble Foundation released the first improved variety of crabgrass called 'Red River' crabgrass [*D. ciliaris* (Retz) Koel.] (Dalrymple, 2001). This variety of crabgrass was originally found growing near the Red River in southern Oklahoma and is geographically adapted to the 21 states that make up the Southeastern and South Central U.S., from Oklahoma to Florida. The specific ecotype of 'Red River' was selected for its known forage yield and quality attributes. In 2007, the same group released another improved variety of crabgrass named 'Quick-N-Big' (Dalrymple, 2007) and additional variety releases by the Noble Foundation are expected in the coming years.

Collectively, varieties of improved crabgrass have the potential to fill both the yield and quality gaps often found in perennial forage systems. In a pilot study on warm season weed species, Bosworth et al. (1980) found that in the vegetative stage, common crabgrass had a greater IVDMD than pearl millet or bermudagrass (79, 59, and 58% IVDMD, respectively) and it had a greater IVDMD than bermudagrass in the booting and heading stages. In a similar study, Ogden et al. (2005) sampled crabgrass on seven dates throughout the growing season and reported that when compared to bermudagrass, crabgrass had greater DM and NDF digestion rates. The authors attributed their findings to crabgrass having overall lower NDF content, ranging from 55.5 to 61.2% of DM compared to bermudagrass (62.1% of DM). In another study looking to quantify the effects of 21, 35, and 49 day harvest intervals on crabgrass yield and quality, Beck et al. (2007b) found a linear decrease in CP (15.6, 14.3 and 11.0 % DM, respectively) and TDN (62.6, 59.1 and 54.8 % DM, respectively) concentrations and a linear increase in fiber fractions of ADF (35.7, 38.9 and 42.7 % DM, respectively) and NDF (61.3, 66.6 and 69.8 % DM, respectively) with increasing harvest interval. Even though there was a reported linear decrease in both TDN and CP concentrations, crabgrass at a harvest interval of 49 days still maintained high enough TDN and CP concentrations to meet the nutrient requirements of a 1,200 lb dry cow in late gestation (NRC, 2000). Other studies have suggested that the largest change in the nutritive value of crabgrass occurs within the first month after emergence (Gelley et al., 2016). Nonetheless, crabgrass shows significant potential as a high quality forage for livestock in the Southeast.

In regards to DM production, the prostrate growth habit of crabgrass does not limit its ability to produce adequate amounts of forage DM. In the previously discussed study, Beck et al. (2007b) reported a quadratic increase in forage yield from 2,872 kg to 7,335 kg and 9,788 kg of DM/ha as harvest interval increased. Similar yields were found in a 2 yr study by McLaughlin et al. (2004) where 'Red River' crabgrass was fertilized with swine effluent and produced a total seasonal yield of 8,100 and 10,000 kg/ha. Dalrymple (2001) reported that in a 9 year study, 'Red River' crabgrass produced an average of 9530 kg ha^{-1} under various growing conditions while Teutsch et al. (2005) reported seasonal crabgrass DM yields ranging from less than 4,000 kg/ha with no nitrogen fertilization to just over 10,000 kg/ha with 336 kg plant-available N ha^{-1}.

Genetic Traits

There are several mutations in the sorghum family that have been found to be advantageous in forage and animal production systems. The utilization of the brown-midrib (BMR) mutation is a genetic approach aimed at producing forage genotypes that have reduced lignin content and altered lignin chemical composition. The relationship between increased forage lignin content and decreased overall forage digestibility and animal performance has been well documented in the literature (Johnson et al., 1962; Tomlin et al., 1965; Van Soest, 1994; Jung and Allen, 1995) , making this genetic mutation of high importance to meat animal production. The BMR mutations were first discovered in the sorghum family by Porter et al. (1978) when sorghum seeds were soaked in diethyl sulfate and resulted in 19 BMR mutant lines. The authors selected 3 of the BMR mutant lines, BMR-6, BMR-12, and BMR-18, on the basis that they were of agronomical importance in regards to cell wall chemical composition (Fritz et al., 1990). Additional work in breeding and genetics has led to the discovery that the BMR-6 mutant line is on an independent loci from the BMR-12 and BMR-18 mutant lines (Gupta, 1995). This is significant in that the BMR-6 alters the lignification process by reducing the activity of cinnamyl alcohol dehydrogenase (CAD) (Bucholtz et al., 1980) while the BMR-12 and BMR-18 mutants decrease caffeic acid O-methyl transferase (COMT) activity (Bout and Vermerris, 2003). Many authors have shown that when compared to the conventional or wild type varieties, the BMR genotype results in improved digestibility in sorghum x sudangrass (Beck et al., 2007a) and forage sorghum (Oliver et al., 2004; Marsalis et al., 2010). In a study conducted by Beck et al. (2007a), a BMR sorghum x sudangrass was found to be higher in DM but lower in NDF and ADF than a non- BMR variety. In a similar study, Chaugool et al. (2013) tested the quality and in vitro dry matter digestibility of 15 different varieties of sorghum x sudangrass. Two of the 15 varieties contained the BMR mutation and consequently had greater rates of IVDMD than the conventional sorghum x sudangrass varieties.

C3 vs C4 Physiology

Although it is believed that C_4 plants evolved from C_3 plants, leaf cell anatomy and function varies extensively between the two. The largest difference occurs between the mesophyll and bundle sheath cells in relation to both anatomy and photosynthetic function. In C_4 plants, cells in the leaves are arranged into what is known as Kranz-type anatomy. This special arrangement is characterized by radially arranged mesophyll cells surrounding organelle rich bundle sheath cells, which in return, surrounds vascular bundles (Ueno et al., 2006). Unlike the C_4 plants, bundle sheath cells in C_3 plants contain few organelles and therefore, are not the primary site of decarboxylation within the photosynthetic pathway. Instead, mesophyll cells in C_3 plants are organelle rich and capture atmospheric CO_2 for photosynthesis.

Compared to C_3 plants, C_4 plants can generally function at a higher temperature optima, have a greater maximum rate of CO_2 uptake, and can sustain higher irradiances before becoming light saturated (Tieszen et al., 1979). They are also more efficient during periods of drought due to their ability to close their stomata during the day and use CO_2 stored as oxaloacetate, thus reducing water loss through transpiration. Oxaloacetate is a four-carbon compound, hence the name, C_4 plants. This compound is unique to C_4 plants and is formed by using phosphoenol pyruvate (PEP), a 3 carbon compound, along with atmospheric CO_2 to form oxaloacetate which can then be stored in mesophyll cells (Nelson, 1995). From there, oxaloacetate can then be converted into malate and shuttled to the bundle sheath cells where it is broken into CO_2 and pyruvate. This system allows for a concentrated flow of CO_2 to be delivered into the rubisco-containing bundle sheath cells in C_4 plants. The CO_2 is then used in the photosynthetic pathway while pyruvate gets shuttled back to the mesophyll cell where it can once again be converted to oxaloacetate and stored.

Unlike C_4 plants, C_3 plants do not have the luxury of using CO_2 stored as oxaloacetate and must have their stomata open during the day to acquire CO_2 used in the light reactions. As a comparison, C_3 plants have a larger proportion of mesophyll cells surrounding each vascular bundle and the mesophyll cells are not as intimately connected to bundle sheath cells as they are in the C_4 plant. This is because the CO_2 fixing enzyme, rubisco, is located in the mesophyll cells. However, without the capability of concentrating CO_2 at the rubisco enzyme, C_3 plants are less efficient at photosynthesis than C_4 species (Ehleringer and Monson, 1993; Ueno et al., 2006). This effect is amplified during hot, dry weather when the stomata are closed to prevent water loss. This scenario results in the rubisco enzyme using O_2 as a substrate for photosynthesis instead of CO_2. When O_2 is used as a substrate, the compound phosphoglycolate is formed and must be processed in an energy consuming pathway known as photorespiration. Without photorespiration, buildup of phosphoglycolate can become toxic to the plant. However, considering global warming and the continual increase in atmospheric CO_2, it may become that C_3 plants work more efficiently because CO_2 levels stimulate photosynthesis in C_3 plants but higher atmospheric levels of CO_2 does not increase photosynthesis of C_4 plants once the efficient CO_2 mechanism has become saturated.

In a forage system, C_3 and C_4 grasses, or cool and warm season grasses, simultaneously complement one another and can increase the length of the grazing season and nutritional quality of a forage program. During the cool spring, fall, and winter months, C_3 grasses are efficient at photosynthesis and are capable of producing large amounts of high quality tonnage. As the season transitions from spring to summer, the climate becomes hot and dry, and C_3 grasses become less efficient at converting sunlight into carbohydrates. This leads to a reduction in forage mass and stimulates the reproductive phase of forge production. Meanwhile, C_4 grasses are in a state of comparatively efficient photosynthesis and low levels of photorespiration. Therefore, the seasonality between C_3 and C_4 grasses allows livestock producers to have forage available for grazing during a large portion of the year.

Warm-Season Annual Forages In Beef Cattle Nutrition

Introduction to Forage-Finishing

Agricultural livestock use almost 3.4 billion hectares of grasslands and/or improved forage pastures (Soussana et al., 2010). Clearly, grasslands are an important feed resource to the beef cattle industry. In the Southeastern U.S., a standard practice is to background cattle on forage or pasture until they reach up to 70% of their final body weight. Cattle are then sent to feedlots where they are finished on high-energy, grain diets for rapid deposition of both lean and adipose tissue. The feedlot system was readily adopted because it led to a decreased production period (Hoveland and Anthony, 1977), reduced production costs while increasing feed efficiencies (Mathews Jr. and Johnson, 2013), and typically resulted in a higher quality, more uniform beef product (Crouse et al., 1984; Garmyn et al., 2010). However, a recent surge in consumer demand for forage-finished beef has created a niche market for forage-finished, value added products and a need for continuing research in this area. Although cattle production systems in the Southeast are primarily cow-calf operations, opportunity in this region exists for weaned calves to be retained and backgrounded and/or finished on grass instead of being sent to feedlots in the western U.S. The temperate climate allows for forage to be grown throughout the year, reducing the need for costly supplemental feeds. However, not all forage is equal when it comes to forage quality and ability to meet the nutrient requirements of growing and finishing cattle.

Forage Intake, Digestion, and Absorption

Too often, forage quality and nutritive value are used interchangeably in livestock production. However, the two terms do not mean one in the same. Forage quality is the relationship of factors influencing digestibility and intake of forage and its potential to produce an animal response (Ball et al., 2001). In contrast, nutritive value is an assessment of the nutrient composition or concentration of nutrients of a feedstuff and is used to formulate rations (Givens et al., 2000). Forage quality does not necessarily indicate the amount of nutrients in a forage. Together, these terms describe the level at which an animal can use a forage resource and turn it into an end product. In a forage-finishing production system, high forage quality and nutritive value are essential to ensure that animals are accumulating both muscle and fat. Therefore, measuring digestibility of forages and their overall concentration of nutrients is of great interest to the industry. In general, ruminal disappearance rates of forage DM is highest for legumes followed by cool season annual and perennial forages, and finally, warm-season perennial forages (Wilson, 1991; Barnes et al., 1994). Therefore, finishing cattle during the summer months on warm-season perennial forages in the Southeast can be difficult. Often, forage-finishing beef producers have to retain cattle for longer periods of time in order to reach preset carcass weight and fat goals or sell lighter animals which is less efficient. Typically, this also leads to an increase in age and maturity of forage-finished cattle which can have negative impacts on carcass quality and palatability. Therefore, assessing forage quality and nutritive value of warm-season annual forages as an alternative to summer perennial forages may be a useful tool to help grass-finished beef producers reach finishing goals.

The majority of the digestible energy in forages is found in structural carbohydrates and simple sugars. A relationship exists between forage quality and animal performance, with lignification of forage tissue being a key mitigating variable. Altercation of fiber concentrations in forage, by genetic manipulation or through managerial strategies such as species selection and stage of maturity at harvest (Ball et al., 2015), is the most efficient way to increase forage digestibility (Jung and Allen, 1995). Beck et al. (2007a) compared DM disappearance of a non-BMR sorghum x sudangrass variety and two BMR varieties and found that when harvested at 34 days, the non-BMR variety not only had higher concentrations of NDF (63.1, 58.7 and 59.7 % of DM, respectively) and ADF (35.5, 33.4 and 34.7 % of DM, respectively) but also had a slower rate of DM disappearance than the average of the BMR varieties (3.57 and 4.04% h^{-1}, respectively). Similarly, Ogden et al. (2005) reported that crabgrass sampled at weekly intervals had a faster rate of DM disappearance over 96 h (overall mean = 0.078 h^{-1}) than a bermudagrass control (0.054 h^{-1}), but disappeared at about half the rate of alfalfa (0.143 h^{-1}). Although NDF concentrations of crabgrass increased linearly with harvest date, average values were numerically lower than that reported for bermudagrass but higher than for alfalfa (Table 2.1). Supporting their work, Beck et al. (2007b) also published similar findings in crabgrass harvested at different intervals (Table 2.1), indicating the importance of fiber concentrations on forage DM digestibility.

In ruminant nutrition, digestion kinetics are used to determine the rate at which feed is degraded in the rumen. Specifically, forage can be broken into fractions A, B and C with A representing the immediately soluble fraction, B describing the fraction that disappeared at a measurable rate, and fraction C illustrating the undegradable portion (NRC, 2000). Comparing these fractions to particular parts of the plant, fraction A is most often considered the soluble cell contents, fraction B as the fibrous portion of the cell, and fraction C as the lignified constituents.

Ogden et al. (2005) found that crabgrass harvested on seven dates in July and August had 4.7 to 7.3% higher ruminal disappearance of the A fraction of DM and 3.3 to 8.0% lower disappearance of the B fraction of DM when compared to bermudagrass hay. When comparing the impacts of 21, 35, and 49 day harvest intervals on crabgrass digestibility, Beck et al. (2007b) reported that in situ disappearance of the A fraction of DM decreased linearly with increased harvest interval (11.7, 8.0 and 6.2% of DM, respectively) but no effect was found between treatment and digestibility of the B fraction. As expected, harvest interval increased the C fraction of DM with digestibility values of 42.5, 43.9 and 51.7% of DM, respectively.

Volatile Fatty Acids

Diets that are capable of producing increased concentrations of volatile fatty acids (VFA) are of great interest to livestock producers because VFA's, which are by-products of microbial fermentation, are the primary energy substrates for tissue maintenance and growth in ruminants. The primary VFA's produced by microbes in the rumen are acetate, propionate and butyrate. In general, increased concentrations of propionate production are associated with high starch diets (Beauchemin et al., 2008) while increased levels of acetate production are a result of diets high in forage. Since little glucose is absorbed from the diet, ruminants rely on a process called gluconeogenesis in order to produce their own glucose. Propionate is the major substrate for gluconeogenesis while acetate is the major precursor for fatty acid synthesis. If propionate for gluconeogenesis is limiting, glucogenic amino acids will be used as glucose precursors (Van Soest, 1994). However, this is a metabolically expensive replacement for propionate, making it important to investigate the impacts of dietary feeding regimen on VFA production. Meale et al. (2011) found that forage species significantly affected total VFA production which had a strong positive relationship with forage IVDMD. Authors also found a forage species effect on the acetate to propionate ratio. In a similar study Doane et al. (1997) examined in vitro VFA production of six forages and found that propionate production in wheat straw was 15.0 mmol L^{-1} of sample DM^{-1} and was lower than that of immature brome grass which had a concentration of 20.9 mmol L^{-1} of sample DM^{-1}. Neutral detergent fiber digestibility was also higher for immature brome grass compared to the wheat straw (92.2 and 51.4 %, respectively) while the acetate to propionate ratio was 2.22 in the wheat straw and 1.48 for immature brome grass.

Gas Production

A topic of interest in ruminant nutrition is the role of ruminants in global warming and whether grazing animal production is sustainable. This debate has primarily been stimulated by the fact that ruminants, in the process of fermenting plant material, release methane which is known to be a potent greenhouse gas (GHG) (Ellis et al., 2007). It has been estimated that food animal agriculture accounts for 54% of all agricultural related GHG emissions in the U.S. (U.S.D.A., 2008) and 70% in Australia (Peters et al., 2010). Globally, livestock production is estimated to account for 18% of all anthropogenic GHG emissions (Steinfeld et al., 2006). Although many factors can influence GHG production, recent research has shown that the ruminant diet is an important variable that can impact GHG production by livestock. Therefore, dietary manipulation to reduce GHG emissions is of great importance. It has been well documented that high grain diets result in a reduction of methane gas when compared to all forage diets (Pitesky et al., 2009; Pelletier et al., 2010). Interestingly, differences in GHG production also exists between forage species. Comparing the effects of pasture type on methane production in dairy cattle, McCaughey et al. (1999) found that grass-only pastures produced higher levels of methane compared to alfalfa-grass pastures (411.0 and 373.8 L d^{-1}, respectively). In a similar study, Meale et al. (2011) found that forage species plays a role in methane gas production with grasses having numerically higher methane emissions (average of 13.1 mg/g digested DM) than non-leguminous shrubs (average of 3.5 mg/g of digested DM) and leguminous shrubs as an intermediate (average of 8.8 mg/g of digested DM). Authors also reported a species difference ($P < 0.05$) in methane production within each category of forage and that the species of forage with the highest methane production also had the highest level of IVDMD. This relationship between IVDMD and methane production has been well documented in the literature (Durmic et al., 2010; Jayanegara et al., 2011).

Animal Performance

One major issue faced by grass-finishing producers is the challenge of maintaining target body weight12 gains throughout the entire year. Cool season annual and perennial species are capable of providing a high plane of nutrition that produces an acceptable performance response in cattle during the spring, fall, and winter. However, this level of production is more difficult in the summer months with the combination of heat stress, unpredictable weather, and the characteristically higher fiber concentrations found in most warm season forages. It has been well documented that cattle finished on grain have higher gains than cattle finished on forage only diets (Bidner et al., 1986; Roberts et al., 2009) but little research exists comparing cattle performance on different warm season annual forage species. Duckett et al. (2013) compared the effects of forage species on cattle live weight gains and found that pearl millet produced greater ADG than a pasture of mixed forage species (bluegrass, tall fescue, orchardgrass, white clover, triticale, Italian ryegrass) or alfalfa (1.61, 1.11, 1.15 kg/d, respectively). In a contradicting study, Schmidt et al. (2013) found that heifers grazing pearl millet had an ADG of 0.56 kg/d which was lower than the ADG of 1.28 kg/d of steers grazing alfalfa. In the same forage-finishing trial, heifers grazing bermudagrass had greater final body weights than pearl millet (579 and 525 kg, respectively), however, no differences were detected in ADG (0.76 and 0.56 kg/d, respectively). Other studies have also reported that summer annual forages are capable of producing targeted body weight gains. In Canada, Holt (1993) reported that steers grazing sorghum x sudangrass had average daily gains of 0.97 to 1.18 kg/d. Similarly, McCartor and Rouquette (1977) found that steers grazing pearl millet had ADG ranging from 0.27 to 1.01 kg and that NDF concentration of pastures and ADG were negatively correlated (r = -0.84) with one another. These results indicate that forage nutritive value is a key component in producing an animal performance response.

Impact Of Finishing Diet On Carcass Parameters

Forage-Finished Beef

Grass-fed beef is not a new concept or method of production. In fact, grass-fed beef was the primary beef finishing system prior to the 1940's. In the 1950's, when grain became a cheap and available commodity, much research was done on finishing cattle on grain in a feedlot system. This system proved to be an efficient way to produce red meat, in that it decreased the days on feed and the amount of land required to grow an animal to slaughter weight. Until recently, grain-finishing has been the standard and accepted method for producing high quality beef. However, there has been a growing interest in grass-fed beef among health conscious consumers in the U.S. as a result of real or perceived benefits of this production system. These real or perceived benefits of the grass-fed production model include greater health benefits associated with consuming grass-fed beef, more environmentally friendly production methods, and improved animal health and welfare (United States Department of Agriculture, 2007).

It is frequently suggested that grass-fed meat products are healthier, with altered fat content and fatty acid profiles when compared to grain-finished beef. Specifically, it has been reported that grass-fed beef contains less cholesterol-elevating saturated fatty acids (SFA) such as myristic acid (C14:0) and palmitic acid (C16:0), higher concentrations of healthy SFA, as well as a more desirable ratio of linoleic and linolenic FA's (n-6:n-3) (Realini et al., 2004; Leheska et al., 2008; Daley et al., 2010). Furthermore, the perception that most grass-finished beef is locally grown has also given rise to an increase in sales and demand of the product (Darby et al., 2006; Lacy et al., 2007). However, there has been a lot of confusion among producers and consumers regarding certification and labeling of forage-finished or grass-fed beef products.

In November of 2007, the Agricultural Marketing Service (AMS) updated the 2006 voluntary standard for grass-fed (forage) products in which producers could market their meat products with a label that would be verified by the USDA (United States Department of Agriculture, 2007). Before use, product labels with the grass fed claim had to be submitted and approved by the USDA's Food Safety and Inspection Service (FSIS), Labeling Program and Delivery Division (LPDD). Together, the AMS and FSIS, LPDD developed the voluntary standard for the grass-fed marketing claim. The standard states that ruminant animals only qualify for the grass-fed marketing claim if their lifetime diet, with the exception of milk or milk replacer, has consisted solely of any herbaceous plant material in the vegetative or pre-grain stage. The standard goes on to state that the herbaceous plant material could be either grazed or harvested, however, animals should have access to pasture during the growing season which is defined as the time from the last frost in spring until the first frost in the fall.

The AMS standard for grass-fed products has been used by many to market a unique product verified by the USDA. However, in January of 2016, the USDA's AMS withdrew the voluntary standard for grass-fed products. The withdrawal was the result of lacking authority from Congress to warrant AMS standing statutory authority to define grass-fed standards (United States Department of Agriculture, 2016). However, this does not mean that producers and companies cannot market a grass-fed product. Applicants must set their own standards for a grass-fed claim and that standard will be verified by FSIS. The AMS will then list each standard on the appropriate Official Listing which can be accessed by consumers.

Comparison of Grain and Forage Finished Beef

The diet-heart (lipid) hypothesis, or the thought that high fat diets are the primary cause of cardiovascular disease (CVD), has stimulated the recommendation by health professionals to reduce consumption of saturated fatty acids (SFA's), trans-fatty acids (TA's) and cholesterol and opt for the more heart-healthy omega-3 (n-3) polyunsaturated fatty acids (Griel and Kris-Etherton, 2006; Kris-Etherton and Innis, 2007). This hypothesis has been backed by the high correlations found between CVD and SFA intake and the mechanisms in which SFA increases serum low-density-lipoprotein (LDL) cholesterol, a known factor in causing CVD (Posner et al., 1991; Hu et al., 1997). As consumers have become aware of this correlation and the recommendations to reduce dietary fat, beef from grass-fed or grass-finished cattle has increased in popularity. This increased demand has primarily been stimulated by reports that grass-fed beef is a leaner beef with a higher concentration of n-3 fatty acids when compared to beef from conventional systems.

Before a direct nutritional comparison can be made of beef finished on forage or grain, it should be noted that there have been numerous studies that have attempted to compare carcass quality between grain and grass-fed cattle, however, the results have been confounded by differences in finishing age, physiological maturity, and body fat content of the cattle studied (Hedrick et al., 1983; Bidner et al., 1986). Typically, grain-fed cattle have fewer days on feed and are therefore younger in age and physiological maturity at slaughter than their grass-fed counterparts. This can result in grain-fed cattle having both higher quality grades and palatability scores since maturity plays a direct role in quality grade determination and overall dining experience. Hilton et al. (1998) reported that skeletal maturity ranging from A to E classification decreased the tenderness (from 2.56 to 3.53 kg shear force) and juiciness (from 5.00 to 4.69 on a scale of 1 = extremely dry to 8 = extremely juicy) of strip loins and was also associated with an increase in off flavor incidences of painty, fishy, and grassy.

Due to the high energy density of the diet, conventionally fed animals also tend to have higher carcass fat and intramuscular fat (IMF), also known to consumers as marbling, than grass-finished cattle. Marbling has been shown to increase the perception of tenderness, juiciness, and flavor of beef and most consumers in the U.S. have grown accustomed to the taste of grain-finished beef. A study by Mandell et al. (1998) wanted to determine the impacts of finishing diet on carcass quality attributes when time on feed was controlled in both grass and grain-finishing diets. The authors found that when finishing Limousin-cross steers on either high moisture corn or alfalfa silage, steers on high moisture corn had heavier carcass weights (272.9 and 228.3 kg, respectively), a greater percentage of backfat (5.2 and 3.9 mm, respectively), a larger ribeye (81.6 and 70.8 cm^2, respectively), and had more intermuscular fat (39.7 and 35.4 %, respectively) compared to their grass-fed counterparts. Leheska et al. (2008) found that steers finished on grain had a significant increase in marbling score compared to steers finished on grass (503 vs 420, respectively). The authors also concluded that the grass-fed steers had a lower percentage of intramuscular fat in strip steaks compared to the grain finished cattle (2.8 and 4.4%, respectively), however, the concentration of cholesterol did not differ between the two feeding regimens (54.6 and 54.7 mg/100 g, respectively). Another study by Daley et al. (2010) compiled the literature of several finishing trials and concluded that grass fed cattle are consistently lower in total fat than cattle finished on grain. Interestingly though, total SFA content was not consistent between feeding regimens across studies. Although the literature consistently reports higher concentrations of IMF and overall fat in grain-fed cattle compared to grass-fed beef, there is a need for more research comparing the effects of forage species on fat content and fatty acid composition of forage-fed cattle.

Beef is a nutrient rich food that provides many essential amino acids, vitamins, and minerals to our diets. It is well known that the ruminant diet can greatly alter the nutrient profiles of beef. Current research has primarily focused on the comparisons of grain and forage diets on the fatty acid (FA) profiles of beef but little research has recorded the effects of forage species. With the discovery that FA's vary in their overall ability to impact serum cholesterol levels, it is more important than ever to understand the effects of diet on carcass composition of FA. Daley et al. (2010) reported that stearic acid (C18:0) did not impact LDL or high-density-lipoprotein (HDL) but lauric acid (C12:0) and myristic acid (C14:0) raised total cholesterol more than palmitic acid (C16:0). In a study by Leheska et al. (2008) comparing strip steaks from grass-fed beef from 15 different producers to conventional fed beef, authors found that grass-fed cattle had a higher total SFA content than grain-fed cattle (48.8 and 45.1g/100 g lipid, respectively). Specifically, stearic acid was significantly higher (17.0 and 13.2 g/100 g of fat) in those animals while myristic acid (2.84 and 3.45 g/100 g of fat, respectively) and oleic acid (36.5 and 38.6 g/100 g of fat, respectively) were lower. In a similar trial, Descalzo et al. (2005) wanted to compare the fatty acid composition of pasture raised cattle compared to grain-fed cattle. They found the grass-fed cattle had higher concentrations, as a percentage of the total fatty acids, of linolenic (1.4 vs 0.7), vaccenic acid (4.2 vs 2.8) and poly-unsaturated fatty acids (PUFA) (10.1 vs 7.29) but lower concentrations of total mono-unsaturated fatty acids (MUFA) (34.17 vs 37.83) and n-6/n-3 ratios (3.72 v s 5.73), emphasizing the fact that diet can impact fatty acid composition of beef cattle. In one of the few studies comparing forage species on fatty acid composition of the longissumius muscle, Schmidt et al. (2013) reported that steers finished on chicory had a higher linoleic (C18:2 cis-9,12) concentration than steers finished on alfalfa, bermudagrass, cowpea, or pearl millet. However, both chicory and pearl millet had an altered n-6:n-3 ratio (2.11 and 2.26) compared to the other forages (mean 1.86).

Through many years and multiple studies comparing grass-fed vs. grain-fed beef, research has found that forage-only diets result in a leaner carcass and an altered fatty acid profile when compared to conventional beef. Although not mentioned in this review, it should also be noted that grass-fed beef contains higher levels of Vitamin A and E precursors (Daley et al., 2010) which adds to the total nutritional package of grass-fed beef. Although there are potential palatability differences between the two beef finishing regimens, ultimately consumer preference and satisfaction will drive the beef industry to continue to look for alternative methods for finishing cattle.

Influences of Forage Quality on Carcass Parameters

Energy is not considered a nutrient but is the most important component of an animal's diet. Feeding strategies and recommendations in ruminant nutrition are all based on energy needs. Energy, supplied to ruminants through the fermentation of feedstuffs into VFAs, is required by animals to do work for both maintenance and production purposes. Since tissues and vital organs are rationed energy for maintenance operations prior to muscle and fat deposition (Aberle et al., 2001), it is important to provide animals with a diet that exceeds their maintenance requirements. In the finishing sector of the beef industry, incorporation of concentrate feeds is the most common method of providing an energy dense diet to cattle, but in grass-finishing operations, this is not a feasible practice. Instead, attention must be focused on providing forages that are high in digestible DM and low in lignin.

Many have researched the impact of lignification of cell walls on fiber digestibility in ruminants (Akin, 1989; Akin and Chesson, 1989; Jung and Allen, 1995). Highly lignified forages not only decrease the energy density of the diet but they can also decrease the passage rate of feedstuffs in the rumen. Consequently, this results in suppressed DMI and can limit the amount of energy being consumed. This relationship between lignification, DMI, and passage rate is most notably found in studies containing BMR and non-BMR forages. In a feeding study by Muller et al. (1972), growing lambs were fed a BMR and non-BMR diet containing equal concentrations of NDF. However, the BMR diet had a 34% lower lignin concentration than the non-BMR diet and BMR-fed lambs were able to consume 29% more DM. Similar results have been found in studies comparing the effects of forage maturity on DMI and digestibility, with less mature forages having decreased concentrations of lignin and increased concentrations and rates of DM digestibility (Llamas-Lamas and Combs, 1990; Beck et al., 2007a; Beck et al., 2007b). Thus, negative impacts on carcass quality can occur if energy is the limiting nutrient in finishing cattle diets. An energy dense diet is critical for rapid growth and deposition of both intramuscular fat and backfat, which are known contributors to both juiciness (Pearson, 1966) and flavor of beef (Hornstein et al., 1960; May et al., 1992).

Another important nutrient that has the potential to impact carcass quality is protein. Protein nutrition in the diet of ruminants is complex and nitrogenous compounds can be classified into two groups, nitrogen that comes from true protein and nitrogen from non-protein nitrogen sources (such as urea). Nitrogenous compounds have two fates in the rumen. They are either passed out of the rumen as undegradable intake protein (UIP) or used by microbes in the synthesis of microbial protein. Usually, protein in the diet is discussed in terms of crude protein which is the total amount of nitrogen in a feed source multiplied by 6.25, the known percentage of nitrogen in a typical protein. This crude protein fraction can also be divided into groups (A, B and C) based on the use and digestibility of the nitrogen content available. Fraction A is equivalent to non-protein nitrogen, fraction B is equivalent to digestible nitrogen and fraction C indicates the amount of protein that is indigestible. Relating nitrogenous fractions to feed quality, the more C fraction a feedstuff contains, the less amino acids available for absorption and utilization by both the microbial population and the ruminant animal. This is critical when it comes to both meat yield and eating quality because the rate and turnover of muscle determines the tenderness of beef. Although much of the factors affecting tenderness of meat is derived from the aging process in which proteolytic enzymes break down muscle components, it has also been shown that cattle performance prior to slaughter influences tenderness, as well (Aberle et al., 2001). Fishell et al. (1985) investigated pre-slaughter level of performance on tenderness of beef. They reported cattle with faster growth rates significantly improved the tenderness of beef as judged by a sensory panel, while a Warner-Bratzler shear test only showed numeric improvements in tenderness. It has been extrapolated that the increased tenderness in beef in rapidly growing cattle is the result of rapid protein turnover and therefore increased proteolytic enzymes (Muir et al., 1998).

Quality of the meat is the primary factor determining total value of the carcass. In beef cattle, quality grades are a combination of both maturity and marbling scores. Maturity is measured by determining the physiological age of the carcass by looking at the buttons and sacral vertebrae. Color and texture of lean also provide an insight as to the physiological age of the animal. Marbling is a key component of quality grade because of its direct impact on both juiciness and flavor of meat. Collectively, these measurements can determine overall value of a carcass with the prime quality grade being the most valuable. As previously mentioned, the nutritive value and quality of a diet can impact several of the factors determining quality grade and overall palatability of the end product. Thus, it is necessary to provide forage-finishing animals high quality forages that contain nutrient concentrations that are above maintenance requirements for both energy and protein in order to promote fat deposition and muscle turnover and development.

Live Carcass Composition Parameters and Ultrasonography

Measuring carcass value prior to slaughter can be an economically important tool regarding marketing decisions for beef cattle producers. With the use of expected progeny differences and genomic selection, producers are able to formulate a general expectation of what the slaughtered animal should be. However, a tool that is capable of quantifying the muscle and fat content of live beef without imposing stress upon the animal would be of more value to producers looking to sell products in value added markets. Wild (1950) first reported that ultrasonography could be a useful tool to measure the body composition of live animals. The procedure uses an ultrasound transducer to measure an echo rebounding from tissues, with tissues of different densities producing varying reflecting surfaces (Houghton and Turlington, 1992). Since its discovery, researchers have attempted to use ultrasonic instrumentation to estimate the body composition of several species of livestock including beef cattle (Brethour, 1990; Greiner et al., 2003; Wall et al., 2004), sheep (Edwards et al., 1989), and swine (Terry et al., 1989; Newcom et al., 2002). In a study evaluating the relationship between ultrasound and carcass measurements, Greiner et al. (2003) reported that the correlation between the two measurements for 12^{th}-rib fat was r = 0.89 while the correlation of longissimus muscle was r = 0.86. However, ultrasonography consistently underestimated 12^{th}-rib fat by 0.06 cm. In another study, Brethour (2000) found that serial ultrasound measurements were useful in the estimation of days in which it took cattle to reach a backfat thickness of 10 mm. In the study, R square values of 0.25, 0.49, 0.65 and 0.70 were reported for 166, 129, 90, and 43 days prior to slaughter, respectively.

Although ultrasonography is a highly acceptable practice and has been used for some time now in the beef industry, the literature reports a clear difference in its accuracy to predict longissimus muscle area (LMA) compared to 12^{th} rib fat. Houghton (1988) compared the live ultrasound measurements of 127 steers to the actual corresponding carcass measurements once harvested. The author reported that LMA could be predicted within 6.25 cm^2 79% of the time and within 3.12 cm^2 only 32% of the time. In contrast, 12^{th} rib fat thickness could be predicted within 0.20 cm 84% of the time and within 0.10 cm 58% of the time. Even with these degrees of inaccuracy, ultrasonography is a useful tool to help estimate the carcass parameters of live animals.

Conclusions

Forage-finished beef is not a new concept but its popularity has recently increased among consumers. The climate of the southeastern U.S. allows forage to be grown almost year round, making it an ideal location to finish cattle on pasture. Although the majority of the literature focuses on comparing forage and concentrate-fed animals, little research exists on forage species effect in finishing beef systems. The growing interest in forage-finished beef has warranted the need for new research in this area, specifically on ways to improve beef production during the summer when forage quality of warm season perennial species can rapidly decrease. Utilizing warm-season annual forages may be an option for forage-finishing beef producers. Therefore, the objectives of the following studies are to evaluate four warm-season annual forage systems on the basis of forage production and quality, cattle performance, and meat yield and quality attributes.

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Table 2.1. Summary of fiber fractions and in-situ effective disappearance from whole-plant crabgrass harvested on 7 dates (Ogden et al., 2005) and crabgrass hay harvested at 3 intervals (Beck et al., 2007b).

Forage/Sampling Date/Interval	NDF	ADF	ADL	Effective Disappearance	
		% of DM		% DM	%NDF
		Ogden et al., 2005			
Crabgrass					
July					
11	55.5	29.4	2.4	74.8	63.5
18	55.6	27.5	1.9	75.4	64.8
25	57.4	28.8	2.4	72.9	60.2
August					
1	60.8	31.2	2.9	71.8	59.9
8	58.8	28.9	2.6	71.2	59.0
15	61.9	31.3	2.9	69.3	57.5
22	61.2	30.9	2.8	70.9	59.1
Control Hays					
Alfalfa	51.9	38.7	7.4	61.2	37.6
Bermudagrass	62.1	27.0	1.5	66.5	59.3
Orchardgrass	97.2	34.9	2.7	64.8	57.6
Contrasts			*P*-Value		
Linear	<0.001	0.001	<0.001	<0.001	<0.001
Quadratic	0.250	0.540	0.520	0.038	<0.001
Cubic	0.320	0.130	0.070	0.001	<0.001
Quartic	0.360	0.080	0.034	0.860	0.075
		Beck et al., 2007b			
Harvest Interval					
21 days	61.3	35.7	-	30.8	25.4
35 days	66.6	38.9	-	27.9	25.3
49 days	69.8	42.7	-	25.9	21.9
Contrasts			*P*-Value		
Linear	<0.001	0.001	<0.001	<0.01	<0.01
Quadratic	0.250	0.540	0.520	0.650	0.02

CHAPTER 3

WARM-SEASON ANNUAL FORAGES IN FORAGE-FINISHING BEEF SYSTEMS: I. FORAGE YIELD AND QUALITY.

[1] Harmon, D. D., D. W. Hancock, R. L. Stewart Jr., A. M. Stelzleni, J. R. Segers, and C. D. Teutsch. To be submitted to *Journal of Animal Science*.

Abstract

The demand for a year-round supply of fresh, locally grown, forage-finished beef products has created a need for forage-finishing strategies for the summertime in the Southeast. A three year study was conducted to evaluate four warm-season annual forages in a southeastern forage-finishing beef production system. Forage treatments included brown midrib sorghum x sudangrass [*Sorghum bicolor var. bicolor*bicolor var. sudanense*; BMR], sorghum x sudangrass [SS], pearl millet [*Pennisetum glaucum* (L.) R.Br.; PM], or pearl millet planted with crabgrass [*Digitaria sanguinalis* (L.) Scop.; PMCG]. Treatments were organized in a randomized complete block design, 16 pastures (0.81-ha) were assigned to one of four forage treatments and were subdivided for rotational grazing. British-cross beef steers (n = 32; 3 yr average: 429 ± 22 kg) grazed for 70, 63 and 56 days in 2014, 2015 and 2016, respectively. Put-and-take grazing was utilized to maintain a forage allowance of 1600-4500 kg ha^{-1}. Forage DM availability was measured by clipping a 4.3-m^2 area in triplicate on d 0 and on 14 d intervals. Hand grab samples for forage quality determination and quadrat clippings for species compositions were measured on d 0 and on 34 d intervals until termination of the trial. Forage DM yield was lowest (P < 0.01) for PMCG at the initiation of the grazing trial, while BMR was greater (P < 0.01) than SS at week 6. Total digestible nutrients in 2014 was greater for SS compared to BMR and PM at the middle harvest (P < 0.01) and BMR, PM and PMCG at the final harvest (P < 0.01). At the middle and final harvests in both 2015 and 2016, PM and PMCG contained greater (P < 0.01) concentrations of CP than SS. Higher stocking densities were maintained on SS than PM and PMCG (P < 0.01) at days 0, 6, 13 and 20 in 2014 and PMCG (P < 0.01) on days 0, 6, 13, and 20 in 2015. Stocking densities of BMR was greater (P < 0.01) than PM and PMCG on day 0, 6, and 13 in 2014. These results suggest that BMR, SS, PM, and PMCG may all be used in

Southeastern forage-finishing beef production systems, as long as the producer strategically accounts for the slight growth and quality differences throughout the season.

Keywords: Forage-finishing, Grass-fed, Beef, Warm-season annuals, Sorghum x sudangrass, Pearl millet, Forage

Introduction

Demand for locally produced, forage-finished beef products has increased in popularity among consumers. This demand has primarily been stimulated by reports that grass-fed beef has a beneficial impact on human health due to an altered fatty acid profile when compared to conventionally raised beef (Duckett et al., 2009). To provide a year round supply of pasture-finished beef, producers must match the nutrient needs of finishing cattle with the nutrients found in available forage. In the spring, fall, and winter months in the southeastern U.S., the use of cool-season annual and perennial forages allows for rapid muscle and adipose deposition needed to produce a high quality, forage-finished product. However, limited forage options in combination with challenging weather conditions during the summer months can make finishing cattle on pasture difficult. Many forage programs in the Southeast utilize warm-season perennial grasses, but these forages are higher in fiber and lower in digestible energy than annual grasses (Hill et al., 1999), limiting their value and use in finishing programs.

In many drought stricken regions of the world, warm-season annual grasses such as sorghum x sudangrass [*Sorghum bicolor* (L.) x *S. Arundinaceum* (Desv.)] and pearl millet (*Pennisetum glaucum* L.R. Br.) are used extensively as forage crops due to their high productivity during a short period of time. Additionally, there has been a growing interest in the utilization of crabgrass as a high quality forage during the summer months in the Southeastern U.S. In Florida, Fontaneli et al. (2001) reported seasonal forage DM yields of sorghum x sudangrass and pearl millet to range from 7.98 to 5.01 Mg ha^{-1} when planted between March and May. In Arkansas, sorghum x sudangrass has been reported to yield up to 7.43 Mg ha^{-1} just 63 days after planting (Beck et al., 2007a) while crabgrass produced 9.79 Mg ha^{-1} in 49 d (Beck et al., 2007b).

With the combination of high DM yields, nutritive value, and drought tolerance, opportunity exists for warm-season annual forages to fill the nutritional gap that often occurs in summer forage-finishing beef production. Little information is available on distribution of DM, forage quality, and stocking rate and animal performance of grazed warm-season annual forages. Thus, the objective of this study was to compare yield, forage distribution, nutritive value and stocking rate of four, rotationally grazed, warm-season annual grass forage systems in Southeastern forage-finishing beef operations.

Materials and Methods

Forage Treatments and Management

Forage treatments of sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM) and a mixture of pearl millet and crabgrass (PMCG; *Digitaria sanguinalis*) were assessed during the summers of 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Sciences Eatonton Beef Research Unit (Eatonton, GA). Forage treatments were compared in a randomized complete block design with four replications. Sixteen 0.81-ha pastures were blocked based on production history, soil type, and topography, and forage treatments were randomly assigned within each block.

In the spring of 2014, based on soil test recommendations, 17-17-17 (N-P-K, %) granular fertilizer was spread at 448 kg ha^{-1} to all pastures. Soil core samples were also taken in the spring of 2015 and 2016 but results did not indicate a need for phosphorus and potassium fertilizer and thus a granular fertilizer was not applied. However, due to soil compaction issues and soil erosion from heavy winter rains, all pastures were disked and cultipacked in the spring of 2015.

On or about 15 May of each yr, pastures were planted with a no-till drill (Haybuster 107; Jamestown, ND) 7 d after the paddocks were sprayed with glyphosate at 1.1 kg a.i. ha^{-1} (Helosate Plus Advanced; Helm Agro US, Inc., Tampa, Florida). Sorghum x sudangrass (cv. 'Sugargrazer' in 2014 or cv. 'AS5201' in 2015 and 2016; Alta Seeds, Irving, TX) and BMR ('Honey Graze' in 2014; Arrow Seed Co, Broken Bow, NE; or 'AS6201' in 2015 and 2016; Alta Seeds, Irving, TX) were planted at 22.4 kg ha^{-1} and at a soil depth of 2.54 cm, PM (cv. 'Tifleaf III'; Coffey Forage Seeds, Inc., Plainview, TX) at 16.8 kg ha^{-1} and at a soil depth of 1.27 cm, and the PM (cv. 'Tifleaf III') plus CG (cv. 'Red River'; R.L. Dalrymple Farm, Thomas, OK) mixture was planted simultaneously at 11.2 kg ha^{-1} at 1.27 cm and 5.6 kg ha^{-1} at 0.64 cm, respectively. Crabgrass was planted in a 1:1 ratio with sand to reduce static cling and allow a consistent flow of crabgrass from the small seed box through the drop tubes. Additionally, half of each pasture was fertilized with a liquid nitrogen fertilizer ('19E'; R.W. Griffin, Attapulgus, GA; or 32% UAN) at a rate of 40 units of N/acre on day 30 and 34 in 2014 and 2015, respectively, and with 30 units of N/acre on day 37 in 2016. Nitrogen fertilizer was applied to the second half of each pasture approximately 7-14 d thereafter.

Each year, forages were scouted weekly for chinch bug [*Blissus leucopterus leucopterus* (Say) (Heteroptera: Blissidae)] and sugarcane aphid [*Melanaphis sacchari* (Homoptera: Aphididae)] damage. In August of both 2015 and 2016, PM and PMCG pastures were sprayed with dimethylcyclopropane carboxylate (Mustang Maxx; FMC Corporation, Philadelphia, PA; or Lambda-Cyhalothrin 1 EC; Nufarm Americas Inc., Burr Ridge, IL) at a rate of 28 g a.i. ha^{-1} to control chinch bug infestation. Pastures were sprayed for chinch bugs once a threshold of 100 bugs/leaf had been reached. In the summer of 2015 and 2016, a section 18 emergency exemption label was issued in Georgia for the use of Transform (The Dow Chemical Company, Indianapolis, IN) to control the sugarcane aphid in sorghum pastures. In July of 2015 and 2016, once a sugarcane aphid threshold had reached 50 aphids on 25% or more of infected leaves, sulfoxaflor was applied to SS and BMR pastures at a rate of 53 g a.i..0234 ha^{-1}.

Cattle Management

Each year, 32 angus-cross steers (*Bos taurus*; 429 ± 22 kg) from the Department of Animal and Dairy Science Eatonton Beef Research Unit were blocked by BW and randomly assigned to one of four forage treatments one week prior to the initiation of the project. Upon initiation of the grazing trial, steers were fasted for 12-h before being weighed. During this time, cattle were also treated for internal parasites before being immediately turned out into their assigned pastures. Initiation of grazing was June 25 in 2014 and 2015, and June 29 in 2016 and was based on a targeted forage allowance of 1000 kg ha^{-1} for all treatments.

All steers were supplied with ad libitum access to shade, water and mineral (McNess Bova Breeder 6; Furst McNess Co., Cordele, GA). Each 0.81-ha pasture was subdivided into two 0.405-ha paddocks with temporary fencing and grazed rotationally. Rotational decisions were made based on forage availability (measured biweekly) and residual height of pastures adequate for optimal regrowth potential (Allen et al., 2011). In this study, stocking density was determined by both objective and subjective measurements. Put-and-take stocking was used to maintain forage DM availability, and steers that were added or removed were from the same contemporary group as the 32 test steers. Put-and-take stocking decisions were also made based on forage availability measurements, and for every 250 kg above or below the targeted forage allowance, a steer was either added or removed to the pasture. Measurements of both stocking density and gain per hectare included weight data for put-and-take steers. Prior to the initiation of grazing or the addition of a steer, put-and-take steers were fasted for 12-h before being weighed. Since body weight measurements were not available for some put-and-take steers once they were removed from the pastures, gains were determined by taking the average ADG for the tester steers in the respective pasture and multiplying that by the number of days a put-and-take steer spent grazing a specific pasture. In late summer, once there was insufficient forage mass to sustain live weight gains, the study was terminated and the steers were transported (71 km) to the University of Georgia's Meat Science Technology Center (Athens, GA) for harvest. End dates were September 03, August 27 and August 31 in 2014, 2015 and 2016, respectively.

Forage Sampling

Forage mass was measured by clipping in triplicate, a 4.3-m^2 area every 14 d with a custom-made plot harvester (University of Missouri, Columbia, MO) mounted on the three-point hitch of a tractor. Forage samples were taken from both the pre- and post-grazed paddocks and were weighed, subsampled, and placed in a 95^{o}C forced air dryer for 7 days for DM determination. At the beginning, middle, and end of the grazing trial, estimates of both forage botanical composition and forage quality were made from the pre-grazed side of each pasture. Forage botanical composition was measured by cutting and separating desirable and undesirable species from 0.1-m^2 quadrats in three locations per pasture. Samples of desired and non-desired forages were immediately weighed and placed into a 95^{o}C forced air dryer for 7 days. Forage quality sampling was conducted by hand grab samples that mimicked the grazing selections made by the cattle. After forage quality samples were dried, samples were double ground, first through a 2-mm screen in a Wiley mill (Thomas Scientific, Swedesboro, NJ) and then through a 1-mm screen in a Cyclotec 1093 Sample Mill (Foss, Eden Prairie, MN). Samples were then sent to the University of Georgia's Feed and Environmental Water Lab (Athens) for determination of crude protein (CP), nitrates, fat, ash, neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, total digestible nutrients (TDN), dry matter intake (DMI), relative forage quality (RFQ) and in vitro true dry matter digestibility at 48 h (IVTDMD48) by near infrared reflectance spectroscopy using a model 6500 (FOSS NIRS System Inc., Laurel, Maryland) NIR analyzer. All predictions were made using the NIR consortiums most recent equations (Hillsboro, WI).

Drought Management

During the summer of 2015 and 2016, the Eatonton Beef Research Unit experienced moderate to extreme drought conditions, and measures to prevent a total loss of the experiment were taken. In 2015, an extra 0.81-ha area of each forage treatment was planted for use as supplemental feed for tester steers. Forage was cut with a mower-conditioner (John Deere, Moline, IL) and allowed to wilt for 18 hours before being harvested for baled silage at 50% moisture. Bales were then wrapped with an individual bale wrapper (RB-400; Anderson Group Co., Chesterville, Qc GOP 1JO (Canada)) in 6 layers of Sunfilm silage wrap (AEP, Montvale, NJ). Bales were ensiled for a minimum of 21 d before drought conditions progressed to a point where supplemental feed was needed to maintain adequate DMI in test steers. Steers were fed balage from their respective forage treatments every 3 days from August 08 through August 23. On each feeding day, 1 bale was equally split among the 4 pastures of the respective forage treatment using a chainless bale feeder (Hustler, Hastings, NZ).

In 2016, extreme drought conditions limited the growth of extra paddocks that were planted in each forage treatment for use as balage. Thus, balage was not available to be fed as emergency forage when the lack of moisture limited forage availability. Instead, cattle were removed from their respective treatments, weighed, and placed together in a holding pasture for 7 days from August 2nd - 9th. The pastures were not equipped with an irrigation system capable of providing continuous irrigation for the remainder of the trial, but during this hiatus all pastures received two rounds of ca. 19 mm of water using a retractable traveling reel and gun in an attempt to keep the forage alive. After one round of irrigation and a 7 d rest period, cattle were weighed and placed back into their respective pastures. Approximately 7 d after the first round of irrigation, pastures were re-irrigated with another ca. 19 mm of irrigation, which exhausted the supply of impounded water. To ensure DMI would not be a limiting factor for growth, a 1.5 x 1.2 round bale of bermudagrass (*Cyndon dactylon* L. Pers.) hay from the same field and harvest, was placed into each pasture for ad libitum feeding until arrangements could be made to harvest the steers at an earlier date than expected.

In Situ Forage Digestibility

Forage quality samples were composited by treatment within year and harvest date to determine in situ DM disappearance. Five-grams of forage was weighed in quadruplicate into dried and weighed nylon bags (10 cm x 20 cm; ANKOM Technology, Macedon NY) of 50 micron porosity and were triple sealed using an impulse sealer (TISH200; TEW Electric Heating Equipment Co. Ltd., Taipei, Taiwan). One replicate of each sample was placed sequentially into two ruminally cannulated Holstein steers (1095 ± 7 kg) in a completely randomized design with two incubation periods, allowing for a total of four replications of forage incubation. Steers were fed a diet consisting of ad libitum access to both bermudagrass (*Cynodon dactylon* L. Pers.) hay and mixed grass pasture consisting of 68% annual ryegrass (*Lolium multiflorum* Lam.), 19% bermudagrass and 13% weed species. Steers were fed this diet for 10 d prior to the initiation of the first 2 d *in situ* trial and were then rested for approximately 72 h before the start of the second incubation period.

Samples of SS, BMR, PM and PMCG were soaked in 36° C water for 30 minutes prior to being placed inside the rumen for incubation for 0, 6, 12, 24 and 48 h in nylon mesh lingerie bags. Upon removal from the rumen, samples were immediately placed into an ice bath for 30 minutes to inhibit microbial activity. Bags were then rinsed by hand until the rinse water was clear, placed in an oven and dried at 90° C for 48 h, and weighed for calculation of DM disappearance.

Statistical Analysis

All statistical analyses were conducted using the GLIMMIX procedure in SAS 9.4 (Cary, N.C.) to determine interaction and main effects of treatment and year. When applicable, day and/or harvest was used as a main effect and analyzed with interactions. Pasture and block were considered random effects and, unless otherwise stated, an alpha level of 0.05 was used to determine significance of main effects, with least squares means separated by pairwise comparisons.

Nonlinear regression was used to analyze forage DM disappearance curves using the NLIN procedure in SAS (SAS Inst. Inc., Cary, NC). Fractions of DM were partitioned based on relative susceptibility to ruminal degradation as described by Ørskov and McDonald (1979). Forage was broken into fractions A, B, and C with A representing the immediately soluble fraction, B describing the fraction that disappeared at a measurable rate, and fraction C depicting the undegradable portion (NRC, 2000). Disappearance rate (Kd) was determined by the nonlinear regression model for fraction B. Fraction C was then calculated by difference [100- (A + B)].

Results and Discussion

Environmental Conditions

Historical climate data as well as monthly precipitation and average maximum temperatures from May to September during the 3-yr trial were obtained from the University of Georgia's Automated Environmental Monitoring Network (Network, 2017) weather station located on the University of Georgia's, Animal and Dairy Sciences Eatonton Beef Research Farm near Eatonton, GA. Monthly maximum temperatures for this study are presented in Figure 3.1. Relative to the 100-yr average, temperatures were below normal in 2014 but above normal in 2015 and 2016. There was approximately 29, 44, and 54 days during the grazing trial in which maximum daily temperatures exceeded 32.2^{o}C in 2014, 2015, and 2016, respectively. Cumulative precipitation during the summer months followed a similar pattern to monthly maximum temperatures, with precipitation exceeding the 100-yr average in 2014 followed by drought and extreme drought conditions in 2015 and 2016, respectively (Figure 3.2). Table 3.1 shows the number of days that received rain and the monthly average precipitation per rainfall event. Overall, there were more rainy days with larger precipitation totals per rainfall event in 2014 compared to 2015 and 2016. Although there were over 15 rainfall events in August of 2016, the average rainfall event produced less than 2 mm of precipitation.

Pre-Grazed Forage Mass

There was an interaction between year and week (P < 0.01) and treatment and week (P < 0.01) on pre-grazed forage mass during the grazing seasons. Main effects of year (P < 0.01) and the interaction of year and week (P < 0.01) can be attributed to differences in rainfall distribution events both between and within years. Pre-grazed forage mass was greatest (P < 0.01) for 2014, followed by 2015, and least for 2016 (3090, 2582, and 2327 kg ha^{-1}, respectively). Upon the initiation of the grazing trial, PMCG had less ($P < 0.01$) pre-grazed forage mass than SS, BMR and PM (Table 3.2). Thereafter, pre-grazed forage mass was similar among the treatments, except at 6 weeks into the grazing trial, when pre-grazed forage mass in the SS paddocks was lower ($P < 0.01$) than that of BMR, though PM and PMCG treatments were intermediate.

Near the end of the grazing trial (week 8), when the largest between year variation in moisture occurred, treatment and year interacted to have an effect on pre-grazed forage mass ($P < 0.01$). Forage mass for SS, BMR and PM was greater ($P < 0.01$) in 2014 than 2015 (2980, 4027, and 3419 kg ha^{-1} vs. 1953, 1931, and 2276 kg ha^{-1}). Likewise, pre-grazed forage mass was least ($P < 0.04$) for SS and BMR in 2016 compared to 2015 (1200 and 1013 kg ha^{-1} vs 1953 and 1931 kg ha^{-1}). Additionally, forage mass of PMCG was greater ($P = 0.03$) in 2014 compared to 2016, with 2015 as an intermediate (2956, 2164, and 2312 kg ha^{-1}, respectively). At week 8 in 2014, pre-grazed forage mass was greater for BMR ($P < 0.01$) compared to SS and PMCG, with PM as an intermediate (4027, 2980, 2956, and 3419 kg ha^{-1}, respectively). However in 2015, no difference ($P > 0.37$) was observed between treatment and pre-grazed forage mass. During the extreme drought year of 2016, forage mass of PMCG was greater ($P < 0.01$) than that of SS and BMR, with PM as an intermediate (2164, 1200, 1013, and 1614 kg ha^{-1}, respectively).

Species Composition

Changes in pasture composition of warm-season annual forages throughout the 3-yr grazing trial is shown in Table 3.3. Percent desirable species of the swards was affected by the main effects of treatment, year, harvest date and the interactions ($P < 0.01$). In both the first grazing year, where precipitation exceeded the 100 year average, and the 2016 grazing season, where an extreme drought occurred, a reduction ($P < 0.01$) in the SS and BMR content of pastures was observed between the initiation of the grazing trial and the intermediate harvest at day 34. A similar pattern ($P = 0.02$) occurred between initial and middle harvests in 2015 for SS, with a further reduction ($P < 0.01$) in desirable species of both SS and BMR from the second to the third harvest in that year. On the first harvest date of each year, the SS and PMCG pastures contained a higher ($P < 0.01$) percentage of desirable species than PM pastures, with BMR as an intermediate. Observations of pastures at emergence and the following weeks thereafter showed that SS and PM emergence was similar but growth rate after emergence appeared greater for SS than for PM. Testing the germination rate and radicle length of forage and weed seeds under drought stress, Hoveland and Buchanan (1973) reported that under drought conditions, pearl millet forage germinated at a more rapid rate than sorghum x sudangrass seeds. However, 96 hours after germination, radicle length did not differ between the two forages with the exception of the most extreme drought treatment, where PM seedlings had a longer radicle than sorghum x sudangrass seedlings. These findings suggest that once germination occurs, sorghum x sudangrass may have a more rapid growth rate than pearl millet and is similar to observations made in this study.

In each of the three years, composition of PMCG did not differ ($P > 0.78$) between harvests, meaning pastures maintained a constant ratio of desirable species in the sward. However, this effect was not seen in the PM forage treatment where desirable species declined ($P < 0.01$) by the end of the grazing trial from harvest 2 to harvest 3 in all trial years. Additionally, PMCG pastures contained a greater ($P < 0.01$) level of desirable species at the middle and final harvest each year compared to treatments of SS, BMR, and PM. This effect may be explained by the addition of the crabgrass in the PMCG and the compatibility of the two species to provide a larger distribution of forage throughout the entirety of the grazing season. In the field, it was observed that crabgrass plants filled in the gaps between the pearl millet plants. This coexistence of forage species not only provided tonnage but also provided ground coverage, making it hard for other weed species to penetrate the canopy. This is consistent with our observations on farms where the PMCG mixture is used.

Although weed species in samples were not individually identified and measured, observational identification of pasture weed species concluded that undesirable species primarily consisted of broadleaf signalgrass (*Brachiaria decumbens* Stapf.). Although little research has been conducted on broadleaf signalgrass in the United States, Roberts (1970) reported that it out-yielded 7 other grass species in Fiji, and produced a total of 33,850 kg ha^{-1} over an 11 month growing season. Broadleaf signalgrass contributed to the total DM found in pastures, allowing pre-grazed forage mass in those pastures with a low proportion of desirable species to maintain similar levels of forage availability.

Nutritive Value

Most nutritive value variables were affected by multiple interactions, including an interaction of treatment, year, and sampling date. Therefore, nutritive value means for each treatment were analyzed and presented by year and sampling date (Tables 3.4-3.6). Changes in, CP, nitrates, fat, and ash content of forage treatments are presented in Table 3.4. In both 2015 and 2016, CP content across all treatments dropped ($P < 0.01$) from the initial to the middle sampling date as plants grew and matured. However, the CP concentration increased ($P < 0.01$) in all treatments between the middle and final sampling date. This increase at the final sampling date may be a result of young, vegetative tissue produced as a result of late season rainfalls and irrigation as well as the timing of the second nitrogen fertilization shortly after the middle sampling date but before the final sampling. Teutsch et al. (2005) reported a linear increase in CP concentration in drought stressed plants fertilized with increasing rates of ammonium nitrate. Pearl millet and PMCG had greater (P < 0.01) CP levels than SS and BMR during the final sampling date of 2015 and 2016, indicating that the pearl millet systems can maintain forage nutritive concentrations longer into the season than the sorghum x sudangrass treatments. Each year at the middle sampling date, CP concentration was greater (P < 0.01) for PMCG than BMR, with PM as an intermediate in 2016. Although crabgrass was not singularly tested for forage nutritive value, the high concentration of CP found in PMCG is likely the result of the added nutritional value of crabgrass forage and is common with other reports in the literature (Dalrymple, 2001; Beck et al., 2007b).

Concentrations of nitrate nitrogen are presented in Table 3.4. Although concentrations did not differ between harvests in 2014 (P > 0.21), a decrease (P < 0.01) from the initial to the middle harvest and an increase (P < 0.01) between the middle and final harvests were observed in 2015. In 2016, an increase (P < 0.01) in nitrate nitrogen occurred between the initial and middle harvests but did not differ (P = 0.11) from the middle to the final harvests. However, as the drought intensified in the summer of 2016, an increase (P < 0.01) in nitrate nitrogen was measured between the initial and final harvests. Nitrate nitrogen was highest for PMCG at both the initial harvest in 2014 (P < 0.04) and the middle harvest in 2015 (P < 0.01) compared to either SS, BMR, or PM. At the initial harvest of 2016, PMCG also had higher (P < 0.01) nitrate concentrations that SS or BMR but did not differ (P = 0.08) from PM, which did not differ from BMR. Although no signs of nitrate poisoning were observed in cattle, BMR, PM, and PMCG at the final harvest in 2015 contained over 8,000 ppm NO_3, and is in the upper critical limit in which acute toxicity and clinical signs can be observed (Gadberry and Jennings, 2016).

It is well established that a ruminant's diet can alter lipid profiles of beef (Daly et al., 1999; Realini et al., 2004; Leheska et al., 2008). Fat content of pastures decreased ($P < 0.01$) from the initial to the middle sampling date in all three trial years. In 2014, fat content of forages was maintained ($P = 0.20$) between the middle and final sampling date while an increase ($P < 0.01$) was observed during this time for pastures in 2015 and 2016. Pearl millet and crabgrass mixed pastures contained greater concentrations of fat at the middle sampling date in 2014 ($P = 0.02$), 2015 ($P = 0.03$), and 2016 ($P < 0.01$) compared to both SS and BMR, with PM as an intermediate of PMCG and BMR. Concentration of fat found in forage in this study is comparable to reports by Schmidt et al. (2013) who found that fat content of warm-season grasses ranged from 17.8 to 28.7 g kg^{-1}. Ash was greatest ($P = 0.05$) for PM and lowest for SS at the initial sampling date in 2014. As pastures became more mature, BMR contained greater ($P < 0.01$) ash levels at the middle sampling date than the other forage treatments. Ash content was least for SS at the middle ($P < 0.01$) and final ($P < 0.01$) sampling dates in 2015 and the initial ($P < 0.01$) sampling date in 2016.

Fiber parameters of warm-season annual pastures are presented in Table 3.5. Similar to results found in CP concentrations, NDF and ADF levels in forage pastures increased between the initial and middle sampling dates in 2015 ($P < 0.01$) and 2016 ($P < 0.01$). A decrease ($P < 0.01$) between the middle and final sampling dates each year was also observed for NDF and ADF, again emphasizing that immature forage was produced during the second half of the trial after overgrazing of pastures during the drought occurred. Brown midrib sorghum x sudangrass had greater ($P < 0.01$) NDF levels than PM at the initial sampling date in 2014, however, by the middle sampling date, NDF concentrations of PM exceeded ($P < 0.01$) those of SS, BMR and PMCG. A treatment effect for NDF was also found during the initial and middle sampling dates in 2015 ($P < 0.03$) and all three sampling dates in 2016 ($P = 0.03$). At the initial sampling date in 2015, SS and BMR had greater ($P < 0.01$) levels of NDF than PMCG, with PM as an intermediate. Levels were also greater for SS than BMR and PMCG at the middle sampling date with PM, again, as an intermediate. Sorghum x sudangrass pastures contained higher levels of NDF compared to PMCG at the initial, middle, and final sampling dates in 2016. At the initial sampling date, BMR and PM also contained higher NDF levels than PMCG but by the final sampling date, NDF concentrations did not differ between BMR, PM, and PMCG and were all lower than SS.

A treatment effect on ADF was found during the middle sampling date in 2014 ($P < 0.01$), final sampling date of 2015 ($P = 0.05$), and for all three sampling dates in 2016 ($P < 0.03$). Concentrations of ADF was highest ($P < 0.01$) for BMR and PM followed by PMCG, and least for SS at the middle sampling date in 2014. At the final sampling date in 2015, BMR had greater ($P < 0.01$) ADF levels than SS, PM and PMCG. Sorghum x sudangrass and BMR had increased ($P < 0.01$) levels of ADF compared to PMCG at both the initial and middle sampling dates in 2016. By the final harvest, SS contained greater ($P < 0.01$) concentrations than either PM or PMCG, with BMR as an intermediate.

Lignin concentration increased between each harvest in 2014 ($P < 0.02$) and between the initial and middle harvests in 2015 ($P < 0.01$) and 2016 ($P < 0.01$). Although lignin concentration did not differ ($P = 0.15$) between the middle and final sampling dates in 2015, a decrease ($P < 0.01$) was observed in 2016. At the initial sampling date in both 2014 ($P < 0.01$) and 2015 ($P < 0.04$), lignin concentration was lower for BMR compared to PM and PMCG but did not differ ($P > 0.26$) in 2016. When comparing the two sorghum treatments, it was found that BMR contained lower lignin concentrations than SS at the initial sampling date in 2014 (P = 0.01) and 2016 ($P < 0.01$). Levels were also lower for BMR than SS at the middle sampling date in both 2015 ($P < 0.01$) and 2016 ($P < 0.01$) but were surprisingly higher in 2014 ($P < 0.01$). By the final sampling date of the grazing trail, differences in lignin content between SS and BMR treatments did not exist ($P > 0.05$). Lignin concentrations between PM and PMCG were similar at each sampling date within each year, with the exception of PMCG having decreased (P = 0.03) levels at the middle sampling date in 2016.

Variables estimating overall forage quality are presented in Table 3.6. As forages matured in 2014, TDN levels decreased ($P < 0.01$) from the initial to the middle sampling date and were maintained (P = 0.15) between sampling dates thereafter. Similar results were found between the first and second sampling dates in both 2015 ($P < 0.01$) and 2016 ($P < 0.01$), however, an increase ($P < 0.01$) in TDN levels was observed between the middle and final sampling date in these years. Forage treatments exhibited similar TDN levels at each sampling date during 2015 ($P > 0.18$) and 2016 ($P > 0.08$). In 2014, SS and PMCG had a greater (P < 0.01) concentration of TDN at the middle sampling date than either BMR or PM. At the final sampling date, SS had greater ($P < 0.01$) TDN levels than the other three forage treatments. The results between the SS and BMR treatments found in 2014 was surprising in that the brown midrib gene is characteristic of lower lignin levels and theoretically should have resulted in a higher concentration of TDN. Although Beck et al. (2007a) did not report TDN values, they reported that sorghum x sudangrass varieties containing the brown midrib gene had higher effective degradability levels than non-BMR varieties. However, in a comparison of the composition of pasture species in this study, it was found that BMR pastures only contained 4%

BMR at the final sampling date in 2014. Thus, undesirable species in those pastures may have been lower in quality than SS forage.

Decreases were observed in NIR-predicted RFQ, DMI, and IVTDMD48 from the initial to the middle sampling date in 2014, 2015, and 2016 ($P < 0.01$). Although RFQ and DMI did not differ ($P > 0.34$) between the middle and final sampling dates in 2014, an increase was detected for both variables in 2015 ($P < 0.01$) and 2016 ($P < 0.01$) and again, confirming the boost in nutritive value of young, green tissue produced during that time. NIR-predicted IVTDMD48 decreased ($P < 0.01$) from the middle to final sampling dates in 2014 and increased in 2015 ($P < 0.01$) and 2016 ($P < 0.01$). Estimated RFQ in 2014 was greater ($P < 0.03$) for BMR compared to PM and PMCG at the initial sampling date and was greater ($P < 0.04$) for PMCG and SS than BMR and PM at the middle sampling date. By the final sampling date, RFQ of SS was greater ($P < 0.03$) than the other forage treatments. Predicted DMI was greater ($P < 0.04$) for the pearl millet forage systems than the sorghum forage systems at the initiation of the grazing trial in 2014. As forages matured that year, DMI levels for SS were greater ($P < 0.01$) than that for BMR and PM at the middle and greater ($P < 0.04$) than BMR, PM and PMCG by the final sampling date. In contrast, DMI was least ($P < 0.04$) for SS at the middle sampling date in 2016, but no effect ($P > 0.05$) of forage treatment was detected in the final sampling date.

Estimates of IVTDMD48 were greatest ($P < 0.03$) for BMR at the initial sampling date in 2014 but were lower ($P < 0.02$) than SS and PMCG at the middle sampling date. At the middle sampling date in 2015, both BMR and PM had greater ($P < 0.01$) predicted levels of IVTDMD48 than SS. Sorghum x sudangrass had a lower predicted 48-hour digestibility than all other forage treatments at both the initial ($P < 0.01$) and middle ($P < 0.01$) sampling dates in 2016 and was lower ($P < 0.02$) than BMR and PMCG at the final sampling date, with PM as an intermediate.

Differences in nutritive value between forages that contain or do not contain the brown-midrib gene have been well documented in the literature. An increase in nutritive value of BMR containing compared to non-BMR containing forages been reported in sorghum x sudangrass hybrids (Fritz et al., 1990) as well as pearl millet species (Cherney et al., 1990). Though the 2014 data in the current trial are inconsistent with these previous reports of improved nutritive value, the higher fiber and lignin, lower digestibility, and resulting lower predicted IVTDMD48, DMI, and RFQ of the BMR treatment in 2014 at the later sampling dates is likely the result of stand loss and aforementioned increases in undesirable species, namely broadleaf signalgrass, observed in that treatment in 2014 (Table 3.3).

In Situ DM Degradation

With the variability seen in rainfall as well as differences seen in forage nutritive value, forage treatment and harvest date interacted ($P < 0.03$) to affect all *in situ* variables and year, harvest date, and forage treatment interacted ($P < 0.01$) to affect the immediately soluble fraction. Therefore, DM degradation parameters are presented in Table 3.7 by year and harvest. The immediately degradable fraction (A) tended to differ ($P < 0.10$) or was found to differ by forage treatment in all but the initial ($P = 0.24$) and final ($P = 0.16$) harvests of 2014 and the initial harvest in 2015 ($P = 0.36$). Each year at the middle harvest date, differences in the immediately soluble fraction were observed among treatments and may be indicative of the effect warmer temperatures in combination with rapidly growing forage has on fiber structures and quantities. In Florida, bermudagrass, bahiagrass, and stargrass were found to have reductions in in vitro organic matter digestibility when harvested at later dates in summer and when forages became more lignified (Johnson et al., 2001). Similarly, Beck et al. (2007b) also reported a linear decrease in the immediately soluble fraction of DM as forage harvest interval increased. Though no forage treatment consistently exhibited a higher A fraction, the PM treatment generally had the lowest A fraction of the forage treatments. The rate of degradation did not differ at any harvest in 2014 ($P > 0.20$) or 2015 ($P > 0.11$), and this is contradictory to digestibility predictions made by NIR analysis for the 2014 harvest. However, the forage treatments did differ at the initial ($P < 0.02$) and middle ($P < 0.04$) sampling dates in 2016, with lowest degradation rates exhibited by the BMR treatment in the former and the SS treatment in the later. At the midseason sampling date in 2015, the potentially degradable DM fraction (B) was greater for PM compared to SS or BMR and consequently, resulted in BMR ($P = 0.03$) and SS ($P < 0.01$) having a greater DM fraction unavailable to degradation than PM.

Total Stocking Capacity

Stocking densities were affected ($P < 0.01$) by an interaction of year, treatment, and day. Thus, weekly stocking data were analyzed and presented by year (Table 3.8). Forage treatment affected ($P < 0.01$) stocking densities before day 20 in the 2014 grazing year. Upon initiation of the grazing trial in 2014, SS and BMR carried a greater ($P < 0.01$) stocking density than PM and PMCG pastures. On days 6 and 13 in 2014, SS carried more ($P < 0.01$) kg of animal ha^{-1} than BMR, and the BMR had a greater ($P < 0.05$) stocking density than PM or PMCG. In the first two weeks of the trial, BMR pastures contained a greater ($P < 0.01$) stocking density than the pearl millet treatments, though this effect disappeared ($P > 0.10$) 20 d into the 2014 grazing trial. Ample soil moisture and a more rapid forage growth in the SS and BMR pastures in 2014 resulted in a greater need to put higher stocking densities on those pastures. However, after the initial challenge of keeping up with the skewed, early season forage productivity in the SS and BMR pastures, grazing pressure became similar across the treatments. This did not occur in 2015 and the effect was generally muted in 2016 because of drier conditions and less rapid, early season forage growth. In 2016, a treatment effect ($P < 0.04$) was found at days 0, 6, 13 and 20. Pearl millet and crabgrass mixed pastures contained the lowest stocking density at day 0 and at day 6 compared to the other forage treatments. On days 13 and 20, SS had a greater ($P < 0.01$) stocking density than PMCG, with both BMR and PM as intermediates. Results found in this study indicate that BMR and SS pastures can maintain higher levels of stocking densities early in a grazing program when conditions allow forage growth rates to reach their potential of that species' skewed productivity distribution.

Gain Per Hectare

Differences in total live weight gain ha^{-1} of warm-season annual pastures are presented in Table 3.9. Gain ha^{-1} was affected by main effects of treatment ($P = 0.02$), year ($P < 0.01$), and the interaction ($P = 0.06$). As expected, the 2014 grazing year, where moisture was plentiful, resulted in greater ($P < 0.01$) gains than 2016 (272 vs 207 kg ha^{-1}, respectively), which was greater ($P < 0.01$) than 2015 (152 kg ha^{-1}). A forage treatment effect was detected in 2014 ($P = 0.12$) and 2015 ($P < 0.01$) but not for 2016 ($P = 0.25$). In 2014, SS pastures produced a greater ($P < 0.03$) amount of total gain ha^{-1} than PM pastures, with BMR and PMCG as intermediates. In contrast, BMR had greater ($P < 0.02$) total gains than SS, PMCG, and PM in 2015. In that year, SS was greater ($P < 0.03$) than PM, but PMCG was an intermediate between the two. In this study, total gain ha^{-1} was less than what was reported by Hill et al. (1993) in steers grazing Tifton 78 (4.67 kg ha^{-1} d^{-1}) and Tifton 85 (6.84 kg ha^{-1} d^{-1}) bermudagrass pastures for 169 days. However, the 3 year average total precipitation during their grazing experiment was greater than what was observed in this study, which potentially limited the performance of pastures. Comparably, Hill et al. (1999) reported that during a two year pearl millet grazing trial, total gain was 6.46 and 5.94 kg ha^{-1} d^{-1}, with average total monthly precipitation during the 84 d trial of

77.7 and 91.9 mm, respectively. In this study, average total monthly precipitation during the trial was 119, 87, and 45 mm for 2014, 2015 and 2016, respectively. Thus, the greater total gain per unit of land found in their study may be reflective of the improved distribution of timely rainfall events in combination with higher inputs of nitrogen fertilizer (252 kg N ha^{-1}).

Conclusions

In this study, sorghum x sudangrass forage systems, with their ability to quickly establish and produce tonnage, required an increase level of management during the first few weeks after emergence. Failure to properly graze both sorghum and pearl millet pastures can result in mature forage that has decreased nutritive value. Under the conditions of this research, pre-grazed forage mass, overall forage distribution and stocking densities of sorghum x sudangrass forage systems was skewed towards the beginning of the growing season. This study also indicated that under grazing, pearl millet forage systems can maintain their plant densities better than sorghum x sudangrass forage systems. Forage nutritive value among forage treatments was variable and appeared to be largely influence by environment as well as grazing management. Sorghum x sudangrass forage systems also produced larger total gains per unit of land than pearl millet forage systems. However, there is very little available literature on using warm-season annual grasses in forage-finishing beef production systems and additional research is needed to determine the effects of using mixed pastures of warm-season annual forages on animal performance. Since warm-season annual grasses of SS, BMR, PM and PMCG performed relatively similarly across years and species, selection of forage species should be based on other factors including seasonal production goals, production costs, seed availability, and adaptability into an already established forage program.

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Figure 3.1. Actual and 100 year normal average monthly maximum temperature from May through September in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

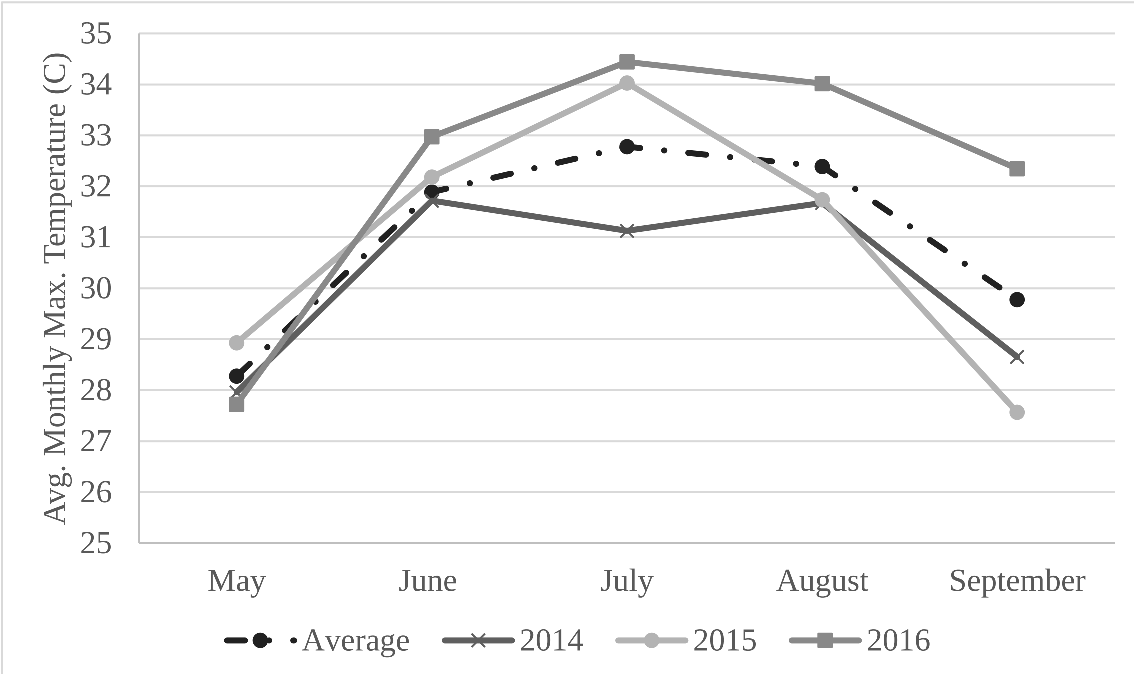

Figure 3.2. Actual and 100 year average total monthly precipitation from May through September in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

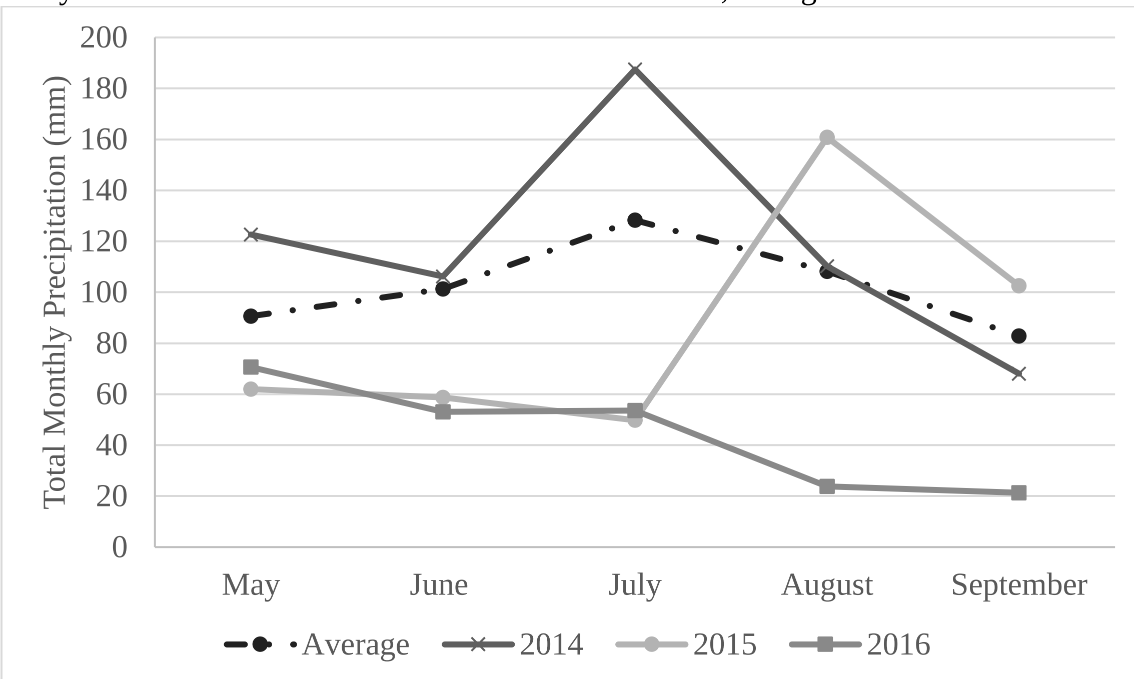

Table 3.1. Average precipitation per rainfall event and total number of rainy days from May through September in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

Month	**Average Precipitation**			**Rain Events**		
	2014	**2015**	**2016**	**2014**	**2015**	**2016**
		mm			days	
May	13.6	8.9	7.1	9	7	10
June	8.2	5.3	5.9	13	11	9
July	15.6	5.5	6.7	12	9	8
August	11.0	12.4	1.6	10	13	15
September	5.2	6.4	3.6	13	16	6

Table 3.2. Pre-grazing forage mass in sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM), and pearl millet and crabgrass mixture (PMCG) pastures harvested at biweekly intervals in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

Week	Forage Treatment				SEM	Effect		
	SS	BMR	PM	PMCG		Trt	Year	Trt*Year
	kg of DM ha[1]							
0	2,314[a]	2,130[a]	2,028[a]	1,591[b]	167	<0.01	<0.01	0.17
2	3,323	3,547	3,074	2,418	379	0.07	<0.01	0.08
4	3,343	3,363	3,051	2,756	366	0.58	<0.01	0.41
6	2,267[b]	3,139[a]	2,699[ab]	2,746[ab]	194	0.01	<0.01	0.91
8	1,960	2,193	2,354	2,446	194	0.39	<0.01	<0.01

[abc] Means within a row without a common superscript differ ($P < 0.05$).

Table 3.3. Botanical composition in sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM), and pearl millet and crabgrass mixture (PMCG) pastures harvested at three dates in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Sciences Eatonton Beef Research Unit in Eatonton, Georgia.

Year/Harvest	**Treatment**				**SEM**	**P-Value**
	SS	**BMR**	**PM**	**PMCG**		
	Desirable Species (%, DM)					
2014[1]						
Initial	82.8[ab]	68.2[bc]	55.5[c]	93.1[a]	8.3	0.01
Middle	58.3[b]	13.3[c]	58.1[b]	96.5[a]	10.9	<0.01
Final	65.6[b]	4.5[d]	31.5[c]	90.9[a]	6.6	<0.01
2015[2]						
Initial	96.0[a]	90.4[ab]	84.8[b]	96.5[a]	2.6	0.01
Middle	79.5[b]	78.5[b]	73.6[b]	100.0[a]	6.0	0.02
Final	14.3[c]	17.0[c]	55.9[b]	99.3[a]	6.9	<0.01
2016[3]						
Initial	69.9[b]	56.3[bc]	51.8[c]	88.0[a]	5.1	<0.01
Middle	28.5[c]	27.3[c]	51.2[b]	81.2[a]	7.7	<0.01
Final	24.9[bc]	13.8[c]	32.0[b]	88.0[a]	5.1	<0.01

[abc] Means within a row without a common superscript differ ($P < 0.05$).
[1] Initial = 6/25/2014; Middle = 7/29/2014; Final = 9/03/2014.
[2] Initial = 6/24/2015; Middle = 7/28/2015; Final = 8/25/2015.
[3] Initial = 6/27/2016; Middle = 8/03/2016; Final = 8/30/2016.

Table 3.4. Concentrations of crude protein (CP), nitrates, fat, and ash, as measured by Near Infrared Spectroscopy, of sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM), and pearl millet and crabgrass mixture (PMCG) pastures harvested at three dates in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

Item/Year/Harvest	Forage Treatment				SEM	P-Value
	SS	BMR	PM	PMCG		
CP (g kg^{-1})[4]						
2014[1]						
Initial	226	217	226	224	5.4	0.58
Middle	198[a]	159[b]	163[b]	182[a]	5.3	<0.01
Final	175	162	181	159	12.7	0.55
2015[2]						
Initial	218	208	213	222	6.7	0.45
Middle	128[c]	141[b]	159[a]	161[a]	4.7	<0.01
Final	208[b]	208[b]	231[a]	225[a]	4.9	0.02
2016[3]						
Initial	141[c]	152[bc]	164[ab]	178[a]	5.2	<0.01
Middle	96[c]	119[bc]	140[ab]	157[a]	8.9	<0.01
Final	155[c]	173[b]	196[a]	208[a]	5.8	<0.01
Nitrates (ppm)						
2014[1]						
Initial	111[a]	315[a]	717[a]	1,747[b]	300	0.02
Middle	1,164	1,265	426	2,643	647	0.18
Final	1,420	965	1,870	1,730	450	0.53
2015[2]						
Initial	3,633	7,814	4,483	4,043	1,364	0.12
Middle	1,723[a]	2,074[a]	1,540[a]	4,700[b]	785	0.01
Final	5,645	8,117	8,380	9,683	1,667	0.43
2016[3]						
Initial	223[a]	437[ab]	1,226[bc]	2,028[c]	282	0.01
Middle	3,718	1,755	2,553	3,142	501	0.06
Final	3,514	4,064	3,919	3,540	659	0.91
Fat (g kg^{-1})						
2014[1]						
Initial	22.6[b]	25.0[a]	23.7[ab]	22.5[b]	0.6	0.05
Middle	16.4[c]	17.9[bc]	19.8[ab]	20.9[a]	0.9	0.02
Final	19.1	18.9	21.3	18.8	0.8	0.14
2015[2]						
Initial	26.9	26.8	28.4	29.4	0.9	0.19
Middle	18.7[c]	19.9[bc]	21.0[ab]	22.4[a]	0.7	0.03

Final	27.1	25.6	26.3	27.6	1.1	0.62
2016[3]						
Initial	25.1^{b}	27.1^{a}	27.3^{a}	28.5^{a}	0.6	0.02
Middle	20.6^{c}	22.6^{bc}	24.2^{ab}	26.3^{a}	0.7	<0.01
Final	25.3^{b}	26.7^{ab}	28.9^{a}	29.4^{a}	0.9	0.03
Ash (g kg^{-1})						
2014[1]						
Initial	81.5^{b}	89.0^{ab}	102.0^{a}	91.8^{ab}	4.3	0.05
Middle	95.9^{b}	123.9^{a}	89.7^{b}	89.6^{b}	4.1	<0.01
Final	78.9	84.2	91.2	94.9	4.1	0.08
2015[2]						
Initial	96.0	119.0	122.5	99.9	10.6	0.26
Middle	76.1^{b}	99.8^{a}	98.0^{a}	91.3^{a}	3.6	<0.01
Final	98.8^{c}	107.5^{b}	113.0^{ab}	114.0^{a}	2.0	<0.01
2016[3]						
Initial	61.6^{b}	72.5^{a}	79.5^{a}	81.9^{a}	3.3	0.01
Middle	67.1	79.0	79.0	76.7	3.6	0.13
Final	87.9	92.8	92.2	93.3	2.2	0.35

[abc]Means within a row without a common superscript differ ($P < 0.05$).

[1] Initial = 6/25/2014; Middle = 7/23/2014; Final = 8/20/2014.

[2] Initial = 6/24/2015; Middle = 7/22/2015; Final = 8/25/2015.

[3] Initial = 6/27/2016; Middle = 7/25/2016; Final = 8/30/2016.

[4]CP: Crude protein = %N x 6.25.

Table 3.5. Concentrations of neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin as measured by Near Infrared Spectroscopy, of sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM), and pearl millet and crabgrass mixture (PMCG) pastures harvested at three dates in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

Item/Year/Harvest	Forage Treatment[1]				SEM	P-Value
	SS	BMR	PM	PMCG		
NDF (g kg)						
2014[1]						
Initial	547^{bc}	562^{c}	511^{a}	521^{ab}	10.9	0.03
Middle	535^{a}	603^{b}	637^{c}	605^{b}	7.0	<0.01
Final	580	605	595	617	18.4	0.56
2015[2]						
Initial	523^{b}	525^{b}	503^{ab}	485^{a}	10.4	0.03
Middle	647^{b}	610^{a}	632^{ab}	611^{a}	9.6	0.02
Final	565	565	529	539	9.9	0.06
2016[3]						
Initial	602^{b}	598^{b}	594^{b}	572^{a}	7.0	0.03
Middle	668^{b}	642^{ab}	645^{ab}	622^{a}	8.3	0.03
Final	589^{b}	557^{a}	548^{a}	541^{a}	9.6	0.03
ADF (g kg)						
2014[1]						
Initial	300	308	292	291	5.4	0.16
Middle	329^{a}	366^{c}	362^{c}	344^{b}	4.8	<0.01
Final	343	354	344	355	12.0	0.84
2015[2]						
Initial	286	300	288	272	9.5	0.16
Middle	338	327	327	328	3.7	0.13
Final	322^{b}	322^{b}	302^{a}	304^{a}	5.6	0.05
2016[3]						
Initial	320^{b}	322^{b}	312^{ab}	302^{a}	4.5	0.03
Middle	369^{b}	358^{b}	349^{ab}	333^{a}	6.7	0.02
Final	330^{b}	309^{ab}	292^{a}	288^{a}	7.1	0.01
Lignin (g kg)						
2014[1]						
Initial	10.7^{b}	5.1^{a}	13.5^{b}	10.8^{b}	1.3	0.01
Middle	7.8^{a}	15.5^{b}	20.9^{c}	17.8^{bc}	1.5	<0.01
Final	15.1	16.6	22.2	21.8	3.5	0.39
2015[2]						
Initial	4.0^{ab}	3.6^{a}	8.9^{bc}	9.4^{c}	1.7	0.05
Middle	15.7^{b}	6.5^{a}	14.2^{b}	15.1^{b}	1.5	<0.01

Final	13.3	9.7	9.8	1.1	1.5	0.37
2016[3]						
Initial	55.8^{b}	49.2^{a}	47.1^{a}	47.3^{a}	1.4	<0.01
Middle	72.3^{c}	57.6^{ab}	60.1^{b}	51.7^{a}	2.6	<0.01
Final	60.9^{b}	56.0^{ab}	53.0^{a}	51.5^{a}	1.8	0.02

[abc]Means within a row without a common superscript differ ($P < 0.05$).

[1] Initial = 6/25/2014; Middle = 7/23/2014; Final = 8/20/2014.

[2] Initial = 6/24/2015; Middle = 7/22/2015; Final = 8/25/2015.

[3] Initial = 6/27/2016; Middle = 7/25/2016; Final = 8/30/2016.

Table 3.6. Predictions of total digestible nutrients (TDN), dry matter intake (DMI), in vitro true dry matter digestibility after 48 h (IVTDMD48), and relative forage quality (RFQ), as measured by Near Infrared Spectroscopy, of sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM), and pearl millet and crabgrass mixture (PMCG) pastures harvested at three dates in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

Item/Year/Harvest	Forage Treatment				SEM	P-Value
	SS	BMR	PM	PMCG		
			TDN ($g\ kg^{-1}$)[4]			
2014[1]						
Initial	606	603	616	613	4.0	0.14
Middle	602[a]	549[c]	574[b]	595[a]	7.4	<0.01
Final	599[a]	566[b]	573[b]	550[b]	8.0	0.01
2015[2]						
Initial	615.2	593	603	637	14.7	0.23
Middle	557.2	570	550	568	6.6	0.18
Final	595.6	595	604	597	5.7	0.64
2016[3]						
Initial	607.7	612	599	604	3.1	0.08
Middle	546.9	569	553	564	5.9	0.10
Final	571.5	589	577	585	5.2	0.15
			DMI (%)[5]			
2014[1]						
Initial	2.8[b]	2.8[b]	2.9[a]	2.9[a]	0.0	0.02
Middle	2.7[a]	2.4[b]	2.5[b]	2.6[a]	0.1	<0.01
Final	2.7[a]	2.5[b]	2.5[b]	2.4[b]	0.1	0.02
2015[2]						
Initial	2.9	2.8	2.8	3.0	0.1	0.20
Middle	2.6	2.6	2.5	2.6	0.0	0.15
Final	2.7	2.7	2.8	2.8	0.0	0.30
2016[3]						
Initial	2.8	2.8	2.8	2.8	0.0	0.26
Middle	2.4[b]	2.6[a]	2.5[a]	2.6[a]	0.0	0.01
Final	2.6	2.7	2.7	2.7	0.0	0.14
			IVTDMD48			
2014[1]						
Initial	81.2[b]	82.8[a]	80.7[b]	80.4[b]	0.5	0.02
Middle	81.7[a]	76.3[c]	77.0[bc]	79.3[ab]	0.8	<0.01
Final	77.7	76.0	76.6	73.3	1.8	0.39
2015[2]						
Initial	82.6	83.1	81.5	83.1	1.1	0.54

Middle	69.9[c]	73.7[ab]	72.9[b]	74.9[a]	0.6	<0.01
Final	79.5	79.9	82.4	81.6	0.7	0.06
2016[3]						
Initial	76.9[b]	78.7[a]	78.6[a]	78.8[a]	0.3	<0.01
Middle	68.8[b]	73.1[a]	73.4[a]	74.3[a]	0.7	<0.01
Final	75.4[b]	78.7[a]	77.6[ab]	79.9[a]	0.8	0.02
			RFQ[6]			
2014[1]						
Initial	138[ab]	136[b]	144[a]	143[a]	1.9	0.05
Middle	133[a]	106[b]	115[b]	127[a]	4.1	<0.01
Final	132[a]	113[b]	118[b]	108[b]	4.1	0.01
2015[2]						
Initial	144	133	139	156	7.6	0.20
Middle	116	122	112	119	2.9	0.19
Final	131	130	137	134	3.2	0.43
2016[3]						
Initial	139	140	134	137	1.8	0.16
Middle	105[b]	118[a]	112[ab]	118[a]	3.0	0.02
Final	121	130	126	130	2.9	0.18

[abc]Means within a row without a common superscript differ ($P < 0.05$).

[1] Initial = 6/25/2014; Middle = 7/23/2014; Final = 8/20/2014.

[2] Initial = 6/24/2015; Middle = 7/22/2015; Final = 8/25/2015.

[3] Initial = 6/27/2016; Middle = 7/25/2016; Final = 8/30/2016.

[4]TDN: Predicted total digestible nutrients = (NFC × 0.98) + (CP × 0.87) + (FA × 0.97 × 2.25) + [NDFn × (NDFDp ÷ 100)] – 10.

[5]DMI: Estimated dry matter intake = 120 / NDF (% of DM).

[6]RFQ: Estimated relative forage quality = DMI (% of BW) x TDN (% of DM) / 1.23.

Table 3.7. In situ DM degradation of sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM), and pearl millet and crabgrass mixture (PMCG) pastures in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

Year/Harvest/Item[4]	Forage Treatment				SEM	*P* - value
	SS	BMR	PM	PMCG		
2014[1]						
Initial						
Degradation fraction, % of DM						
A	17.6	18.4	24.1	21.7	1.92	0.24
B	73.6	71.4	58.3	60.5	7.16	0.10
C	11.0	10.3	17.6	17.8	6.97	0.62
Rate of Degradation, % h^{-1}	2.84	3.79	3.90	4.20	0.98	0.70
Middle						
Degradation fraction, % of DM						
A	22.8[b]	26.8[a]	18.3[c]	24.1[ab]	0.70	0.01
B	48.6	35.3	69.5	46.9	6.14	0.10
C	28.6	37.9	12.2	29.2	5.85	0.11
Rate of Degradation, % h^{-1}	4.43	4.55	3.03	2.65	1.12	0.20
Final						
Degradation fraction, % of DM						
A	21.2	17.8	19.0	20.6	1.14	0.16
B	66.8	54.8	52.0	54.7	10.23	0.63
C	12.0	27.4	29.0	24.7	9.58	0.53
Rate of Degradation, % h^{-1}	2.32	2.93	4.10	3.11	0.83	0.51
2015[2]						
Initial						
Degradation fraction, % of DM						
A	25.9	26.4	24.5	27.3	1.70	0.36
B	41.9	39.9	49.3	37.5	5.16	0.19
C	31.7	33.8	26.1	34.3	3.21	0.17
Rate of Degradation, % h^{-1}	3.84	4.14	4.87	4.61	1.23	0.78
Middle						
Degradation fraction, % of DM						
A	24.0[b]	25.6[a]	21.0[c]	25.0[ab]	0.53	<0.01
B	32.1[c]	37.7[bc]	56.6[a]	45.2[ab]	5.23	0.01
C	43.9[c]	36.8[bc]	22.4[a]	29.8[ab]	5.47	0.02
Rate of Degradation, % h^{-1}	4.08	4.73	3.51	3.55	0.62	0.11
Final						
Degradation fraction, % of DM						

A	18.9	22.9	22.4	23.6	1.11	0.06
B	54.6	48.0	54.4	46.4	5.39	0.40
C	26.4	29.1	23.2	30.0	4.94	0.55
Rate of Degradation, % h^{-1}	4.25	3.77	4.09	4.38	0.68	0.77
2016[3]						
Initial						
Degradation fraction, % of DM						
A	21.7^{b}	25.1^{a}	22.7^{b}	25.9^{a}	0.76	0.01
B	49.2^{a}	50.3^{a}	51.5^{a}	40.4^{b}	6.81	0.04
C	29.0	25.5	25.8	33.7	6.02	0.14
Rate of Degradation, % h^{-1}	4.08^{b}	2.80^{b}	4.39^{ab}	5.75^{a}	1.02	0.02
Middle						
Degradation fraction, % of DM						
A	27.8^{a}	26.8^{a}	23.4^{b}	24.5^{b}	0.75	0.01
B	28.4	29.2	36.5	33.6	5.53	0.47
C	43.9	44.0	40.1	41.9	5.16	0.85
Rate of Degradation, % h^{-1}	2.66^{b}	4.65^{a}	4.52^{a}	4.62^{a}	0.66	0.04
Final						
Degradation fraction, % of DM						
A	26.6	29.0	28.7	26.5	1.11	0.08
B	29.8	33.6	29.6	33.4	4.59	0.37
C	43.6	37.4	41.7	40.1	4.04	0.15
Rate of Degradation, % h^{-1}	5.04	4.01	4.88	5.50	0.66	0.38

[abc] Means within a row without a common superscript differ ($P < 0.05$).

[1] Initial = 6/25/2014; Middle = 7/23/2014; Final = 8/20/2014.

[2] Initial = 6/24/2015; Middle = 7/22/2015; Final = 8/25/2015.

[3] Initial = 6/27/2016; Middle = 7/25/2016; Final = 8/30/2016.

[4] Degradation fraction: A = fraction immediately degradable; B = fraction degradable at a measurable rate; C = fraction unavailable to ruminal degradation.

Table 3.8. Daily stocking densities of sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM), and pearl millet and crabgrass mixture (PMCG) pastures in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

Year/Day	Forage Treatment				SEM	P-Value
	SS	BMR	PM	PMCG		
	kg ha^{-1}					
2014						
0	3,998[a]	4,036[a]	2,158[b]	2,157[b]	38.9	<0.01
6	6,987[a]	4,086[b]	2,177[c]	2,187[c]	224	<0.01
13	9,719[a]	6,175[b]	4,099[c]	4,799[c]	312	<0.01
20	8,918[a]	6,265[b]	4,404[b]	5,626[b]	724	0.01
27	7,036	5,634	4,704	5,468	634	0.11
34	3,223	3,212	4,488	4,536	932	0.61
41	2,711	2,499	3,581	3,309	484	0.38
48	2,738	2,530	2,791	2,493	192	0.63
55	2,766	2,561	2,831	2,517	195	0.62
62	2,793	2,593	2,872	2,540	198	0.61
69	2,821	2,624	2,912	2,563	202	0.60
2015						
0	5,382	5,325	5,695	4,684	355	0.30
6	4,643[b]	5,396[ab]	5,760[a]	4,738[b]	392	0.05
13	3,626	3,606	3,526	3,267	402	0.79
20	3,951	4,187	3,842	3,566	310	0.20
27	3,730	3,667	3,610	3,612	354	0.99
34	2,325	2,348	2,315	2,306	14.9	0.28
41	2,332	2,369	2,322	2,322	13.4	0.10
48	2,340	2,390	2,328	2,337	15.0	0.06
55	2,347	2,411	2,335	2,353	18.8	0.07
62	2,354	2,432	2,341	2,368	23.9	0.10
2016						
0	3,048[a]	3,246[a]	2,744[a]	2,020[b]	268	0.01
6	3,331[a]	3,303[a]	2,790[a]	2,059[b]	226	<0.01
13	6,047[a]	4,473[ab]	4,504[ab]	2,680[b]	789	0.04
20	6,133[a]	4,367[ab]	4,363[ab]	2,735[b]	761	0.04
27	2,187	2,183	2,392	2,493	176	0.54
34	2,196	2,197	2,189	2,179	27.2	0.96
41	2,240	2,248	2,234	2,235	28.6	0.98
48	2,283	2,300	2,279	2,291	30.5	0.96
55	2,325	2,351	2,324	2,348	33.1	0.90

[abc]Means within a row without a common superscript differ (P < 0.05).

Table 3.9 Total live weight gain per hectare of sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM), and pearl millet and crabgrass mixture (PMCG) pastures in 2014, 2015, and 2016 at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit in Eatonton, Georgia.

Year[1]	**Forage Treatment**				**SEM**	**P-Value**
	SS	**BMR**	**PM**	**PMCG**		
	kg ha^{-1}					
2014	375^{a}	257^{ab}	207^{b}	249^{ab}	45.0	0.12
2015	156^{b}	189^{a}	126^{c}	136^{bc}	8.29	<0.01
2016	207	233	210	180	17.0	0.25

[abc]Means within a row without a common superscript differ ($P < 0.20$).

[1]Grazing days: 2014 = 70 d; 2015 = 63 d; 2016 = 56 d.

CHAPTER 4

WARM-SEASON ANNUAL FORAGES IN FORAGE-FINISHING BEEF SYSTEMS: II. ANIMAL PERFORMANCE AND CARCASS CHARACTERISTICS

[1] Harmon, D. D., D. W. Hancock, R. L. Stewart Jr., A. M. Stelzleni, J. R. Segers, and C. D. Teutsch. To be submitted to *Journal of Animal Science*.

Abstract

More information on expected animal performance and carcass traits of forage-finished steers grazing warm-season annual forages is needed. To achieve this objective, a grazing trial was conducted in 2014, 2015, and 2016 (70, 63 and 56-d, respectively), with variation in length of grazing based on forage availability. Sixteen pastures (0.81-ha) were assigned to one of four forage treatments in a randomized complete block design. Forage treatments were brown midrib sorghum x sudangrass (BMR; *Sorghum bicolor var. bicolor*bicolor var. sudanense*), sorghum x sudangrass (SS), pearl millet [PM; *Pennisetum glaucum* (L.)R.Br.], or pearl millet planted with crabgrass [PMCG; *Digitaria sanguinalis* (L.) Scop.]. Each year, British-cross beef steers (n = 32; 3 yr average: 429 ± 22 kg) were stratified by weight and randomly assigned to one of the 16 pastures for forage-finishing. Each pasture was subdivided into two 0.405-ha paddocks for rotational grazing and a put and take stocking method was used to maintain a forage allowance of 1500-3000 kg/ha. Shrunk BW and ultrasonically measured carcass composition was recorded at the initiation, middle, and end of each grazing season. Steers were harvested once forage availability became limited and chilled carcasses (24-h) were evaluated for yield grade and quality grade attributes. Statistical analysis was conducted using the GLIMMIX procedure in SAS 9.4 (Cary, N.C.) with main effects of treatment, year, and the interaction. Pasture and block were considered random effects while date was assessed as a main effect when applicable. Forage treatment did not affect ($P > 0.17$) total gain, total ADG, or BW at any time point. Ultrasound composition traits of LM Area, 12^{th} rib fat thickness, IMF and rump fat was impacted ($P < 0.01$) by scanning date. No differences ($P > 0.05$) in forage treatments were observed for carcass characteristics associated with yield grade, quality grade, or proximate analysis variables. The findings suggest that cattle forage-finished during the summer months on BMR, SS, PM,

and PMCG perform similarly, giving producers the option to use the most economical or practical forage type for their production system.

Keywords: Forage-finished, Beef, Grass-fed, Summer annuals, Carcass, Performance

Introduction

In the U.S., the majority of beef cattle are finished in confined animal feeding operations on grain based rations. These operations have been readily adopted because of their reduced production period (Hoveland and Anthony, 1977), decreased overall costs, increased efficiency (Mathews Jr. and Johnson, 2013), and ability to produce a uniform, high quality beef product (Crouse et al., 1984; Garmyn et al., 2010). Although consumers have become accustom to the taste of grain-fed beef, there has been growing interest in forage-finished beef products. The interest in forage-finished beef products has primarily been stimulated by a general aversion to confined animal feeding systems, and reports that grass-fed beef is a healthier alternative and contains an altered fat content and fatty acid profile when compared to grain-fed beef (Duckett et al., 2009). As a result, it has been reported that consumers are willing to pay a premium for grass-finished beef products (Darby et al., 2006; Lacy et al., 2007).

In the southeastern United States, grass-finishing cattle during summer months can be difficult due to the combination of heat stress, unpredictable weather, and the characteristically high portion of indigestible fiber found in warm-season perennial forage species. Although forages such as bermudagrass (*Cynodon dactylon* L. Pers.) and bahiagrass (*Paspalum notatum* Flugge) produce high forage yields and are well suited for cow/calf operations, their nutritive value is typically not high enough to produce desirable rates of lean and adipose tissue growth needed for finishing cattle (Schmidt et al., 2013). Consequently, providing a year-round supply of grass-finished beef is challenged by an inability to finish cattle in the summer months.

In contrast, warm-season annual species such as sorghum x sudangrass hybrids [*Sorghum bicolor* (L.) x *S. Arundinaceum* (Desv.)], pearl millet (*Pennisetum glaucum* L.R. Br.), and crabgrass [*Digitaria sanguinalis* (L.) Scop.] are high in nutrient value and are high yielding, potentially enabling adequate animal performance in summer forage-finishing programs. Although an abundance of literature has been published comparing grain vs forage-finished beef (Mandell et al., 1998; Leheska et al., 2008; Daley et al., 2010), there is little information regarding the effects of varying forage species on animal performance and carcass characteristics, especially studies comparing summer annual forage systems. In one of the few published studies, Schmidt et al. (2013) compared carcass characteristics of steers grazing 5 forage species, including both perennial and annual forages as well as a mix of cool and warm-season grass and legume species. Although only one warm-season annual grass was included in this study, authors reported a forage species effect on both cattle performance and carcass characteristics, with pearl millet pastures producing average daily gains (ADG) over 0.5 kg/d and quality grades comparable to steers grazing alfalfa. In Canada, it was reported that sorghum x sudangrass could produce gains in steers of 0.97-1.18 kg/d. However, there has been no published research comparing sorghum x sudangrass and pearl millet forage systems in grass-finishing operations in the southeastern USA. Therefore, the objective of this study was to compare four warm-season annual forage systems for summer forage-finishing of beef steers and their effect on animal performance, carcass characteristics, and beef quality in Southeastern beef production systems.

Materials and Methods

The experimental procedures were reviewed and approved by the University of Georgia Institutional Animal Care and Use Committee.

Forage Treatments

A 3-yr forage-finishing trial was conducted in the summers of 2014, 2015 and 2016 to determine the effects of forage treatment on animal performance and carcass merit. In a randomized complete block design with four replications, forage treatments of sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM) and a mixture of pearl millet and crabgrass (PMCG; *Digitaria sanguinalis*) were assessed. The trial consisted of sixteen, 0.81 ha^{-1} pastures located at the University of Georgia, Department of Animal and Dairy Science Eatonton Beef Research Unit (Eatonton, GA). Pastures were blocked based on previous use, soil type, and topography, and forage treatments were randomly assigned within each block.

Forage treatments were planted into glyphosate (Helosate Plus Advanced; Helm Agro US, Inc., Tampa, Florida) burned (1.1 kg a.i. ha^{-1}) pastures each year on or about the 15 of May using a no-till drill (Haybuster 107; Haybuster, Jamestown, ND). Sorghum x sudangrass (cv. 'Sugargrazer' in 2014 or cv. 'AS5201' in 2015 and 2016; Alta Seeds, Irving, TX) and BMR ('Honey Graze' in 2014; Arrow Seed Co, Broken Bow, NE; or 'AS6201' in 2015 and 2016; Alta Seeds, Irving, TX) were planted at 22.4 kg ha^{-1} and at a soil depth of 2.54 cm, PM (cv. 'Tifleaf III'; Coffey Forage Seeds, Inc., Plainview, TX) at 16.8 kg ha^{-1} and at a soil depth of 1.27 cm, and the PM (cv. 'Tifleaf III'; Coffey Forage Seeds, Inc., Plainview, TX) plus CG (cv. 'Red River'; R.L. Dalrymple Farm, Thomas, OK) mixture was planted simultaneously at 11.2 kg ha^{-1} at 1.27 cm and 5.6 kg ha^{-1} at 0.64 cm, respectively. Crabgrass was planted in a 1:1 ratio with sand to reduce static cling and allow a consistent flow of crabgrass from the small seed box through the drop tubes.

During the spring of all trial years, soil core samples were taken from each pasture and analyzed for nutrient deficiencies. Based on soil core samples in 2014, it was recommended that 17-17-17 granular fertilizer be applied to all pastures at a rate of 448 kg ha^{-1}. Soil test from 2015 and 2016 did not indicate a need for phosphorus and potassium fertilizer and thus, it was not applied. Additionally, half of each pasture was fertilized with a liquid nitrogen fertilizer ('19E'; R.W. Griffin, Attapulgus, GA; or 32% UAN) at a rate of 40 units of N/acre on day 30 and 34 in 2014 and 2015, respectively, and with 30 units of N/acre on day 37 in 2016. Nitrogen fertilizer was applied to the second half of each pasture approximately 7-14 days thereafter.

Cattle Management

Each year, 32 angus-cross steers (3 yr average: 429 ± 22 kg) from the Department of Animal and Dairy Science Eatonton Beef Research Unit were utilized. Steers engaged in this study were from the same herd and breeding season each year. Upon fall weaning at approximately 7 months of age, steers were backgrounded on stockpiled, mixed-grass pastures that consisted primarily of bermudagrass and tall fescue. During the winter months, yearling steers were sent to the University of Georgia's, Georgia Mountain and Research Education Center for winter feeding of a corn silage, mixed ration. Each spring, steers were returned to the Eatonton Beef Research Unit where they were pastured on cool-season annual forages or tall fescue until the initiation of the summer annual grazing trial.

One week prior to the initiation of grazing, steers were blocked by BW and randomly assigned to one of four forage treatments. Upon initiation of the grazing trial, steers were fasted for 12-h, weighed and ultrasound measurements were made for body composition by a trained ultrasound technician using an Aloka 500V with a 17-cm, 3.5-MHz transducer (Aloka Inc., Tokyo, Japan). In addition to BW measurements, real time ultrasound was used to estimate carcass measurements upon the initiation (d-0), middle (d-34), and on the last day of the grazing trial during each year. Ultrasound measurements of ribeye area (uLM) at the 12^{th} and 13^{th} rib juncture, 12^{th} rib fat thickness (uFT), rump fat thickness (uRFT), and intramuscular fat percentage (uIMF) were collected from the right side of each steer and analyzed using Beef Image Analysis Feedlot software (Designer Genes Technologies Inc., Harrison, AR).

All steers were supplied with ad libitum access to shade, water, and mineral (McNess Bova Breeder 6; Furst McNess Co., Cordele, GA.; Table 4.1) throughout the trial. Each 0.81 ha^{-1} pasture was subdivided into two 0.405 ha^{-1} pastures with temporary fencing and grazed rotationally. Rotational decisions were made based on forage availability (measured biweekly) and residual height of pastures adequate for optimal regrowth potential (Allen et al., 2011). Put-and-take stocking was also used to maintain forage DM availability and steers that were added or removed were from the same contemporary group as the 32 test steers. Put and take stocking decisions were also made from forage availability measurements and for every 250 kg above or below the targeted forage allowance, a steer was either added or removed to the pasture.

Carcass Data Collection

Once forage became limiting, steers were transported to the Department of Animal and Dairy Science Meat Science Technology Center in Athens, Georgia. Steers were held in outside, covered pens and were given ad libitum access to fresh water for 12 hr prior to being harvested under United States Department of Agriculture federal inspection. Steers were slaughtered in two separate but equal groups approximately 48 h apart in order to accommodate the facilities daily slaughter capacity. Immediately prior to slaughter, BW was collected on each animal. Following hide removal, carcasses were split, weighed, and washed with a 4.5% lactic acid wash before being measured for hot carcass weight and chilled for 24h at -2^{o}C. Following the chilling period, the right side of each carcass was ribbed between the 12th and 13th rib junction and allowed to bloom for approximately 30 mins before carcass yield and quality measurements were taken. Variables measured included 12th rib fat thickness, loin-muscle area, percent KPH, marbling score, and skeletal, lean and overall maturity. In addition, both subjective and objective lean and fat color measurements were taken. Objective measurements of lean were taken in a 50-mm diameter area, in triplicate, on the loin muscle with a Hunter-Lab Miniscan EZ (CR-310; Hunter Associates Laboratory, Inc.; Reston, VA) illuminated at a 10^{o} viewing angle, 2.54 cm aperture, and standardized to white and black tiles. Objective fat color measurements were taken near the posterior rib and on the same carcass side as for lean color. Yield and quality grades were also calculated for each carcass using standard methods (USDA-AMS, 1997).

Proximate Analysis

Following data collection, boneless short loins were removed from the right side of the carcass, vacuum sealed, and stored at (0 ± 2^{o}C) for 21 d of aging. At the end of the aging period, short loins were fabricated to produce steaks with a thickness of 2.54-cm of which the anterior most steak was vacuum packaged and frozen at -20 ± 2^{o}C for proximate analysis. Proximate analysis was used to determine moisture, protein, lipid, and ash composition of the short loins.

Steaks were thawed at 2 ± 2^{o}C for approximately 24 h before being trimmed to remove all external fat and visible connective tissue. Samples were then minced, placed in liquid N (-

129^{o}C), and homogenized using a standard commercial blender. Percent moisture was analyzed by drying crucibles in a 90^{o}C forced-air oven for 12 h before being removed and cooled in a desiccator. Once cooled, empty crucible weight was recorded and 3 ± 0.05g of homogenized sample was measured in duplicate. Crucibles were then placed into a forced-air oven (90^{o}C) and allowed to dry for 48h. Once dry, samples were placed into a desiccator for 10 minutes before a final dry weight was recorded. Dry samples were then placed into a 500^{o}C cool muffle furnace for 2 hr for ash determination. Determination of inorganic content was calculated by the difference in weight as described by AOAC (2000). Percent protein was measured in duplicate by placing 0.2 mg homogenized sample into aluminum foil cups. Cups were then placed into a combustion chamber of a nitrogen analyzer (FP-528 Nitrogen Analyzer; LECO Corp, St. Joseph, MI) to assess nitrogen concentration.

Percent lipid content of samples was measured following the procedure described by Folch et al. (1957) where total lipid content was extracted from samples in duplicate. Approximately 1 ± 0.1g was placed into dried extraction tubes with 8.1 mL of a mixture of 3.5 parts methanol to 1 part water. Samples were vortexed for 15 s prior to the addition of 3.25 mL of chloroform and vortexed for an additional 20 s. A Burrell Wrist Action Shaker (Model 75; Burrell Corp., Pittsburgh, PA) was then used to mix the samples for 1 h before 3.8 mL of chloroform and 3.8 mL of aqueous KCL (0.37%) were added. Samples were then centrifuged for 20 min at 2250 x g (IEC HN SII Centrifuge, International Equipment Co; Ramsey, MN) and the upper aqueous layer was aspirated. Five milliliters of KCL (0.37%) was then added and the centrifuge and aspiration process was repeated. A Buchner funnel with a Whatman #1 (4.25 cm) filter paper was then used to filter samples into clean vials. Samples were then evaporated in vials under N_2 gas, hand vortexed, and 2 mL of extract was placed in duplicate into dried and weighed 12- x 75- mm culture tubes. Culture tubes were once again evaporated under N_2 gas before being placed into a forced air oven (60ºC) for 30 min. After drying, samples were allowed to dry in a desiccator for 10 min prior to the recording of a final weight. Percent lipid was calculated by the following equation: Percent lipid = [([[(tube + lipid wt)/tube wt] x 5)/wet tissue wt] x 100.

Break-even Analysis

Each year, break-even price evaluations were calculated solely on the premises of cost of purchasing steers at the initiation of the trial and value of carcasses at slaughter. Agronomic and labor costs were not factored into this analysis. The initial purchase price of steers was established by taking the average price received for contemporary steers sold by video auction each spring and adding a 4% shrink to tester steer live weight at purchase. Purchase prices of 177, 197, and 130 $/45 kg were used in 2014, 2015, and 2016, respectively. Additionally, carcass values were calculated based on the USDA beef carcass select price equivalent index value (U.S.D.A, 2017) at the time of slaughter. Select price equivalents for 2014, 2015, and 2016 were 223, 211, and 162 $/45 kg, respectively.

Statistical Analysis

All statistical analyses were conducted using the GLIMMIX procedure in SAS 9.4 (Cary, N.C.) to determine interaction and main effects of treatment and year. When applicable, day was used as a main effect and analyzed with interactions. Pasture and block were considered random effects and an alpha level of 0.05 was used to determine significance of main effects, with least squares means separated by pairwise comparisons.

Results and Discussion

Animal Performance

Body weight and steer performance differed by year ($P < 0.01$; Table 4.2). However, animal performance was not affected by treatment overall or within any given year. Steers were heavier ($P < 0.01$) at initiation of the grazing trial in 2014 and 2015 compared to 2016 (440, 437, and 411 kg, respectively), indicating steers in those years were more advanced in their growth and may have been on an increased nutritional plane prior to the start of the grazing trial. Consequently, steers in 2014 and 2015 were also heavier ($P < 0.01$) at the middle of the grazing trial (466, 470, and 450 kg, respectively). However, this effect may also be attributed to the timely precipitation events that occurred after emergence and early in the grazing trial in those two years but was not observed in 2016. Final BW was greater ($P < 0.01$) in 2014 than in 2015 and 2016 (496, 481 and 474 kg, respectively) and may be reflective of the mild climate in combination with the increased number of grazing days in 2014.

Total gain and average daily gain (ADG) differed by year ($P < 0.01$; Table 4.2). Steers in both 2014 and 2016 exhibited greater ($P < 0.01$) total body weight gain compared to steers in 2015 (59.1, 63.1 and 41.0 kg, respectively). However, steers in 2016 had a greater ($P < 0.01$) ADG in comparison to steers in 2014 (1.25 vs. 0.84 kg/d, respectively), and both of these were greater ($P < 0.01$) than in 2015 (0.65 kg/d). Greater ADG in 2014 compared to 2015 was likely the result of more favorable weather conditions (see chapter 3 'the forages chapter') which provided ample soil moisture for greater forage production and less heat stress for the calves in the first year. Though the weather conditions in 2016 were less favorable than 2014 or 2015, the superior ADG in 2016 may have been the result of compensatory gain for steers that entered the trial at a lighter weight than the steers in the other two years.

Although the main effect of year was significant for all measures of growth at each time point and period, there were no effects of treatment within or between years ($P > 0.15$). At the end of the grazing trial, final BW, total BW gain, and total ADG did not differ ($P > 0.17$) among treatments. In a comparison of two sorghum x sudangrass varieties, McCuistion et al. (2011) found similar 56 d ADG to those reported in this study. In their study, steers grazing BMR had an ADG of 0.96 kg/d while steers grazing a non-bmr sorghum x sudangrass variety exhibited an ADG of 0.82 kg/d. The authors suggested that the trends seen in ADG was the result of differences in forage nutritional composition associated with digestibility and the BMR gene.

Schmidt et al. (2013) reported steers grazing PM had an ADG that exceeded 0.56 kg/d but was less than that for steers grazing bermudagrass (0.76 kg/d). McCartor and Rouquette (1977) reported a wide range in ADG of steers grazing PM, from 0.27 to 1.01 kg, depending on stocking rate and forage availability. Ball et al. (2002) suggested that pearl millet was only high in nutritive value while in the immature state, explaining the range in gains in the literature. Though the addition of crabgrass to the pearl millet in the current study did not result in an improvement in total or average daily gains, the nutritive value of crabgrass (Dalrymple, 2001; Ogden et al., 2005) clearly did not detract from it, either. As shown in the discussion of forage distribution and percentage of desirable forage species in the sward (see chapter 3 'the forages chapter'), the addition of crabgrass to the mixture may have benefits other than animal performance.

Ultrasound Measurements

Ultrasonically measured carcass composition traits are presented in Table 4.3. Main effect of treatment was not significant for any measured variable on any scan date. As expected, both uLM and uRFT increased by date ($P < 0.01$) and were greatest ($P < 0.01$) for steers in 2014 and 2015 compared to 2016 (63.0, 61.8, and 58.5 cm^2, respectively for uLM and 0.58, 0.56, and 0.40 cm, respectively for uRFT). Similarly, uFT also increased by scan date ($P < 0.01$) and was greatest ($P < 0.01$) for steers in 2014 compared to 2015 and 2016 (0.54, 0.49, and 0.45 cm, respectively). Increases in uLM, uRFT, and uFT as days on pasture increased is reflective of the nutritive value of warm-season annual grass pastures and their ability to meet nutrient requirements of growing and finishing cattle (NRC, 2000). Intramuscular fat (uIMF) decreased ($P < 0.01$) between the initial scan date and the middle scan date and increased ($P < 0.01$) from the middle to the final scan date for steers grazing SS, BMR, PM and PMCG pastures. The observed relationship may be a result of the unproportioned and rapid increase in LM area compared to IMF and thus altering the overall ratio of the two components (Owens et al., 1993).

Carcass Characteristics

Least square means of treatment for carcass characteristics associated with yield grade are reported in table 4.4. Forage treatment did not have a large impact on carcass characteristics or calculated yield grade. Though SS tended have a better dressing percentage ($P = 0.06$) and the PM tended to have larger ribeye area ($P < 0.10$), these differences were relatively minor and of questionable practical significance. However, the effect of year on carcass characteristics and yield grade was significant ($P < 0.01$) for all the measured variables, with the exception of shrunk BW and fat thickness ($P > 0.31$). Steers finished in 2014 and 2015 had a greater HCW (P

< 0.01) and dressing percent (*P* < 0.01) than steers in 2016. This is likely the result of extreme drought and heat these cattle experienced in 2016. Carcasses from steers finished in 2014 had a greater LM area (*P* < 0.01) than carcasses in 2015 and 2016 (73.21, 67.68, and 65.81 cm^2, respectively). The greater LM area in 2014 compared to 2015 is likely the result of the aforementioned greater ADG in 2014. However, the difference between 2014 and 2016 in measures of LM area is likely the result of a difference between the years in liveweight and hot carcass weight.

Much of the current literature has focused on utilizing cool-season grasses and legumes because of their high nutritive value and resulting impact on animal performance and carcass quality. However, Neel et al. (2007) reported that steers finished on a mix of cool-season grass and legume pastures to have a HCW of 247 kg and was lighter than what was found in this study, even though final BW between the two studies was comparable. Furthermore, the LM area reported for the pasture-finished steers in that study was 66 cm^2, which is similar to slightly less than the range of LM area found in the SS, BMR, PM and PMCG treatments. There was no difference (*P* = 0.34) attributed to forage source for KPH, however steers finished in 2014 and 2015 had a lower (*P* < 0.01) percentage of KPH than steers from 2016 (1.41, 1.31, and 1.89%, respectively). Though not impacted by forage treatment, yield grade was lower (*P* < 0.02) for carcasses in 2014 compared to 2015 or 2016 (1.94, 2.20, and 2.25, respectively) and may reflect differences seen in steer BW between years. The lack of forage-finishing treatment effect on yield grade is consistent with other reports (Schmidt et al., 2013).

Carcass characteristics associated with carcass quality grade including maturity, color, firmness, and texture did not differ (*P* > 0.11) among forage species (Table 4.5). Year had a significant effect on many of the variables tested, suggesting that environment is capable of influencing finishing performance in forage-fed cattle. Steers finished in 2014 displayed an increase (P < 0.01) in lean maturity over those finished in 2015 and 2016 (211, 169, and 166, respectively) while overall maturity was lower (P < 0.01) in 2015 compared to the other two trial years (143 vs 154 and 153, respectively). These results again reiterate the advancement in growth at the initiation of the trial for steers in year 2014. Skeletal maturity was greatest (P < 0.01) for steers in year 2016, followed by 2015 and least for 2014 (173, 147, 132 maturity, respectively). Steers in 2015 exhibited (P < 0.01) a slightly darker red lean color compared to the moderately dark red color seen in steers from 2014 and 2016 (5.19, 4.16, and 4.00, respectively). Additionally, a greater (P < 0.01) subjective yellow external fat color, which has been characteristically associated with grass-fed beef, was visible in 2015 and 2016 steers compared to 2014 (5.16, 5.25, and 3.25, respectively). Redness values (a^*) were greater in fat (P < 0.01) and lean (P < 0.01) in 2015 than 2014 or 2016 (9.57, 8.03, and 8.40, respectively; and 30.7, 29.6, and 29.1, respectively). Yellowness values (b^*) for fat were least (P < 0.01) in carcasses from 2014 steers compared to 2015 and 2016 (22.0, 25.0, and 24.7, respectively) while lean yellowness values were greatest (P < 0.01) for those harvested in 2015 vs 2014 and 2016 (22.8, 21.5, and 21.0, respectively). There was a tendency (P > 0.06) for year to effect carcass firmness (1.91, 1.63, and 2.13, for years 2014, 2015, and 2016, respectively) but not texture. Steers in 2014 had a greater quality grade and greater marbling score than steers in 2015 and 2016 (5.94, 5.19, and 5.25 quality grade score, respectively and 386, 349, and 348 marbling score, respectively); however, all steers finished with a marbling score of slight, and a quality grade of select, or better.

Marbling scores in this study were less than what was reported by Schmidt et al. (2013), who found that steers finished on pearl millet and cowpea had marbling scores of 473 and 513, representing slight and small degrees of marbling, respectively. The differences in quality grade between years in this study can be attributed to the impact temperature and heat stress has on carcass composition and is similar to what others have reported. For example, Mitlöhner et al. (2002) found that heifers provided with shade had a greater quality grade than unshaded heifers. Kreikemeier et al. (1998) reported a similar impact on quality grade for cattle harvested during the summer months compared to those harvested in milder conditions. Additionally, time on feed may explain differences in year to year variation of marbling score and quality grade.

Proximate Analysis

The concentration of moisture, protein, lipid, or ash of the beef product was not affected by forage treatment within or among years (Table 4.6). However, beef from steers finished in 2015 had a greater moisture content than those finished in 2014 (73.90 vs. 73.13, respectively), with 2016 as an intermediate (73.63%). Protein composition of forage-finished steers in this study was not affected by treatment or year and is comparable to the protein content of the longissimus muscle in steers finished on warm-season annual forages of pearl millet and cowpea (22.66 and 23.92% protein, respectively) reported by Schmidt et al. (2013). Lipid concentration differed by year ($P = 0.05$) with carcasses in 2014 having a greater percent lipid content than carcasses from the 2015 grazing season (3.16 vs. 2.54%, respectively), and 2016 as an intermediate (2.73%). Differences in lipid composition among years can be explained by the aforementioned increase in marbling score observed in the 2014 carcasses. This linkage between marbling score and lipid concentration in beef has been well established in the literature (Van Koevering et al., 1995; Mandell et al., 1998). The concentration of total minerals, as measured by ash content, of the LM area was greater ($P < 0.01$) in 2015 than in 2014 (1.19 vs. 1.12%, respectively), and least for 2016 (1.03%).

Break-even Analysis

Break-evens for finished steers based on a select pricing standard are presented in Table 4.7. A forage treatment by year interaction occurred for value difference ($P = 0.04$), premium required ($P = 0.01$), percent premium increase ($P = 0.02$), and for break-even price ($P = 0.01$), and thus the data are presented by year. Initial purchase price of steers was greatest ($P < 0.01$) in 2015, followed by 2014, and least for 2016 ($1730, $1602, and $1151 hd^{-1}, respectively). Total finished carcass value differed ($P < 0.01$) between years and decreased from $1,314 hd^{-1} in 2014 to $1,274 hd^{-1} in 2015, and to $923 hd^{-1} by 2016. Value difference between the initial purchase price of the steers and the finished carcass value differed ($P < 0.01$) between years and was greatest for 2015, followed by 2014, and least for steers harvested in 2016 (-$457, -$287, and -$228 hd^{-1}, respectively). Large negative value differences seen in 2015 can be contributed to the historic high cattle prices that occurred during the spring of the year when the cattle were initially purchased and was then followed by an unprecedented rapid drop of cattle prices in the fall, during the time in which cattle were harvested. As a result of these value differences, beef produced in 2015 required the greatest ($P < 0.01$) break-even premium per 45 kg, followed by carcasses in 2014, and was least for those in 2016 ($75.9, $49.1, $40.2 $/45 kg, respectively). However, when the premium required to break-even was expressed as a percentage of the USDA select standard price, carcasses from 2015 required the greatest ($P < 0.01$) percentage increase at 35.9% followed by a 24.8% increase in 2016 and a 22.0% in 2014. Carcasses in 2015 required a greater ($P < 0.01$) breakeven price in comparison to steers in 2014 ($287 vs $272, $/45 kg, respectively), and both were greater ($P < 0.01$) than in 2016 ($202 $/45 kg). In our study, breakeven prices were not affected ($P > 0.20$) by forage treatment but were primarily a function of fluctuations seen in the cattle market. This resulted in a net loss between live animal purchase price and carcass value on a select price index. However, with the willingness of consumers to pay an increased price for grass-finished beef (Lacy et al., 2007), a premium is often added to the final beef product at retail. A study by Umberger et al. (2002) investigated consumers' willingness to pay for corn-fed versus grass-fed beef and found that participants were willing to pay a premium of $136 per 45 kg more for grass-fed beef products. Break-even premiums found in this study were lower than what was reported by Umberger et al. (2002) and therefore, finishing cattle on SS, BMR, PM, and PMCG may each be a profitable option for grass-finishing beef producers in the Southeast.

Conclusions

There is very little information on the utilization of warm-season annual grasses in forage-finishing beef systems. Much of the literature has focused on utilizing cool-season grasses and legumes because of their impeccable forage quality and resulting impact on animal performance and carcass quality. With the increase in demand for forage-finished beef products and the opportunity to produce a high quality product, alternative forage systems must be considered for summer forage-finishing of beef in the southeastern U.S. In this study, steers grazing SS, BMR, PM, and PMCG pastures all performed similarly during summer forage-finishing. Environmental impacts on forage had a greater impact on steer performance and carcass composition than forage treatments. Forage treatment did not affect live animal performance, or carcass characteristics used to determine both yield and quality grades in cattle. Proximate analysis and break-even cost analysis were also not affected by forage treatment. Producers can utilize these forage systems interchangeably in forage-finishing operations, without negatively impacting the final beef product or profitability. Producers can utilize these forage systems interchangeably in forage-finishing operations, without negatively impacting the final beef product.

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Table 4.1. Composition of free choice mineral.[1]

Ingredient	Guaranteed analysis
Calcium, %	13.2
Phosphorus, %	6.1
NaCl, %	20
Magnesium, mg/kg	2.6
Zinc, mg/kg	9,000
Manganese, mg/kg	6,500
Copper, mg/kg	3,000
Iodine, mg/kg	184.5
Cobalt, mg/kg	45
Selenium, mg/kg	39
Vitamin A, IU/kg	661,387
Vitamin D-3, IU/kg	66,139
Vitamin E, IU/kg	1,322

[1]McNess Bova Breeder 6 (Furst McNess Co., Cordele, Ga.).

Table 4.2. Least square means for growth performance of forage-finished steers pastured on sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM) or a mixture of pearl millet and crabgrass (PMCG) during a forage-finishing trial conducted during the summers of 2014-2016 at the UGA Animal and Dairy Science Department's Beef Research Unit near Eatonton, Georgia.

Item	**Forage Treatment**				**SEM**	**Effect**		
	SS	**BMR**	**PM**	**PMCG**		**Trt**	**Year**	**Trt*Year**
BW, kg								
Initial	430	430	430	428	4.1	0.98	<0.01	1.00
Middle	463	464	459	464	4.5	0.80	<0.01	0.96
Final	481	490	481	484	4.7	0.49	<0.01	0.97
Total Gain	51.5	59.6	50.8	55.6	3.3	0.21	<0.01	0.50
ADG, kg/d								
Period 1	0.99	0.99	0.84	1.04	0.06	0.16	<0.01	0.28
Period 2	0.72	1.00	0.85	0.92	0.10	0.20	<0.01	0.15
Total ADG	0.86	0.99	0.85	0.97	0.06	0.17	<0.01	0.20

[abc] Means within a row without a common superscript differ ($P < 0.05$).

Table 4.3. Least square means for ultrasound measurements of forage-finished steers pastured on sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM) or a mixture of pearl millet and crabgrass (PMCG) during a forage-finishing trial conducted during the summers of 2014-2016 at the UGA Animal and Dairy Science Department's Beef Research Unit near Eatonton, Georgia.

Item/Time Point[1]	**Forage Treatment**				**SEM**	**Effect**		
	SS	**BMR**	**PM**	**PMCG**		**Trt**	**Year**	**Trt*Year**
uLM, cm^2								
Initial[2]	57.7	57.0	57.6	55.4	1.04	0.28	0.01	0.79
Middle[3]	62.3	61.5	64.7	60.7	1.28	0.16	<0.01	0.65
Final[4]	65.6	63.4	63.3	64.1	1.10	0.40	<0.01	0.69
uFT, cm								
Initial[2]	0.39	0.41	0.38	0.36	0.03	0.45	0.06	0.80
Middle[3]	0.50	0.54	0.52	0.50	0.03	0.77	0.06	0.61
Final[4]	0.55	0.59	0.62	0.57	0.04	0.54	<0.01	0.72
uIMF, %								
Initial[2]	3.55	3.43	3.59	3.59	0.10	0.66	0.03	0.07
Middle[3]	3.17	3.28	3.24	3.37	0.10	0.53	<0.01	0.14
Final[4]	3.75	3.62	3.85	3.65	0.12	0.50	0.58	0.16
uRFT, cm								
Initial[2]	0.43	0.44	0.46	0.41	0.02	0.47	<0.01	0.28
Middle[3]	0.54	0.50	0.51	0.51	0.03	0.90	<0.01	0.41
Final[4]	0.57	0.62	0.61	0.55	0.03	0.41	<0.01	0.97

[abc] Means within a row without a common superscript differ (*P* < 0.05).

[1] uLM = ultrasound measurement of the loin-muscle area at the 12th to 13th rib juncture; uFT = ultrasound measurement of the 12th-rib back fat thickness; uIMF = ultrasound measurement of the percent LM intramuscular fat; uRFT = ultrasound measurement of the rump fat thickness.

[2] Initial = 6/25/2014, 6/25/2015, and 6/29/2016.

[3] Middle = 7/29/2014, 7/29/2015, and 8/02/2016.

[4] Final = 9/03/2014, 8/27/2015, and 8/31/2016.

Table 4.4. Least square means for yield associated carcass characteristics for forage-finished steers pastured on sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM) or a mixture of pearl millet and crabgrass (PMCG) during a forage-finishing trial conducted during the summers of 2014-2016 at the UGA Animal and Dairy Science Department's Beef Research Unit near Eatonton, Georgia.

Item	Forage Treatment				SEM	Effect		
	SS	BMR	PM	PMCG		Trt	Year	Trt*Year
Shrunk BW, kg	459	470	462	463	4.43	0.37	0.31	0.81
HCW, kg	267	268	267	265	3.29	0.91	<0.01	0.62
Dressing %	58.0	57.0	57.8	57.2	0.30	0.06	<0.01	0.51
LM Area, cm^2	66.9	69.7	71.5	67.5	1.40	0.08	<0.01	0.58
LM Area/kg LWT	14.6	14.9	15.5	14.6	0.30	0.10	<0.01	0.56
LM Area/kg HCW	25.1	26.1	26.9	25.5	0.54	0.08	<0.01	0.61
KPH, %	1.54	1.63	1.54	1.44	0.11	0.34	<0.01	0.08
Fat Thickness, cm	0.49	0.51	0.50	0.50	0.04	0.99	0.77	0.82
Yield Grade	2.22	2.13	2.01	2.16	0.10	0.39	<0.01	0.63

[abc] Means within a row without a common superscript differ ($P < 0.05$).

Table 4.5. Least squares means for quality associated carcass characteristics for forage-finished steers pastured on sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM) or a mixture of pearl millet and crabgrass (PMCG) during a forage-finishing trial conducted during the summers of 2014-2016 at the UGA Animal and Dairy Science Department's Beef Research Unit near Eatonton, Georgia.

Item	Forage Treatment				SEM	Effect		
	SS	BMR	PM	PMCG		Trt	Year	Trt*Year
Lean Maturity[1]	175	185	187	181	4.98	0.38	<0.01	0.80
Skeletal Maturity[1]	152	150	152	149	2.89	0.86	<0.01	0.45
Overall Maturity[1]	147	151	152	149	2.74	0.57	<0.01	0.88
Subjective Lean Color[2]	4.25	4.63	4.63	4.29	0.21	0.39	<0.01	0.87
Subjective Fat Color[3]	4.58	4.67	4.50	4.46	0.21	0.90	<0.01	0.59
Objective Lean Color								
L^{*4}	36.8	37.2	36.4	37.3	0.49	0.51	0.01	0.62
a^{*5}	30.0	30.4	29.1	29.7	0.38	0.12	<0.01	0.24
b^{*6}	21.9	22.4	21.0	21.7	0.41	0.13	<0.01	0.14
Objective Fat Color								
L^{*4}	80.1	80.3	79.7	80.2	0.44	0.80	0.31	0.67
a^{*5}	8.75	8.71	8.89	8.32	0.34	0.69	<0.01	0.13
b^{*6}	23.9	24.2	24.5	23.2	0.69	0.56	<0.01	0.51
Firmness[7]	1.71	2.08	1.92	1.83	0.17	0.47	0.06	0.71
Texture[8]	1.25	1.29	1.58	1.42	0.12	0.15	0.27	0.54
Marbling[9]	364	352	370	359	8.39	0.47	<0.01	0.23
Quality Grade[10]	5.42	5.33	5.54	5.54	0.26	0.93	<0.01	0.85

[abc] Means within a row without a common superscript differ ($P < 0.05$).
[1] 100 = A00; 200 = B00.
[2] 1 =extremely dark red; 2 = very dark red; 3 = dark red; 4 = moderately dark red; 5 = slightly dark red; 6 = cherry red; 7 = moderately bright cherry red; 8 = light cherry red.
[3] 1 = white; 2 = creamy white; 3 = slightly yellow; 4 = moderately yellow; 5 = yellow.
[4] Measurement of lightness; 0 = darker; 100 = lighter.
[5] Measurement of green to red; greater value indicates increased redness.
[6] Measurement of blue to yellow; greater value indicates increased yellowness.
[7] 1 = Very firm; 2 = Firm; 3 = Slightly firm; 4 = Slightly soft; 5 = Soft.
[8] 1 = Very fine; 2 = Fine; 3 = Slightly fine; 4 = Slightly coarse; 5 = Coarse.
[9] 300 = Slight00; 400 = Small00; 500 = Modest00.
[10] 12= Prime$^+$; 11 = Prime^o; 10 = Prime$^-$; 9 = Choice$^+$; 8 = Choice^o; 7 = Choice$^-$; 6 = Select$^+$; 5 = Select^o; 4 = Select$^-$; 3 = Standard$^+$; 2 = Standard^o; 1 = Standard$^-$.

Table 4.6. Least squares means for proximate analysis of the loin muscle area for forage-finished steers pastured on sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM) or a mixture of pearl millet and crabgrass (PMCG) during a forage-finishing trial conducted during the summers of 2014-2016 at the UGA Animal and Dairy Science Department's Beef Research Unit near Eatonton, Georgia.

Item, %	**Forage Treatment**				**SEM**	**Effect**		
	SS	**BMR**	**PM**	**PMCG**		**Trt**	**Year**	**Trt*Year**
Moisture	73.4	73.7	73.9	73.3	0.24	0.23	0.03	0.19
Protein	22.5	22.6	22.5	22.6	0.15	0.93	0.29	0.50
Lipid	3.00	2.65	2.55	3.06	0.52	0.22	0.05	0.11
Ash	1.11	1.13	1.11	1.10	0.01	0.56	<0.01	0.17

[abc] Means within a row without a common superscript differ ($P < 0.05$)

Table 4.7. Least squares means for break-even analysis for forage-finished steers pastured on sorghum x sudangrass (SS), brown-midrib sorghum x sudangrass (BMR), pearl millet (PM) or a mixture of pearl millet and crabgrass (PMCG) during a forage-finishing trial conducted during the summers of 2014-2016 at the UGA Animal and Dairy Science Department's Beef Research Unit near Eatonton, Georgia.

Item/Year	Forage Treatment				SEM	P-Value
	SS	BMR	PM	PMCG		
Initial Purchase Price[1], $						
2014	1,598	1,628	1,577	1,604	25.9	0.60
2015	1,752	1,722	1,724	1,723	30.9	0.88
2016	1,151	1,151	1,147	1,155	23.5	1.00
Finished Carcass Value[2], $						
2014	1,330	1,315	1,316	1,297	24.4	0.83
2015	1,268	1,302	1,252	1,272	20.5	0.40
2016	918	916	941	917	18.7	0.76
Value Difference, $						
2014	-269	-312	-262	-307	-22.9	0.31
2015	-483	-420	-472	-451	-26.4	0.31
2016	-233	-235	-206	-238	-20.0	0.65
Premium Required, $/45 kg						
2014	45.3	53.3	44.5	53.1	4.64	0.39
2015	80.6	68.0	79.8	75.0	4.77	0.20
2016	41.1	42.0	35.6	42.2	4.05	0.61
Premium Increase[3], %						
2014	20.3	23.9	20.0	23.8	2.08	0.39
2015	38.2	32.2	37.8	35.5	2.26	0.20
2016	25.4	25.9	22.0	26.1	2.50	0.61
Break Even Price, $/45 kg						
2014	268	276	268	276	4.65	0.39
2015	292	279	291	286	4.77	0.20
2016	203	204	198	204	4.05	0.61

[1]Initial purchase price: 2014 = $177; 2015 = $197; 2016 = $130 $/45 kg.
[2]Finished carcass value based on a select pricing index: 2014 = $223; 2015 = $211; 2016 = $162 $/45 kg.
[3]Percent premium increase required above the select pricing index.

CHAPTER 5

SELECTING A WARM-SEASON ANNUAL FORAGE VARIETY

[1] Harmon, D. D., D. W. Hancock, R. L. Stewart Jr., A. M. Stelzleni, J. R. Segers, and C. D. Teutsch. To be submitted to *Journal of Forage & Grazinglands*.

Abstract

Warm-season annual forages have increased in popularity over the last decade, but varieties of sorghum x sudangrass [*Sorghum bicolor* (L.) x *S. arundinaceous* (Desv.); (SS)], forage sorghum [*Sorghum bicolor* (L.) Moench; (FS)], or pearl millet [*Pennisetum glaucum* L.R. Br.; (PM)] are often chosen on the basis of local availability and affordability. Although there are many commercially available varieties on the market, it is important to compare their performance in numerous environmental conditions. The objective of this study was to help producers identify superior varieties of SS, FS and PM that consistently performed well over time and across multiple environments. Forage yield data from 1998-2016 was collected from the University of Georgia (1998-2016), University of Kentucky (2001-2016), Virginia Tech (2009-2015), and the Noble Foundation (2001-2010). There were 229, 161, and 62 individually identified varieties of SS, FS, and PM, respectively. The analysis excluded varieties that had been evaluated in fewer than 6 site-year combinations. To standardize across environments, yields were expressed as a percentage of the mean within a given site-year. Standardized means were averaged across all available site-years for that variety and a correlation of variation (CV) was calculated. Outstanding SS varieties identified on the basis of a relative yield greater than 100% and a CV equal to or less than 10 were AS5201, Summergrazer III, Headless Trudan, Special Effort, Headless Sordan, ExtraGraze BMR and Nutri-Plus BMR. Forage sorghum varieties included 86S and Centurion BMR while outstanding PM varieties were identified as Tif Exp. 6, Tifleaf 3, Elite III, SS 635, DMP4SR and DMP5SR. Results from this study will help producers identify robust varieties that consistently produce well in diverse environmental conditions.

Keywords: Sorghum x sudangrass, Forage sorghum, Pearl millet, Variety Test, Yield.

Introduction

The use of sorghum x sudangrass [*Sorghum bicolor* (L.) x *S. arundinaceous* (Desv.); (SS)], forage sorghum [*Sorghum bicolor* (L.) Moench; (FS)], and pearl millet [*Pennisetum glaucum* L.R. Br.; (PM)] as forage crops in the southeastern U.S. is increasing, largely as a result of their exceptional dry matter (DM) production even under moisture stress (Sanchez et al., 2002). Additionally, these warm-season annual forages can help fill the summer gap in cool-season forage production while also extending the entirety of the grazing season (Fontaneli et al., 2001). To keep up with the growing interest in using these forages for grazing or ensiling purposes, seed companies are continuously developing and releasing new varieties. Current breeding efforts primarily focus on increasing the yield and quality of warm season annuals, as well as pest and disease resistance.

Commercially available varieties of SS, FS, and PM are often selected on the basis of local availability and price with less emphasis on the performance of specific varieties. Although good management is key to a successful summer annual forage program, planting a performance tested, proven variety is also an important for maximizing return on investment because not all varieties on the market perform equally. Several land-grant universities and unbiased third party organizations (e.g., the Noble Foundation) have historically conducted variety testing programs to help identify warm season annual varieties that are well adapted to a specific climate or region. However, not all geographical regions are represented by these programs. Additionally, a collective comparison of the yield performance of a large number of warm-season annual forage varieties across multiple environments and years has not been made. Thus, the objective of this study was to compare forage DM production of SS, FS, and PM varieties across multiple years and environments to determine superior varieties that consistently perform well.

Materials and Methods

Variety Trial Locations

Warm-season annual forage yield data was collected from multiple state and local variety testing programs for 1998 to 2016. The dataset included yield information collected from two test sites at the University of Georgia and the University of Kentucky, and one test site at Virginia Tech and at The Samuel Roberts Noble Foundation (Table 5.1). All test sites were rain-fed with the exception of the University of Georgia's test sites which received irrigation only to ensure germination (Table 5.2). The data set included information from 5 varying geographical regions and 6 different soil types (Table 5.2). In total, there were 229 SS, 161 FS, and 62 PM varieties that were individually identified in the dataset. Varieties included in the testing programs consisted of both commercial and experimental types. Since some experimental varieties are entered into the variety trials with an alphanumeric code that may change over time or that later becomes a named variety and the variety trial programs are usually not privy to the progression of those codes and variety names, some duplication across the sites and years likely occurred and was unavoidable.

Screening Methods and Calculations

To standardize across years and locations, forage yields for each species were expressed as a percentage of the mean total yield within a given site and year. Thus, a relative yield of 100% was equal to the mean of all entries for that species within a site and year combination and anything above 100% was considered to be above average and desirable. For a more accurate measure of performance, the analysis then excluded varieties that had been evaluated in fewer than six site-year combinations. For each of the remaining varieties, the mean of the relative yields of each available site-year combination was calculated. A coefficient of variation (CV), as described by Rayburn (2009), was then calculated across all site-year combinations for those varieties that were included in the analysis. Finally, the overall mean relative yield and CV for the varieties within each species were classified into one of four categories, as follows: 1) above average relative yield and below average variability, 2) above average relative yield and above average variability, 3) below average relative yield and below average variability, and below average relative yield and above average variability.

Results and Discussion

Screening criterion led to a final analysis that included 40 varieties of SS, 26 varieties of FS, and 16 varieties of PM (Table 5.3.). As expected, differences in performance and stability of forage dry matter production was detected between varieties of warm-season annual forages. In each species, varieties that fell into the above average relative yield and below average variability category were considered most desirable because they consistently performed above average across multiple years and varying environmental conditions (Figures 5.1, 5.2 and 5.3). In contrast, varieties that fell in the below average relative yield and above average variability category were considered least desirable to use in a forage system because of their decreased performance and increased risk. Furthermore, varieties that had an above average relative yield in combination with a CV equal to or less than 10 were considered to be outstanding varieties due to their extraordinary consistency across year and varying geographical and climatological locations. Sorghum x sudangrass varieties that met this criterion were AS5201, Summergrazer III, Headless Trudan, Special Effort, Headless Sordan, ExtraGraze BMR and Nutri-Plus BMR (Figure 5.1.). Only two FS varieties, 86S and Centurion BMR, met this criterion (Figure 5.2), while PM varieties included Tif Exp. 6, Tifleaf 3, Elite III, SS 635, DMP4SR, and DMP5SR (Figure 5.3).

Findings in this study suggest that differences in forage production can occur between varieties and is consistent with research reported by Chaugool et al. (2013) who found that total dry matter yield of 15 sorghum x sudangrass hybrids ranged from 78.6 – 139.7 g DM plant^{-1} and 3 varieties of forage sorghum ranged from 109.1 to 139.4 g DM plant^{-1}. Additional work by Fike et al. (2005) concluded that differences in forage production can occur amongst year, geographical location, and forage variety. In contradiction, Beck et al. (2007a) reported that forage yield of sorghum x sudangrass hybrids was not affected by variety per se, but rather an interaction between harvest date and variety since some varieties mature more quickly than others. In this experiment, maturity or growth stage was not reported for all test sites and therefore was not included in this analysis.

Conclusions

It is well established that genotype by environment interactions do exist and can play a crucial role in the success of a warm-season annual forage program, but identifying superior varieties that perform well across multiple years and environments can create a substantial advantage for producers, especially in areas where local variety testing programs do not exist. Based on this analysis, producers should choose from AS5201, Summergrazer III, Headless Trudan, Special Effort, Headless Sordan, ExtraGraze BMR, or Nutri-Plus BMR as a variety of

SS; 86S and Centurion BMR as a variety of FS; and Tif Exp. 6, Tifleaf 3, Elite III, SS 635, DMP4SR, and DMP5SR as a variety of PM, if available. Additional comparisons of varietal performance across multiple local and national forage variety testing programs for each forage crop species is strongly recommended.

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Table 5.1. Summary of variety testing programs used in this analysis.

Affiliation/Location	Test Years		
	SS	**FS**	**PM**
University of Georgia			
Griffin, GA	1998-2016	1999-2016	1998-2016
Tifton, GA	1998-2016	1998-2016	1998-2016
University of Kentucky			
Lexington, KY	2007-2016	2013-2016	2012-2016
Quicksand, KY	2001-2003	2001	2001-2003
Virginia Tech			
Blackstone, VA	2009-2012, 2014-2015	2009-2012, 2014-2015	2009-2012, 2014-2015
Samuel Roberts Noble Foundation			
Ardmore, OK	2001-2004	2001, 2003-2004, 2008, 2010	2001-2004

Table 5.2. Summary of irrigation and geographical information of variety testing programs used in this analysis.

Affiliation/Location	Irrigation	Geographic Region	Elevation	Latitude and Longitude	Soil Series
University of Georgia					
Griffin, GA	At planting, as needed	Piedmont	974	33.25 N, 84.26 W	Cecil Clay Loam
Tifton, GA	At planting, as needed	Upper Coastal Plain	354	31.45 N, 83.51 W	Tifton Loamy Sand
University of Kentucky					
Lexington, KY	None	Interior Low Plateaus	978	38.04 N, 84.50 W	Maury Silt Loam
Quicksand, KY	None	Appalachian Plateaus	810	37.53 N, 83.34 W	Nolin Silt Loam
Virginia Tech					
Blackstone, VA	None	Piedmont	446	37.08 N, 78.00 W	Appling-Wedowee Sandy Loam
Samuel Roberts Noble Foundation					
Ardmore, OK	None	Central Lowland	873	34.17 N, 97.14 W	Dale Silt Loam

Table 5.3. Summary of sorghum x sudangrass, forage sorghum, and pearl millet varieties that were tested in at least 6 site and year combinations

Figure Variety Code	Variety Name	Company/Brand Name	Site-Year Count[1]	Mean Relative Yield[2] (%)	Coefficient of Variation[3] (%)
		SORGHUM X SUDANGRASS			
1	Fastgrass 5	MBS	6	119.9	14.9
2	SS 211	Southern States	38	116.3	11.5
3	AS5201	Alta Seeds	9	113.8	5.6
4	SU2-LM	Moss	16	112.6	13.7
5	Sordan 79	Sorghum Partners	9	111.6	14.1
6	Summergrazer III	Pennington	27	110.4	8.2
7	Headless Trudan	NK	6	109.4	7.5
8	Exp. 3010 BMR*	Coffey	8	108.9	14.6
9	Special Effort	-	8	107.8	9.2
10	AS9302	Alta Seeds	6	106.6	11.3
11	Super Sugar	Gayland Ward	22	106.5	12.3
12	705F (SGxS)	Dyna-Gro	6	106.3	11.5
13	Sordan Headless	Sorghum Partners	6	106.0	13.1
14	Headless Sordan	NK	6	105.9	9.0
15	AS6501	Alta Seeds	6	105.8	14.6
16	Mega Green	Moss	26	105.2	20.2
17	Green Grazer V	Seed Resource	11	104.7	10.3
18	SG-2000	Coffey	10	104.4	12.4
19	Super Sugar (DM)	Gayland Ward	9	103.8	10.4
20	Sweeter-N-Honey	Southland	7	103.4	13.7
21	Sweet For Ever	Gayland Ward	10	103.3	11.1
22	AS6401	Alta Seeds	18	103.1	15.2
23	AS9301	Alta Seeds	12	102.2	11.0
24	Sugar Graze Ultra	Coffey	11	101.7	12.3
25	SS 220	Southern States	41	101.5	12.1
26	ExtraGraze BMR	Coffey	3	101.4	2.8
27	Nutri-Plus BMR	Production-Plus	8	100.5	9.4
28	Exp. 2010 BMR*	Coffey	8	98.3	9.9
29	Surpass XL BMR	Coffey	7	98.0	10.8
30	AS6402	Alta Seeds	20	96.3	9.5
31	GW 300 BMR	Gayland Ward	12	93.6	15.3
32	Maxigain	Coffey	15	93.5	14.9
33	Century BMR	Moss	21	92.6	14.3

34	Sweet Six BMR Dry Stalk	Gayland Ward	9	91.0	21.8
35	Nutri-Plus	Production-Plus	7	89.5	16.1
36	Haymaster BMR	MBS	6	88.8	20.9
37	Sweet For Ever BMR	Gayland Ward	16	88.4	18.8
38	MaxiGain BMR-6	Coffey	6	87.1	16.0
39	38 Special BMR	Moss	6	82.9	7.6
40	SS 130	Southern States	11	75.3	16.0
		FORAGE SORGHUM			
1	SS405	NK	18	130.4	22.8
2	AF8301	Alta Seeds	10	121.0	13.2
3	86S	Grabow	7	118.9	9.4
4	Full Graze	Dyna-Gro	6	115.7	13.9
5	Ensile Master	Gayland Ward	10	113.8	17.1
6	1990	Sorghum Partners	14	108.4	11.0
7	Silo Master D	Southland	8	108.3	10.5
8	4Ever Green	Moss	27	107.0	15.3
9	Centurion BMR	Coffey	7	105.7	8.7
10	SS-85F	Southern States	16	104.8	22.0
11	SS1515	Southern States	37	104.5	12.8
12	GW 600 BMR	Gayland Ward	9	103.3	16.2
13	NK300	NK	18	103.1	11.6
14	GW 2120	Gayland Ward	10	95.4	15.7
15	4Ever Green BMR	Moss	16	95.3	20.6
16	MaxiGain BMR-6	Coffey	8	94.7	9.7
17	SS2010BDF	Southern States	13	93.9	6.5
18	GW 400 BMR	Gayland Ward	14	90.5	17.7
19	AF7401	Alta Seeds	18	90.4	13.7
20	Exp. 816 BMR*	Coffey	8	89.7	19.8
21	AF7201	Advanta	15	89.1	15.7
22	Millennium BMR	Moss	23	84.1	27.1
23	AF7101	Alta Seeds	6	82.1	13.5
24	AF7301	Alta Seeds	8	82.1	21.9
25	Penn02BMR	Pennington	6	81.6	27.9
26	Silo-Pro BMR Dwarf	Gayland Ward	6	68.8	44.3
		PEARL MILLET			
1	Tif Exp. 4*	GA CPES	17	111.8	13.5
2	Tif Exp. 6*	GA CPES	11	107.1	8.9
3	Tifleaf 3	GA CPES	46	106.5	6.9
4	Elite III	CSC	8	106.0	3.6
5	SS 635	Southern States	43	104.3	7.7

6	DMP4SR	USDA-ARS	17	101.5	6.0
7	Leafy 60	Coffey/MBS	10	101.3	10.8
8	DMP5SR	USDA	13	100.0	4.8
9	Mil-Hy 500	Seed Resource	8	99.6	4.6
10	DMP3SR*	USDA-ARS	17	98.7	7.4
11	Millex 32	Sorghum Partners	12	98.4	12.1
12	Pennleaf	Pennington	32	97.8	9.2
13	Mil-HY 300	Seed Resource	6	95.1	9.0
14	SS 501	Southern States	29	92.5	18.3
15	PP102M	Production-Plus	6	91.1	7.8
16	Exp. 40-1 BMR*	Coffey	6	89.0	11.9

* Indicates experimental varieties
[1]Site-Year Count: sum of the number of times a variety has been included in a testing program and across all tested years.
[2]Mean Relative Yield: expressed as the percentage of the mean total yield within a given site and year.
[3]CV: calculated as (standard deviation/mean relative yield)*100

Figure 5.1. Mean and coefficient of variation in relative yield for sorghum x sudangrass varieties tested in at least six site and year combinations.

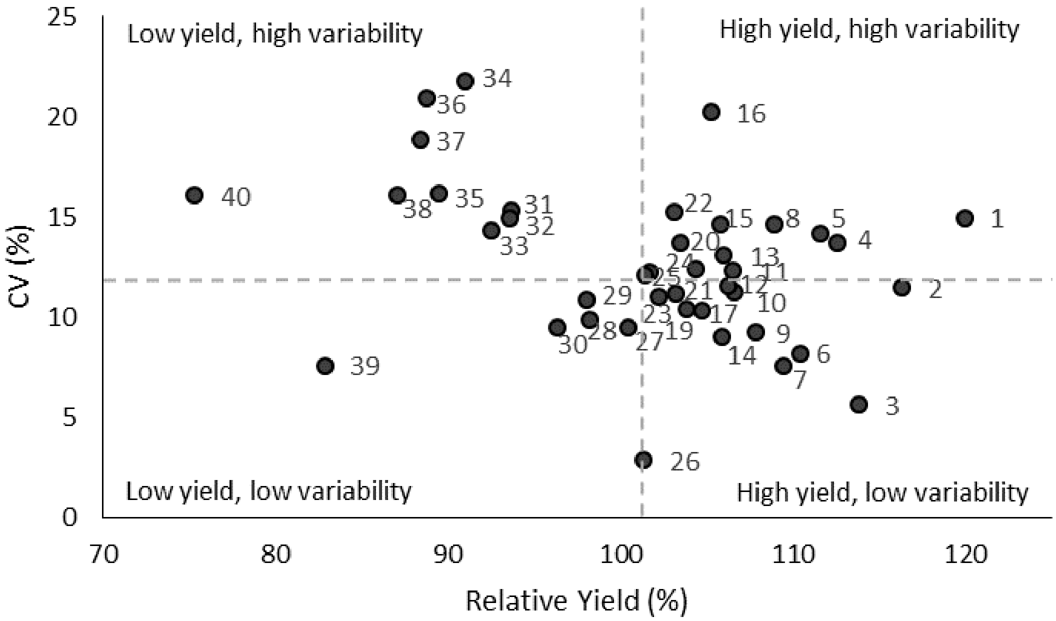


Figure 5.2. Mean and coefficient of variation in relative yield for forage sorghum varieties tested in at least six site and year combinations.

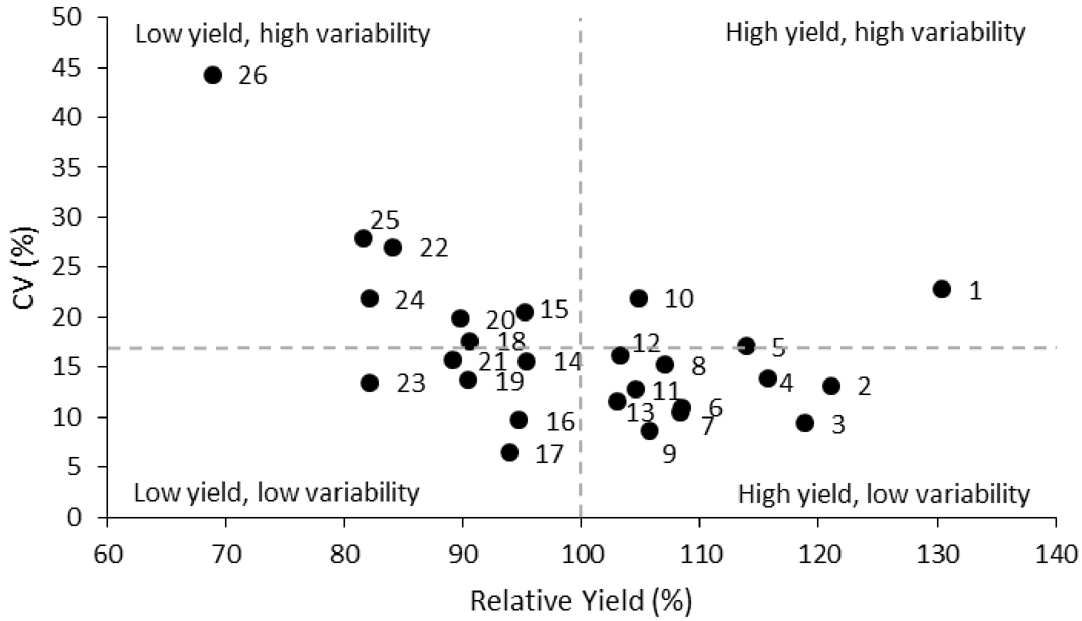
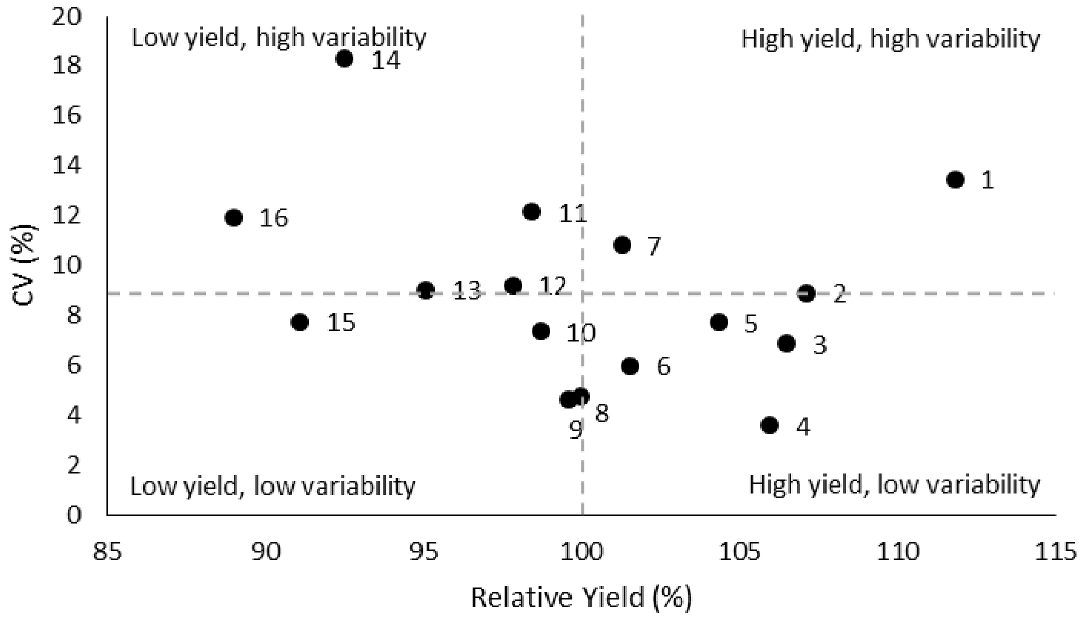


Figure 5.3. Mean and coefficient of variation in relative yield for pearl millet varieties tested in at least six site and year combinations.



CHAPTER 6

CONCLUSIONS AND IMPLICATIONS

The growing interest in forage-finished beef products has led to a need for alternative finishing strategies during the summer months in the Southeast so that producers can provide a year-round supply of fresh beef. Prior to this project, there was very little information on using warm-season annual forages of sorghum sudangrass [*Sorghum bicolor* (L.) x *S. Arundinaceum* (Desv.)], brown midrib sorghum x sudangrass, pearl millet (*Pennisetum glaucum* L.R. Br.) and a mixture of pearl millet and crabgrass (*Digitaria sanguinalis*) to produce forage-finished beef. This study examined all parameters of forage-finished beef, from cultivar to cutability. Although the end product of beef production is of great importance to producers, estimating forage production and animal performance are crucial to determining profitability of that end product.

In this study, it was observed that environment played an important role in forage parameters, animal performance, and carcass attributes. Specifically, sorghum x sudangrass, brown midrib sorghum x sudangrass, and pearl millet produced more pre-grazed forage DM than pearl millet plus crabgrass at the beginning of the grazing trial. However, shortly thereafter, performance of pearl millet plus crabgrass did not differ from the other forage treatments. The rapid growth of the two sorghum x sudangrass forage systems in addition to a skewed forage distribution towards the beginning of the growing season, required an increased level of management to prevent pastures from becoming overly mature. As a result of this effort, the two sorghum x sudangrass forage treatments had a greater stocking density early in the grazing season. This led to a greater gain ha^{-1} for the sorghum x sudangrass forage treatment compared to pearl millet in 2014 and 2015 and greater for brown midrib sorghum x sudangrass compared to pearl millet and pearl millet plus crabgrass in 2015. Such differences were muted or negated by the severity of the drought in 2016.

Forage nutritive parameters were variable among forage treatments and appeared to be largely influenced by environment, as well as grazing management. Failure to maintain pastures in a vegetative state can result in mature forage that has decreased nutritive value. In addition to maturity's impact on forage nutritive value, weed pressures can also alter quality and overall forage production. In this study, brown midrib sorghum x sudangrass species rapidly decreased within a stand and throughout the grazing season, and were replaced by less desirable weed species that have the potential to lower overall forage quality of pastures. Unlike pearl millet or the two sorghum x sudangrass forage systems, the addition of crabgrass to pearl millet resulted in pastures that maintained a greater amount of desirable species throughout the entirety of this study. Additionally, during drought years when rainfall was limited or when precipitation per rainfall event was small, the shallow rooted crabgrass was able to take advantage of the available moisture. Thus, it was observed that cattle in those pastures preferred to graze the highly palatable crabgrass over the drought stressed pearl millet plants.

Year to year variations, such as the severity and duration of drought and temperature extremes, had a greater impact on steer performance than forage system. Live animal performance was not impacted by forage treatment, although there was a tendency for total ADG to be greater in steers pastured on brown midrib sorghum x sudangrass and pearl millet plus crabgrass. This tendency may be reflective of the addition of the brown midrib gene, with its ability to alter lignin content, in sorghum x sudangrass, and of the high nutritive value associated with crabgrass. No differences in forage treatments were detected for proximate analysis of the loin muscle area, or for carcass characteristics used to determine both yield and quality grades in cattle. Carcasses of finished beef in this study graded at Select or better. Typically, prime carcasses are considered the gold standard, however, the consumer market in which forage-finished beef producers are targeting, typically prefer leaner beef over beef that contains a higher concentration of fat.

One of the most important factors in beef production is the ability to turn a profit. In this study, although agronomic costs and labor were not factored in, no effect of forage treatment was found for any variable in the break-even analysis. In 2015, the price required to break-even was greater than that of 2014 and 2016, and was primarily a function of the markets record high cattle prices in spring, followed by a steep decline in cattle prices in the fall, when steers from this study were harvested. Carcasses in all three years required a premium to breakeven. However, it is not uncommon for forage-finished beef to be sold at a premium to consumers. Additionally break-even costs found in this study were lower than the reported national average price for forage-finished beef in 2014, 2015, and 2016 by the USDA-AMS, indicating that forage-finishing on warm-season annuals in the Southeast has the potential to be a profitable enterprise.

Differences in performance of varieties within a species is another contributing factor that may determine the success or failure of a forage system. Currently, there are many commercially available varieties of sorghum x sudangrass, forage sorghum, and pearl millet. Although some states have a forage variety testing program in place to help producers understand the expected performance of a variety, it is difficult to extrapolate those performance results across state lines and across multiple environments. In order to help producers throughout the Southeast make summer annual variety selections, research was conducted to identify superior varieties of sorghum x sudangrass, forage sorghum, and pearl millet that consistently performed well across multiple years, environments, and locations. In this study, yield performance differences were found between varieties of a given species. In the analysis of varieties, of the 40 sorghum x sudangrass, 26 forage sorghum, and 16 pearl millet varieties that met the criterion of being tested in at least 6 site and/or years, only 7 sorghum x sudangrass, 2 forage sorghum, and 5 pearl millet commercial varieties had an above average relative yield in combination with a coefficient of variation below 10. Based on their tested performance, recommended varieties of sorghum x sudangrass are 'AS5201', 'Summergrazer III', 'Headless Trudan', 'Special Effort', 'Headless Sordan', 'ExtraGraze BMR', and 'Nutri-Plus BMR'. Recommended varieties of forage sorghum are '86S' and 'Centurion BMR', and for pearl millet are 'Tifleaf 3', 'Elite III', 'SS 635', 'DMP4SR', and 'DMP5SR'. Selecting a variety that consistently performs well can help increase the chances of having a successful summer forage-finishing program, although management is still an important component to that success.

In conclusion, results from this study indicate that sorghum x sudangrass, brown midrib sorghum x sudangrass, pearl millet, and pearl millet plus crabgrass may generally be used interchangeably in forage-finishing beef production systems in the Southeast, without negatively impacting the final beef product or profitability of that product. Despite the wealth of information on forage production, cattle performance, and carcass attributes that this research provided, there are still many unanswered questions regarding utilizing these forages in forage-finishing systems. Future endeavors in this field should include planting these warm-season annual forages on multiple dates and utilizing them in forage mixtures. Specifically, with the early seasonal production of sorghum x sudangrass and brown midrib sorghum x sudangrass, improving and distributing total seasonal production may be beneficial to cattle performance. In general, the two sorghum x sudangrass forage systems in this study rapidly provided a large quantity of forage early in the grazing trial, but desired plant populations decreased later in the season and were replaced by undesirable weed species. By adding multiple planting dates of sorghum x sudangrass and brown midrib sorghum x sudangrass, producers may be able to extend the forage distribution and take advantage of the greater stocking densities for an extended period of time. Additionally, producers can profit from the resulting increase in gain ha^{-1} those forages can accommodate.

Although not examined in this study, the addition of crabgrass to sorghum x sudangrass or brown midrib sorghum x sudangrass may be another tool to potentially increase forage distribution, quality, and animal performance. In general, pearl millet plus crabgrass outperformed pearl millet in this study. It was observed that crabgrass filled in the space between individual pearl millet plants and shaded out undesirable weed species. The addition of crabgrass to sorghum x sudangrass forage systems may be crucial in providing high quality forage late in the season when plant densities of sorghum x sudangrass and brown midrib sorghum x sudangrass tend to diminish. Again, increasing the forge distribution with the addition of crabgrass, also has the potential to increase stocking densities and total gain per unit of land. However, before implementation of these endeavors, a more thorough investigation should take place to better understand the effects of multiple planting dates and mixtures of sorghum x sudangrass, brown midrib sorghum x sudangrass, pearl millet, and crabgrass in forage-finishing beef production systems in the Southeast.